# CASSY Lab 2

524 221en

LD DIDACTIC

# CASSY Lab 2

## 524 221en

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# Contents

## Introduction

This manual is intended to provide an overview of the many exciting possibilities of the CASSY Lab software. The text is identical to the help texts that can be accessed using the mouse for all program functions.

The help texts in the program provide the following additional support:

- You can jump directly to cross-referenced information using the mouse.
- You can load experiment examples and settings by clicking on them.
- The help system permits both indexed and full-text search modes.

### Installation

CASSY Lab 2 can be installed either

- automatically after inserting the CD-ROM or
- manually by executing the file **setup.exe**

and following the instructions that appear on the screen.

## Important information after installing CASSY Lab 2

### Using the software with CASSY-S (Sensor-CASSY, Sensor-CASSY 2, Power-CASSY, Profi-CASSY, CASSY-Display, Pocket-CASSY and Mobile-CASSY)

The first time you start CASSY Lab, you should enter your activation code, which you can find in your bill of delivery and your invoice under the number 524 220. The software then supports CASSY without restrictions (CASSY support without the activation code is limited to 16 sessions).

### Using the software with other measuring instruments

CASSY Lab supports other measuring instruments, the Joule and wattmeter and the Universal measuring instrument physics/chemistry/biology without requiring an activation code.

### Manual

CASSY Lab is supplied with a comprehensive manual. In order to exploit the full potential of CASSY Lab 2, you need to read and understand this manual completely. You can do this in several ways:

- Open the manual from CD-ROM
- Order the printed manual (524 221en).
- ■ Download the manual from the Internet (in Adobe PDF format).
- Use the software help function (text identical to the printed manual, context-sensitive and with numerous jump links and enhanced search capabilities).

### Getting started

■ Displays the introduction
■ Displays experiment examples

You can also read the supplied experiment examples and use these for further evaluations without CASSY. You can use the program settings from the examples to run new measurements, and match these to your experiment conditions.

### Support

If there should be any questions left despite the comprehensive help with its numerous experiment examples, please mail to cassy@ld-didactic.de.

### Updates

We have an ongoing commitment to expanding and enhancing CASSY Lab 2 – particularly in response to the comments and experiences of our users.

■ Download update from the Internet

## New features in CASSY Lab 2

This section is intended for users who are familiar with CASSY Lab 1 and want to know quickly what has been changed with CASSY Lab 2:

- There is a central settings window where a quick overview of all of the settings can be found. In the case of major problems (e.g. wrong CASSY, wrong sensor box, syntax fault in a formula), a yellow ⚠ indicates what to do.
- Several tables and diagrams can be displayed on the screen at the same time. To do this, one of the tabs is simply dragged with the mouse and the display is dropped as desired. With a floating window, double-clicking the window title line sorts it back in.
- New features of Sensor-CASSY 2 are supported (4 channel measuring, 1 MHz sampling rate, pre-triggering, measuring of mains voltage. By means of the pre-triggering of Sensor-CASSY 2 and Pocket-CASSY, recording of measured values is possible in the time before the triggering event.
- Drag & Drop is realized consistently within and between the setting window, the upper button bar, the display instruments, the tables and the diagrams. This allows, for example, numeric values to be copied, evaluation texts to be shifted, sequences to be changed, and curves to be moved from one diagram to another.
- Evaluations are alive. The evaluation is already displayed while the evaluation range is being marked. The evaluation range can subsequently be modified by double-clicking the evaluation. By re-starting a (repeating) measurement, the old evaluations are not deleted but the new measurement is newly calculated and displayed.
- Additional evaluations (e.g. tangent, triangular interpolation, CAN/LIN decoder) add to the available options. Gaussian fits are now found under fits, the x-ray energies under markers and the peak center below the mean value.
- Freely selectable curve colors as well as transparent areas (e.g. for integrals and histograms) increase clarity.
- Symbols for measured and evaluated quantities are shown in display instruments, tables and diagrams, and evaluated results are displayed using italic fonts.
- Slower measurements can at the same time make use of different CASSY modules (e.g. Sensor-CASSY and Pocket-CASSY). Faster measurements continue to require a single CASSY or a cascade of CASSY modules (e.g. two Sensor-CASSYs plugged together) in order to ensure that the measurements are taken simultaneously.
- Inputs and outputs can, in most cases, be activated individually. E.g. the voltage source S can be activated without the relay R, or the obscuration time $t_E$ can be activated without the obscuration time $t_F$.
- An automatic measuring range selection (Autorange) can be selected.
- It can be triggered onto the path s (±1 mm) of the Motion transducer box or that of the Timer S. This is helpful for measurements without a holding magnet.
- A stop condition is available which can automatically end measurements.
- Every text field in which a formula can be entered has its own help menu with information on allowed variables, functions and operators.
- The differential equations of model values can now be dependent on formulas which in turn depend on the model values. This allows a clearer notation of the differential equations.
- When a symbol is renamed, all dependent formulas are correspondingly changed automatically.
- The dependency of "old" in formulas is no longer necessary. Instead, the own symbol representing the formula can be used. If the "last old" was used in a convoluted way to access a specific element in a table (e.g. starting value $U_0$ = (n = 1) * UA1 + (n > 1) * last old), this is now possible in a much more elegant way by stating an index (e.g. starting value $U_0$ = UA1[1]).
- "last" and "next" is no longer required in formulas either. The same function offers universal access via an index (e.g. UA1[n-1] and UA1[n+1]).
- Multiple series of measurements are no longer separated from each other by means of an empty line in the same columns but side by side in new columns in the table. This simplifies the access or deleting of specific series of measurements in a diagram and the access of formulas to special series of measurements, e.g. UA1#1 accesses the voltage in the first series of measurements.
- Values of outputs, such as the voltage source S, are only calculated when they are output and are then saved in the table. If later on the formula for the output is changed, the same no longer applies retrospectively but only for later outputs. This logic has been changed in order to keep the measuring data record comprising input values and output values consistent.
- Several rapid and triggered digital measurements are possible by means of the Timer box or the Timer S and analogue inputs, e.g. the obscuration times at a light barrier and a force sensor.
- The recording of MCA spectra was made similar to other operations. The settings are entered in the central settings window (including the energy calibration). After the energy calibration, the energy can be dragged to the diagram in order to change the axes. Simultaneous measurements can be made via further CASSY inputs. The single channel operating mode of the MCA box is no longer available.

CASSY Lab 2 can load CASSY Lab 1 files. In most cases the old measurement can be either immediately repeated or evaluated.

There are only a few idiosyncrasies to be observed:

- The measured values for the obscuration times $t_E$ and $t_F$ at the Timer box are now evaluated in the formulas in the units in which they were measured, in milliseconds rather than seconds. The factor 1/1000 may have to be manually entered in the derived formulas. In this way these two measured values now behave like all the other measured values, with the exception of the measuring time t, which is evaluated in seconds as before wherever it occurs in formulas.
- Temporal derivations are now always calculated as time-weighted symmetrical derivations. This means that the derivations of measured values not recorded at equidistant times now fit with the measured value. Auxiliary formulas which were necessary for CASSY Lab 1 for compensating for this fault now become counter-productive.
- Most measured values can be recorded both for small and for larger measuring intervals. However, there are measured values which result in sensible values only for small time intervals (obscuration time $t_E$, obscuration $n_E$ of the Timer box or of Timer S and path s of the Ultrasonic motion sensor S) or only for larger time intervals (e.g. events $N_E$, frequency $f_E$, temperature, $CO_2$ concentration, rel. air humidity). Measured values in those two categories now no longer can be measured together. Instead of the rapid obscuration counter $n_E$, the slower event counter N can be used and vice versa.
- The overview diagram of the MCA spectra and the option for adding and subtracting spectra are no longer available. Instead, the new options for the simultaneous display of several diagrams and formulas are available, which can access any series of measurements (e.g. NA#1-NA#2).
- There are very old serial measuring devices which are no longer supported by CASSY Lab 2.

On account of the numerous new features of CASSY Lab 2, export into the old CASSY Lab 1 data format is no longer possible.

## User programs for CASSY

You can also program CASSY-S yourself. To assist you in this, we have placed a description of the protocol of the interface as well as a Delphi/Lazarus component (with source code) on the Web for free downloading.

Download developer information from the Internet.

### Delphi (Windows) and Lazarus (Linux)

Support of CASSY with your own Delphi or Lazarus programs is easy because this only requires inclusion of the component described above.

### C/C++/Visual Basic

Other programming languages can access CASSY via CASSYAPI.DLL (Windows) or libcassyapi.so (Linux). For this CASSYAPI.DLL or libcassyapi.so has to be included and called. The necessary declarations for C/C++ are contained in CASSYAPI.H. All three files are also contained in our free Developer Information from the Internet.

### LabVIEW (Windows and Linux)

Our LabVIEW driver for CASSY is also free available on the Internet. In addition to the VIs (Virtual Instruments) for driving CASSY, the driver also contains application examples.

LabVIEW is a registered trademark of National Instruments.

# CASSY Lab 2

## Introduction

- Measurement
- Evaluation
- Experiment examples
- New features in CASSY Lab 2
- User programs for CASSY

CASSY Lab 2 supports one or more CASSY-S modules (Sensor-CASSY, Sensor-CASSY 2, Power-CASSY, Profi-CASSY, CASSY-Display, Pocket-CASSY and Mobile-CASSY) at the USB port or at the serial interface of the computer. The software also supports a variety of other serial measuring instruments, the Joule and wattmeter and the Universal measuring instrument physics/chemistry/biology.

For CASSYs with a serial interface, the serial interface is selected in the Settings CASSYs.

## Activation code

When using CASSY Lab 2 together with CASSY, you need to enter a 24-digit activation code. You can find this activation code in your bill of delivery and your invoice under the number 524 220; you must enter this number once, together with the name that appears on the invoice. This activates the software for CASSY. Please observe our copyright.

If you only intend to use CASSY Lab 2 with other devices, with the Joule and wattmeter or with the Universal measuring instrument physics/chemistry/biology, **no** activation code is necessary.

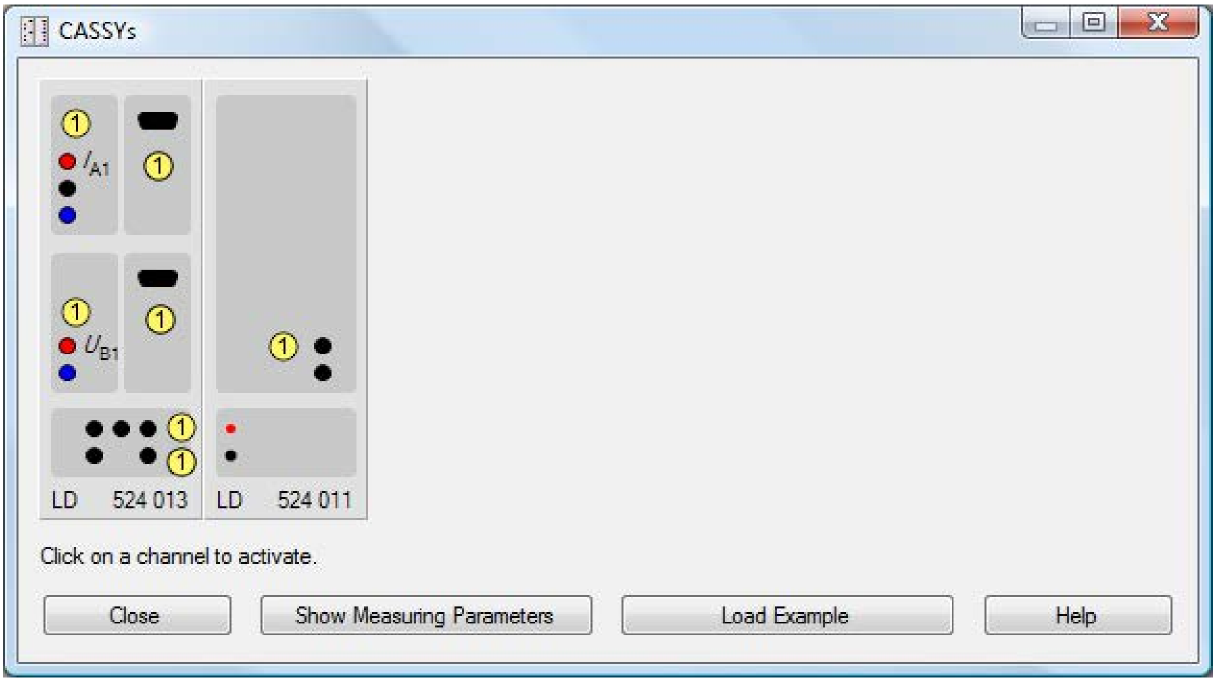
If you did not receive an activation code, please fax your invoice for CASSY Lab 2 (524 220) to +49-2233-604607. We will fax you the activation code as soon as possible. CASSY Lab can also be used with CASSY without the activation code for a limited time (up to 16 sessions).

Future versions, such as updates available for downloading on the Internet, will also use this activation code. This means that there are no restrictions on the use of updates.

- Download update from the Internet

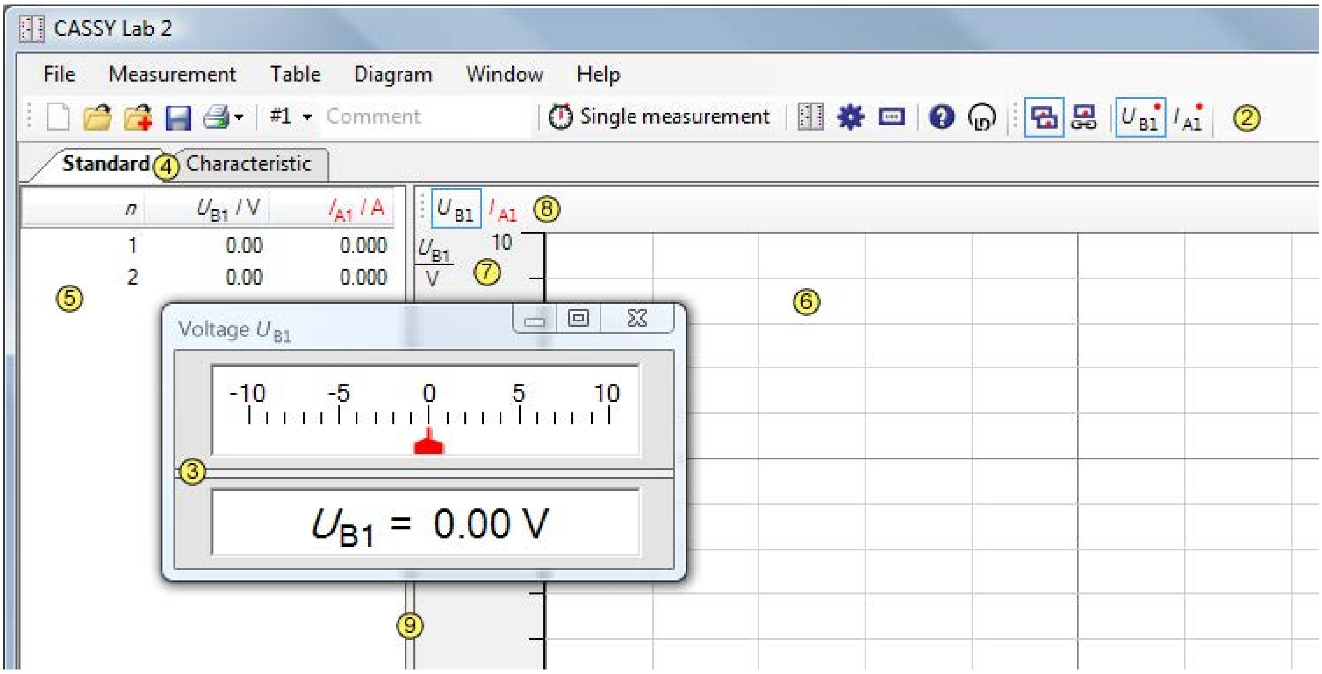
## First measurements

If one or more CASSYs have been recognized, all CASSY modules are displayed with their current configuration (if applicable with the plugged in sensor boxes). To conduct a measurement, just click on the corresponding input or output ①.



Click on a channel to activate.

An active input or output (channel) is then marked in color and placed among the channel buttons ② at the top right of the main window (here I*A1* and $U_{B1}$). These buttons are the fastest way to display or close a display instrument ③ for that channel (left mouse button) or to change a setting (right mouse button). In addition, the channel initially appears automatically in the table ⑤ and in the diagram ⑥.



| n | $U_{B1}$ / V | $I_{A1}$ / A |
|---|---|---|
| 1 | 0.00 | 0.000 |
| 2 | 0.00 | 0.000 |

$U_{B1}$ = 0.00 V

You can access the basic functions quickly using the menu or the buttons ② in the top bar:

File Measurement Table Diagram Window Help

In the button line a brief **comment** on the measuring series can also be entered.

Below this bar, you can toggle between the displays of the table ④ and the diagram ⑤ by clicking on one of the display tabs ⑥ when different Displays have been defined (here **Standard** and **Characteristic**). The table and diagram can be enlarged or reduced with respect to each other by moving the boundary ⑨ with the mouse.

Displays can be sorted differently or displayed differently by dragging their tabs ④ (e.g. several diagrams simultaneously), and they can be turned into floating windows. With a floating window, double-clicking the window title line sorts it back in.

At many points, **both** mouse buttons (left and right) can be used to execute different functions:

| **Control element** | **Left mouse button** | **Right mouse button** |
|---|---|---|
| ① CASSY setup | Activate and modify a channel | Activate and modify a channel |
| ② Channel button | Open and close a display instrument, drag and drop in ② and ⑤ through ⑧ | Set up a channel |
| ③ Display instrument | Move boundary between analog and digital display, drag and drop values in ⑤ | Set up a channel |
| ④ Name of display | Toggle to another defined display, change the layout | |
| ⑤ Table | Edit measured values, drag and drop values within the table or the channels to ② | Set display attributes of table, e.g. font size, delete table rows |
| ⑥ Diagram | Mark evaluation ranges | Settings and evaluations in diagram |
| ⑦ Scale | Move scale | Set minimum, maximum and conversion of scale |
| ⑧ Axis symbols | Toggle y-scale, drag and drop into ② | Set up a channel |
| ⑨ Boundary | Move boundary between channel and diagram | |

## File menu

### File → New (F4)

Deletes either the current measurement series maintaining the settings or, if the current measurement series is empty, all measured values, or, if no measured values are available, the current settings.

Applying this twice or three times completely deletes a measurement with its settings.

### File → Open (F3)

Opens a measurement series with its settings and its evaluations.

The software is also equipped with a text import filter (file type ***.txt**).

### File → Append

Appends a measurement series to an existing series (without loading its settings and evaluations as well). This is possible when the same measurement quantities are used for both series. Alternatively, a further measurement series can be measured and appended subsequently.

### File → Save (F2)

Saves the current measurement series with its settings and its evaluations.

You can also save just the settings (without measurement data) to make it easier to repeat an experiment at a later date.

The software is additionally equipped with a text export filter (file type ***.txt**).

### File → Page Setup

Establishes the paper format and margins for a printout.

### File → Print Preview

Shows a preview of the printout of the current table or current diagram.

### File → Print

Prints out the currently active table or diagram.

### Text export and import

You can import and export text files quickly and easily by selecting the file type ***.txt** in the file selection dialog.

The data format begins with a header, in which all lines begin with a keyword. This specifies the measuring ranges, (MIN, MAX), the SCALE, the number of decimal places (DEC) and the actual definition of the measurement quantities (DEF). All lines except DEF are optional. The table of measured values follows the header.

You can view the exact syntax e.g. in the file that is created using the data export function.

## Measurement menu

A measurement is configured by means of the measuring parameters and thereafter started and stopped by means of this menu.

### Measurement → Start/Stop Measurement (F9)

Starts and stops a new measurement.

Alternatively, you can stop measurements by setting a measuring time.

You can use the right mouse button to open the table display menu in the table and the evaluation menu in the diagram.

### Measurement → Continue Measurement

Continues a measurement. A measurement can be continued if the selected time interval is 100 ms or greater and there is measuring time remaining.

### Measurement → Append new Measurement Series

The Append function enables sequential recording of multiple measurement series. In the case of the automatic recording of measured values, this switch has to be set only once in order to append all subsequent measurements. In the case of the manual recording of the measured values, the switch has to be reset every time that a new measurement series is started.

If more than one measurement series is being recorded, the serial index for the series is appended to the symbols in order to distinguish them by series, e.g. $U_{A1}$#1 and $U_{A1}$#2. This allows the measurement series to be distinguished from one another for the assignment of column headings in tables and the axis assignment of a diagram.

Alternatively, the individual measurement series can first be recorded one after another and saved individually. When loading multiple comparable measurement series (with identical quantities), measured series can also be appended "retroactively".

This selection is identical to Measuring Parameters → Append new measurement series.

### Measurement → Select Measurement Series

Selects the current measurement series. The current measurement series is

- the measurement series into which values are entered if no new measurement series is appended
- the measurement series which is deleted when the current measurement series is deleted
- the measurement series whose values are dragged by Drag & Drop from the channel buttons into the table and the diagram.

### Measurement → Delete Current Measurement Series

Deletes the currently selected measurement series. Here all the values are deleted which were recorded during this measurement series even if they are not currently being displayed.

## Table menu

You can change the table display also by clicking on the right mouse button when the pointer is over the table.

### Editing measured values

Individual measured values can be edited after being clicked on using the left mouse button or they can be dragged to different measured value cells (Drag & Drop).

### Selecting rows

When the Shift key or the Alt key are pressed at the same time, one or more rows of the table can be selected. Once rows have been selected, the selection is taken into account for Table → Copy Table, and with File → Print → Print Table the selected rows can be used as the print area.

The selected rows can be deselected by double-clicking on a table cell.

### Status line

A single selected table row is displayed in the status line at the bottom of the screen. You can toggle display of this information in a larger window on and off by pressing ▭ or **F6**.

### Table → Change Column Header

Activates the Settings Display. Here the table column headers can be edited.

Alternatively, you can move columns back and forth between channel buttons and the table using drag and drop.

### Table → Select Font Size

The table's font size is selectable. Small, medium and large fonts can be selected.

### Table → Delete last Row in Table (Alt+L)

Deletes the last row in the current measuring series in the table.

### Table → Copy Table

Copies the table in text format into the Windows clipboard. Once there, it are available for further processing in other Windows programs.

### Table → Copy Window

Copies the main window as a bitmap into the Windows clipboard. Once there, it is available for further processing in other Windows programs.

## Diagram menu

You can access a wide variety of powerful graphical evaluation functions in the diagram also by clicking the right mouse button.

- Change Axis Assignment
- Display Coordinates
- Select Line Width
- Select Value Display
- Select Rulers
- Show Grid
- Zoom
- Zoom Off
- Set Marker
- Text
- Vertical Line
- Horizontal Line
- Measure Difference
- X-Ray Energies
- Draw Mean
- Calculate Peak Center
- Fit Function
- Calculate Integral
- Calculate Poisson Distribution
- Calculate Gaussian Distribution
- Calculate Minimum and Maximum
- Calculate Form Factor
- Calculate Ripple
- Find Equivalence Point
- Carry out Triangular Interpolation
- Find Systole and Diastole
- Decode CAN/LIN Message
- Delete Last Evaluation
- Delete All Evaluations
- Delete Range (only Measured Values)
- Copy Diagram
- Copy Table

### Selecting a measured value

By clicking on a measured value, it becomes selected in the diagram and at the same time its y-value is selected in the table. This selection can by changed by selecting a different y-value in the table or deleted by selecting an x-value in the table.

### Marking a curve section

In some cases, you may wish to mark a particular curve section for which the evaluation function is to perform a calculation.

To mark a curve section, hold down the left mouse button and drag the pointer to the end of the curve section. Alternatively, you can also click on the starting and end points.

When a part of a curve is selected, the selected range is displayed in cyan and the evaluation is calculated.

### Editing an evaluation

An evaluation can be edited by double-clicking the evaluation. When the range is edited, the evaluation is re-calculated.

If the range is shifted out of the diagram, the evaluation is deleted.

The evaluations are automatically re-calculated whenever the measurement is re-started without first selecting Append new Measurement Series or whenever the measured values are changed (e.g. when recording a spectrum).

### Status line

Evaluation results always appear in the status line at the bottom of the window. You can toggle display of this information in a larger window on and off by pressing ▭ or **F6**.

### Drag & drop functionality

Using the mouse, you can drag the evaluation results from the status line and drop them in the table or the diagram. In this way diagrams can be created which depend on the results of the evaluation or you can rapidly enter the evaluation results in a diagram.

If several evaluation results are displayed in the status line, the status line is copied from the evaluation result on which the mouse was positioned when it was dragged.

### Diagram → Change Axis Assignment

Activates the Settings Display. This lets you change the assignment of the diagram. Mathematical conversion of axes is also possible.

Alternatively, you can move the axis assignments back and forth between the channel buttons and the diagram using drag and drop.

### Diagramm → Display Coordinates (Alt+C)

When you activate this function, the status line shows the current coordinates of the mouse pointer, as long as it is over a diagram. The coordinate display remains active until you deactivate this menu point by selecting it again, or an evaluation shows a result in the status line.

You can also insert the current coordinates in the diagram. However, make sure that you access the evaluation function Text via the keyboard with Alt+T without changing the coordinates of the mouse pointer, as otherwise the wrong coordinates would be adopted.

### Diagram → Select Line Width

You can modify the line width for display of the diagrams and the evaluations which you carry out in them. You can choose between thin, medium and thick lines.

### Diagram → Select Value Display

CASSY Lab provides six functions for customizing the display of measured values.

| | |
|---|---|
| **Show Values** | Display as squares, triangles, circles, pound characters, … |
| **Show Connecting Lines** | Connecting lines between measurement points |
| **Akima Interpolation** | Values between the measuring points interpolated according to Akima's method |
| **sinc Interpolation** | Values between the measuring points interpolated with sinc(x)=sin(πx)/πx |
| **Show Bars** | Values shown by bars |
| **Show Axes** | Zero lines of x and y axis |

The Akima and sinc interpolations are neither calculated over gaps in the domain of definition nor during a measurement. During the measurement, the points are only connected by straight lines. Only after the measurement does the interpolation calculate the curve sections between the measuring points. The sinc interpolation is ideal for signals that do not contain any frequency components higher than half the sampling frequency. In this case it leads to 10-fold oversampling.

### Diagram → Select Rulers

In the diagram the x-ruler and y-ruler can be displayed or hidden.

### Diagram → Show Grid

Allows you to toggle a grid on and off in the diagram.

### Diagram → Zoom (Alt+Z)

After activating this menu point, define the range which you wish to magnify. Use the left mouse button to do this.

A previously zoomed display can be zoomed further. To reset a zoom, select Zoom Off.

### Diagram → Zoom Off (Alt+O)

Restores the currently selected section of the diagram to its original size.

### Diagram → Set Marker

This software provides five different mark-up functions.

### Diagram → Set Marker → Text (Alt+T)

This text function lets you label all parts of the diagram using any text you wish to enter. Once you have entered your text, just move it to the desired position and anchor it with the left mouse button.

After all evaluations which return a numerical value in the status line, these numerical values are suggested as a text insertion which you can accept, edit or reject.

### Diagram → Set Marker → Vertical Line (Alt+V)

This function lets you draw vertical lines in any positions in the diagram. The respective position is given in the status line.

### Diagram → Set Marker → Horizontal Line (Alt+H)

This function lets you draw horizontal lines in any positions in the diagram. The respective position is given in the status line.

### Diagram → Set Marker → Measure Difference (Alt+D)

After clicking on a reference point, you can draw a line to any point in the diagram. The coordinate difference between the starting and end points of that line are given in the status line.

### Diagram → Set Marker → X-Ray Energies

Displays a periodic table and inserts the relevant X-ray energies of the selected element as marks in the diagram provided the x-axis of the diagram has the unit keV.

### Diagram → Draw Mean

After choosing mean value calculation, just select the curve section for which you wish to find the mean value with the left mouse button. The mean value appears in the status line along with its statistical error.

### Diagramm → Calculate Peak Center

This function calculates the center of the marked peak and inserts this in the status line.

### Diagramm → Fit Function

The software offers various best-fit operations:

| | |
|---|---|
| **Best-fit straight line** | y=Ax+B |
| **Line through origin** | y=Ax |
| **Tangent** | y=Ax+B |
| **Normal parabola** | $y=Ax^2$ |
| **Parabola** | $y=Ax^2+Bx+C$ |
| **Hyperbola 1/x** | y=A/x+B |
| **Hyperbola $1/x^2$** | $y=A/x^2+B$ |
| **Exponential function** | y=A*exp(-x/B) |
| **Envelope of an oscillation** | y=±A*exp(-x/B)+C (attenuation through air friction) |
| **Gaussians of equal Width** | y=Σ Gaussian curves with equal ζ |
| **Gaussians of specified Energy** | y=Σ Gaussian curves with fixed κ and equal ζ |
| **Free Fit** | y=f(x,A,B,C,D) |

After choosing the corresponding operation, select the curve section you wish to apply it to using the left mouse button.

In the simplest case the Gaussian fits match precisely a Gaussian curve in the selected range. If a sum of several Gaussian curves is to be fitted the number and approximate position of the individual maxima (peaks) must be specified. This is done by means of markers set in advance (peak centers, vertical lines or selected x-ray energies).

**Gaussians of equal width** matches the amplitudes $A_i$ and positions $\kappa_i$ of all Gaussian curves and for this always uses the same width ζ:

$$\sum_i A_i \cdot e^{-\frac{(x-\mu_i)^2}{2\sigma^2}}$$

**Gaussian curves of a specified energy** only fits the amplitudes $A_i$ and the width ζ. This is particularly suitable for marked x-ray energies.

To define a **free fit**, you need to specify the function f(x,A,B,C,D) and meaningful starting values before marking the range. The standard rules apply for entering the function. Choose starting values that are as realistic as possible to increase the chances of obtaining a successful fit. If it is not possible to fit the function, try repeating this process with different starting values. In addition, individual parameters A, B, C or D can be maintained constant during the fit.

During the fit, the current parameters of the operation (A, B, C and D) appear in the status line.

### Diagram → Calculate Integral

The value of the integral corresponds to the area which is enclosed by the curve section selected by means of the left-hand mouse button and the x-axis, by the peak area, or by the area which is enclosed by the selected curve section from the origin. The value of the integral appears in the status line.

The result of a MCA measurement, however, is not a real integral over the x-axis (energy or channels), but simply the sum over the channels the unit being "events".

### Diagram → Other Evaluations → Calculate Poisson Distribution

(only suitable for frequency distributions)

The total number n of events, the mean value κ and the standard deviation ζ are calculated in the marked range of the histogram and displayed in the status line and the Poisson distribution calculated on the basis of these appears in the diagram:

$$y = n\frac{\mu^x}{x!}e^{-\mu}$$

### Diagram → Other Evaluations → Calculate Gaussian Distribution

(only suitable for frequency distributions)

The total number n of events, the mean value κ and the standard deviation ζ are calculated in the marked range of the histogram and displayed in the status line and the Gaussian distribution calculated on the basis of these appears in the diagram:

$$y = \frac{n}{\sigma\sqrt{2\pi}} \cdot e^{-\frac{(x-\mu)^2}{2\sigma^2}}$$

### Diagram → Other Evaluations → Calculate Minimum and Maximum

The minimum and the maximum of the selected range are calculated and are displayed in the status line.

### Diagram → Other Evaluations → Calculate Form Factor

(only suitable for periodic curves)

For the marked range [$t_1$,$t_2$] of a periodic signal (e.g. U(t)) the following values are calculated and displayed in the status line:

| | |
|---|---|
| Rectified mean value (mean of the absolute value) | $U_{\text{ABS MEAN}} = \frac{1}{t_2 - t_1} \cdot \int_{t_1}^{t_2} \lvert U(t) \rvert \cdot dt$ |
| Root-mean-square value | $U_{\text{RMS}} = \sqrt{\frac{1}{t_2 - t_1} \cdot \int_{t_1}^{t_2} U^2(t) \cdot dt}$ |
| Form factor | $f = \frac{U_{\text{RMS}}}{U_{\text{ABS MEAN}}}$ |

For these calculations, always an integer number of periods should be marked.

### Diagram → Other Evaluations → Calculate Ripple

(only suitable for periodic curves)

For the marked range [$t_1$,$t_2$] of a periodic signal (e.g. U(t)) the following values are calculated and displayed in the status line:

| | |
|---|---|
| Mean value | $U_{\text{MEAN}} = \frac{1}{t_2 - t_1} \cdot \int_{t_1}^{t_2} U(t) \cdot dt$ |
| Root-mean-square value | $U_{\text{RMS}} = \sqrt{\frac{1}{t_2 - t_1} \cdot \int_{t_1}^{t_2} U^2(t) \cdot dt}$ |
| Ripple | $r = \frac{\sqrt{U^2{}_{\text{RMS}} - U^2{}_{\text{MEAN}}}}{U_{\text{MEAN}}}$ |

For these calculations, always an integer number of periods should be marked.

### Diagram → Other Evaluations → Find Equivalence Point

(only useful for titration curves of pH over volume)

The equivalence point and the pK value are determined for the marked range of the titration curve and displayed in the status line. In the case of strong acids or bases (with pK < 1), it is recommendable to mark only the area immediately before and after the equivalence point in order to avoid the output of an incorrect pK value.

### Diagram → Other Evaluations → Carry out Triangular Interpolation

For the triangular interpolation two ranges are selected in which initially a straight line is fitted.

Between the two straight lines a vertical line is fitted in such a way that the two triangles between the vertical line, the two straight lines and the measured curve, end up having the same area.

The position of the vertical line is displayed in the status line.

### Diagram → Other Evaluations → Find Systole and Diastole

(only suitable for blood-pressure curves)

The systole and diastole are determined for the marked range of the blood pressure curve and displayed in the status line

### Diagram → Other Evaluations → Decode CAN/LIN Message

By clicking on a CAN message or LIN message this is decoded and the result is displayed in the status line.

### Diagram → Delete Last Evaluation

Undoes the most recent evaluation operation.

### Diagram → Delete All Evaluations

Undoes all evaluation operations of this display.

### Diagram → Delete Range (only Measured Values)

The measured values of the marked curve section are deleted. This only applies to measured values that are displayed on the y-axis. Values that are calculated (e.g. by means of a formula) or values on the x-axis cannot be deleted.

### Diagram → Copy Diagram

Copies the diagram as a bitmap or metafile into the Windows clipboard. Once there, it are available for further processing in other Windows programs.

### Diagram → Copy Window

Copies the main window as a bitmap into the Windows clipboard. Once there, it is available for further processing in other Windows programs.

## Window menu

### Window → Show CASSY Modules (F5)

Displays the current arrangement of CASSY modules and sensor boxes.

### Window → Show Settings

Displays the current settings (e.g. CASSYs, computer, displays).

### Window → Show Measuring Parameters

Displays the current measuring parameters.

### Window → Toggle Large Display of Status Line On/Off (F6)

Toggles large display of the status-line information on and off.

### Window → Toggle Display Instruments Off/On (F7)

Closes all open display instruments or reopens them.

### Window → Group Display Instruments (F8)

Groups all of the open display instruments so that they can be shifted, scaled-down or scaled-up together.

### Window → Align Display Instruments

Arranges all of the open display instruments in order next to one other or on top of one other.

## Help menu

### Help → Help (F1)

Opens this help file.

### Help → New in CASSY Lab 2

Displays the most important changes in comparison to CASSY Lab 1.

### Help → Experiment Examples

Displays an overview of all of the experiment examples included with CASSY.

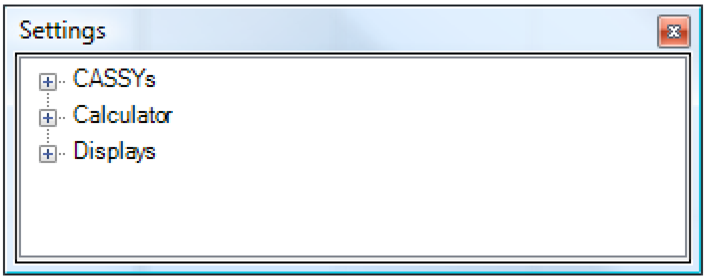
### Help → About ...

Displays the current version number of the software and enables entry of the activation code.

## Settings and Measuring Parameters

### Window → Show Settings

All settings can be made in this central dialog window. The tree diagram provides three root nodes for this:

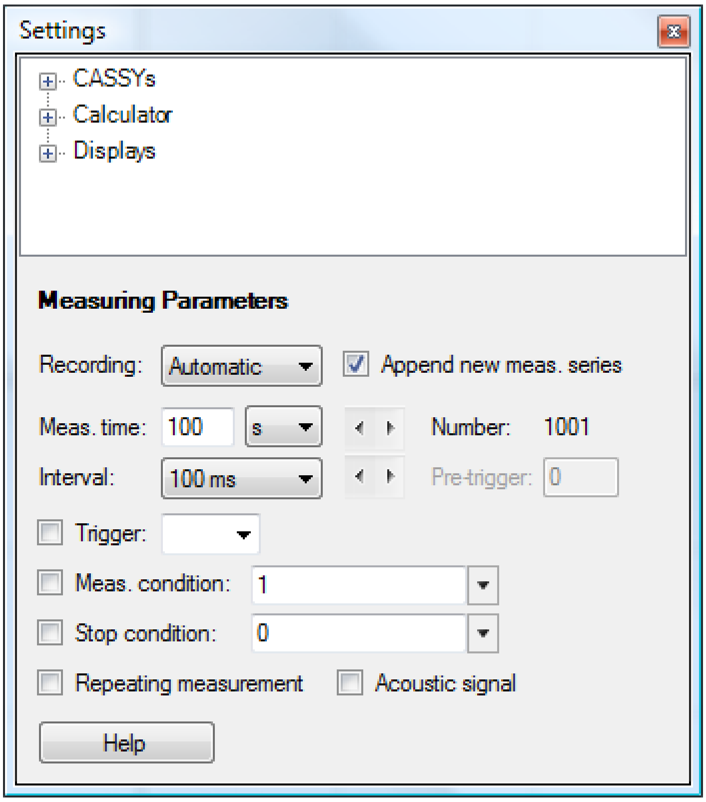


- CASSYs (definition of the inputs and outputs of the connected CASSYs)
- Calculator (definition of additional values)
- Displays (changes the column assignments of the tables and axis assignments in the diagrams)

If in the tree structure in one of the sub-nodes a problem is identified (e.g. wrong CASSY, wrong sensor box, syntax fault in one of the formulas), the first visible (higher-level) node shows a yellow ❗, which alerts the user to the problem.

### Window → Show Measuring Parameters

The measuring parameters are also displayed during every setting of an input or output and whenever no node is selected in the tree diagram.



**Measuring Parameters**

Recording: Automatic ☑ Append new meas. series

Meas. time: 100 s Number: 1001

Interval: 100 ms Pre-trigger: 0

☐ Trigger:

☐ Meas. condition: 1

☐ Stop condition: 0

☐ Repeating measurement ☐ Acoustic signal

The defaults that appear in this dialog depend on the currently connected sensor boxes. This simplifies matching to a particular measuring task, as the typical sensor box configuration is already finished.

### Automatic recording

The software determines the exact time for the recording of a measured value. After a measurement is started with ⏱ or **F9**, the software first waits for any **trigger** that may have been set, and then records one measured-value row each time the predefined time interval elapses. The **interval**, the **number** of measuring points per measurement as well as the total **measuring time** can be matched to the individual requirements before starting the experiment. You can select continuous display by setting a **repeating measurement**.

For intervals below 100 ms, Sensor-CASSY 2 and Pocket-CASSY support a pre-trigger which indicates how many measured values are to be recorded before the actual trigger time t = 0.

At time intervals above 10 ms, the software evaluates the **measuring condition** and the **stop condition** in addition to the trigger, and can also emit an **acoustic signal** when a measured value is recorded. The measuring condition and the stop condition are formulas.

A measuring condition not equal to 0 means ON="Measured-value recording possible", while a measuring condition equal to 0 means OFF="Measured-value recording inhibited". The measuring procedure is active once the measurement has been started **and** the result of the formula is ON. For example, if you want to run a measurement on 21 April 1999 between 1:00 p.m. and 2:00 p.m. (13:00 and 14:00 hours), you can use the formula: date = 21.4.1999 and time >= 13:00 and time <= 14:00.

A stop condition not equal to 0 means ON="Measurement stopped", while a stop condition equal to 0 means OFF="Measurement not stopped".

For some measurement quantities (e.g. rate, frequency, transit time, obscuration time, path when using the GM box or the timer box), the software does not evaluate the specified time interval. In this case the measurement is controlled by the gate time or the measurement pulses themselves.

### Manual recording

The user determines the exact time for the recording of a measured value. At each start with ⏱ or **F9** the software records precisely **one** measured-value row, i.e. the current display values of the instruments are entered in the table and the diagram. Thus, manual recording must be executed repeatedly in order to capture a complete measurement series.

### Append new measurement series

The Append function enables sequential recording of multiple measurement series. In the case of the automatic recording of the measured values, this switch has to be set only once in order to append all subsequent measurements. In the case of the manual recording of the measured values, the switch has to be reset every time that a new measurement series is started.

If more than one measurement series is being recorded, the serial index for the series is appended to the symbols in order to distinguish them by series, e.g. $U_{A1}$#1 and $U_{A1}$#2. This allows the measurement series to be distinguished from one another for the assignment of column headings in tables and the axis assignment of a diagram.

Alternatively, the individual measurement series can first be recorded one after another and saved individually. When loading multiple comparable measurement series (with identical quantities), measured series can also be appended "retroactively".

This selection is identical to Measurement → Append new Measurement Series

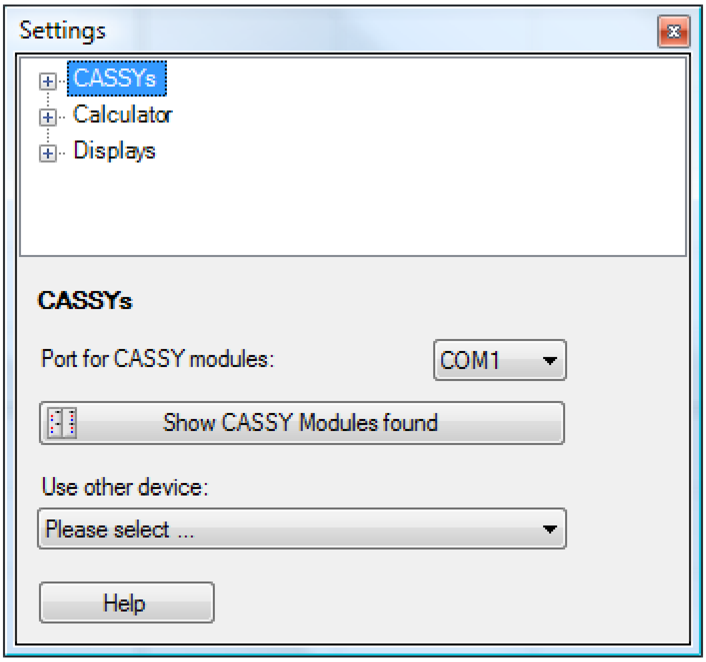
### Changing and deleting measured values / entering parameters

You can edit all measured values (except time and formulas) in the table. To do this, click on the corresponding table row and edit the numerical value using the keyboard.

You can delete measured values in several ways:

- Measurement → Delete Current Measurement Series
- Table → Delete last Row in Table
- Diagram → Delete Range

## Settings CASSYs

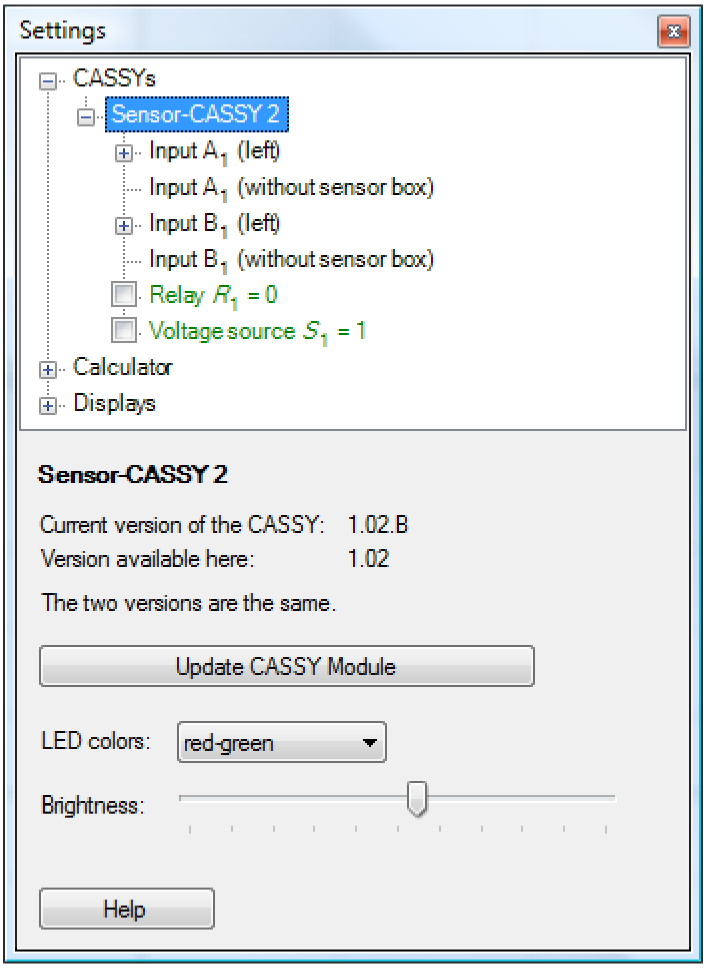


Here the interface can be specified where serial CASSY modules are to be searched for. CASSYs with USB interfaces are found automatically.

Even when a CASSY module is to be connected to a USB port on the computer via a USB serial adapter, it remains a serial CASSY module. Here the serial interface on the USB serial adapter has to be specified, which e.g. can be identified in the Windows device manager.

**Show CASSY Modules found** opens a window where all identified CASSYs are displayed.

If other devices are used for the measurement, they can be selected here.



**Sensor-CASSY 2**

Current version of the CASSY: 1.02.B
Version available here: 1.02

The two versions are the same.

LED colors: red-green

Brightness:

The CASSY module described here identifies the detected device and the version information of the CASSY module. If the version of the software implemented in the CASSY module is newer or older than this software, a message is generated. Selecting **Update CASSY Module** causes this software version to overwrite the software implemented in the CASSY module (regardless of whether it is newer or older).

For CASSY-Display and for Mobile-CASSY, the data logger can also be read here, and the real-time clock in CASSY can be set to the computer system time.

For Sensor-CASSY 2, the colors and the brightness of the LEDs on the sides can be set here.

### Hint

If this software is older than the CASSY module or you wish to update your software, you can download the latest version from our website: http://www.ld-didactic.com.

- Download update from the Internet

## Analog input settings / Timer input settings

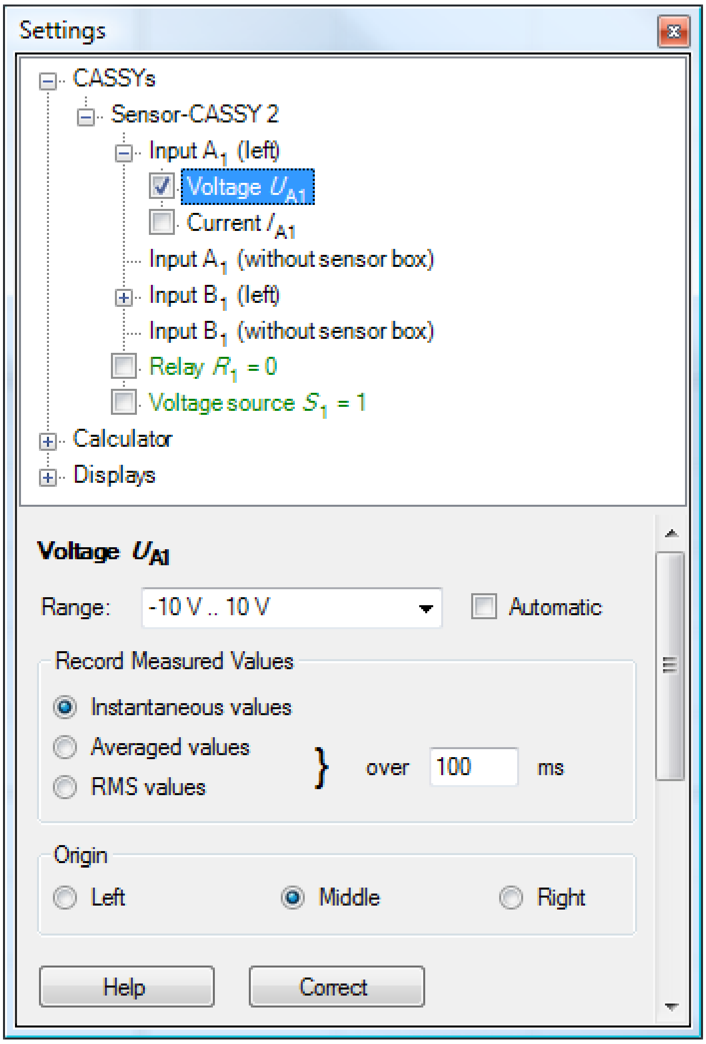
Sensor-CASSY is equipped with two electrically isolated sensor inputs A and B, which can be used to capture voltage values (resp. current as well at input A) as well as other measurement quantities – as determined by the attached sensor box. CASSY Lab detects the sensor box and thus the measuring options **automatically**, i.e. the visual image of the CASSY arrangement shows the inputs with any sensor boxes that are connected. In this display they can also be configured for measuring by clicking on them.

The available measurement quantities and the measuring ranges thus depend on whether a sensor box is connected, and which one. You will need different sensor boxes for different measuring requirements (see also our product catalogue).

Sensor-CASSY 2 even provides four inputs A and B, of which the left-hand inputs A and B are electrically isolated and can be used at the same time as the right-hand sensor inputs A and B.

In addition to the function generator output for voltage or current, Power-CASSY also provides an analog input which is used to measure the other corresponding quantity.

Profi-CASSY is equipped with two analog inputs A and B with the fixed measuring range ±10 V.



Settings

- CASSYs
  - Sensor-CASSY 2
    - Input $A_1$ (left)
      - ☑ Voltage $U_{A1}$
      - ☐ Current $I_{A1}$
    - Input $A_1$ (without sensor box)
    - Input $B_1$ (left)
    - Input $B_1$ (without sensor box)
    - ☐ Relay $R_1$ = 0
    - ☐ Voltage source $S_1$ = 1
- Calculator
- Displays

**Voltage $U_{A1}$**

Range: -10 V .. 10 V ☐ Automatic

Record Measured Values

● Instantaneous values

○ Averaged values

○ RMS values

} over 100 ms

Origin

○ Left ● Middle ○ Right

The selected quantity can be measured as an instantaneous value, averaged over several values or output as the corresponding RMS value. Normally, measurement of **instantaneous values** without averaging will be sufficient. However, if the input signal shows noise or hum, you need to measure **averaged values**. AC voltages are usually measured as **RMS values**. If the time interval is less than 10 ms, the measured values recorded in the table and the diagram will deviate from those shown in the display instruments in the latter two cases. This means that it is possible to display the curve form and the RMS values simultaneously.

As a standard the averaged values and RMS values are calculated during a time interval of 100 ms. This time interval can be changed globally for all channels. If Power-CASSY or Profi-CASSY is used, this time interval is changed on every change in frequency of the output signal so that always an integer number of periods is evaluated.

If the accuracy of the measured values is not sufficient, you an increase this by executing a correction. This can be necessary e.g. when matching a special pH electrode to the software.

### Special buttons (often hidden)

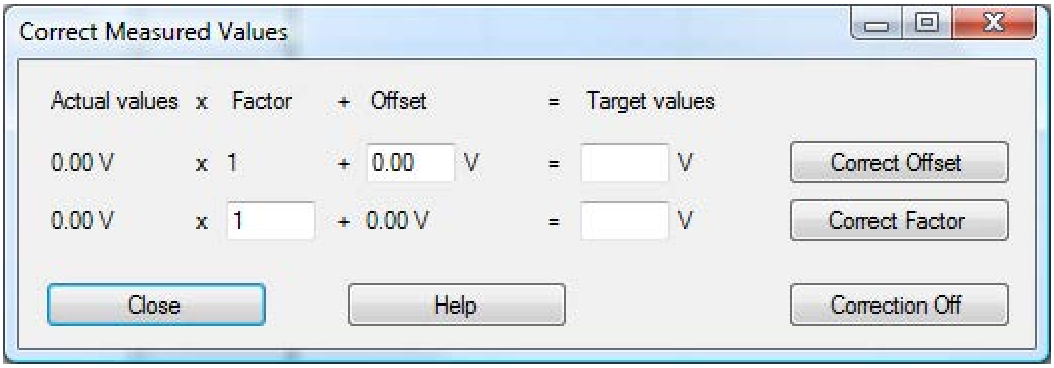
| | |
|---|---|
| **Box-LED** | LED on the sensor box on/off, e.g. SMOOTH (bridge box) or COMPENSATION (prerequisite for tare compensation of B box) |
| **→ 0 ←** | Zero-point adjustment (takes current value as zero point), e.g. for path, force, pressure, events, collision |
| **s ↔ –s** | Sign inversion for path (motion sensing element with the BMW box) |

There are also special input fields which make it much easier to use the BMW box, GM box and timer box (e.g. gate time, width of interrupter flag) and which are only visible when the corresponding box is attached.

When using the reaction test box, the reaction signal must first be requested by pressing a switch (hand or foot switch). The reaction itself must then occur after the pointer appears on the display instrument in accordance with the color of the pointer (red, green or yellow).

When using the climate box, you need to calibrate the humidity sensor (529 057) before the first measurement. The four values C1 to C4 printed on the sensor are provided for this purpose. You only need to enter these values once; they are then stored and retained in CASSY. These values do not need to be entered again, as they remain available for subsequent measurements with CASSY-Display.

## Correct measured values



| Actual values | x | Factor | + | Offset | = | Target values |
|---|---|---|---|---|---|---|
| 0.00 V | x | 1 | + | 0.00 V | = | V |
| 0.00 V | x | 1 | + | 0.00 V | = | V |

You can correct measured values in a variety of ways, all of them easily accessible via Windows dialogs.

You can enter an offset value and/or a factor to the left of the equal sign; the software then uses these values to calculate the displayed values to the right of the equals sign (target values) from the measured values displayed on the left of the equal sign (actual values). To calculate the correction, click on the appropriate button, **Correct Offset** or **Correct Factor.**

Alternatively, you can also define both target values, or one target value and one calculation value. **Correction Off** cancels the correction.

### Saving

A correction is saved with the other program settings. To ensure that the correction corresponds to the real situation when the program is loaded subsequently, be sure to use the same electrodes and sensor boxes on the same Sensor-CASSY (you may want to mark the electrodes, sensor boxes and CASSY devices).

### Examples

Two buffer solutions with pH 3 and pH 9 are to be used for correction. The two target values are then 3 and 9 (enter these on the right side). When the pH electrode is immersed in the pH 3 solution, activate the button next to the target value (e.g. **Correct Offset**), and activate the other button (e.g. **Correct Factor**) for the pH 9 solution.

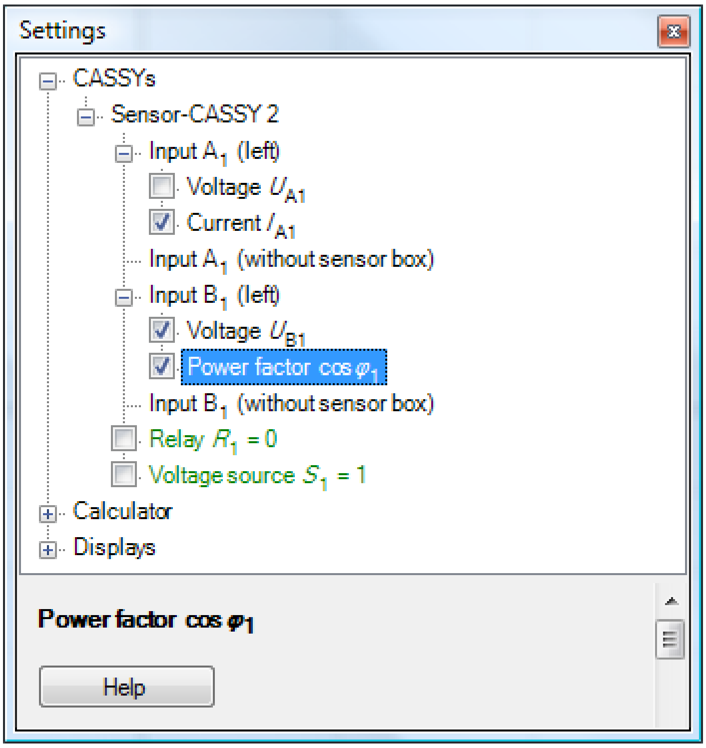
A conductivity electrode with the K-factor 1.07 must be matched to the software. To do this, simply enter the factor 1.07 in the second line as a factor and select **Correct Factor.**

## Power factor cos φ / phase shift φ settings

Sensor-CASSY, Sensor-CASSY 2 and Profi-CASSY support the measurement of the power factor cos θ when effective values are measured at both voltage/current inputs. The power factor can be activated in the settings $U_B$ when both inputs are activated.

Power-CASSY supports the measurement of the phase angle θ between the current and the voltage which can be activated as required.

Profi-CASSY supports the measurement of the phase angle θ between output $U_X$ and input $U_A$ which can be activated as required.



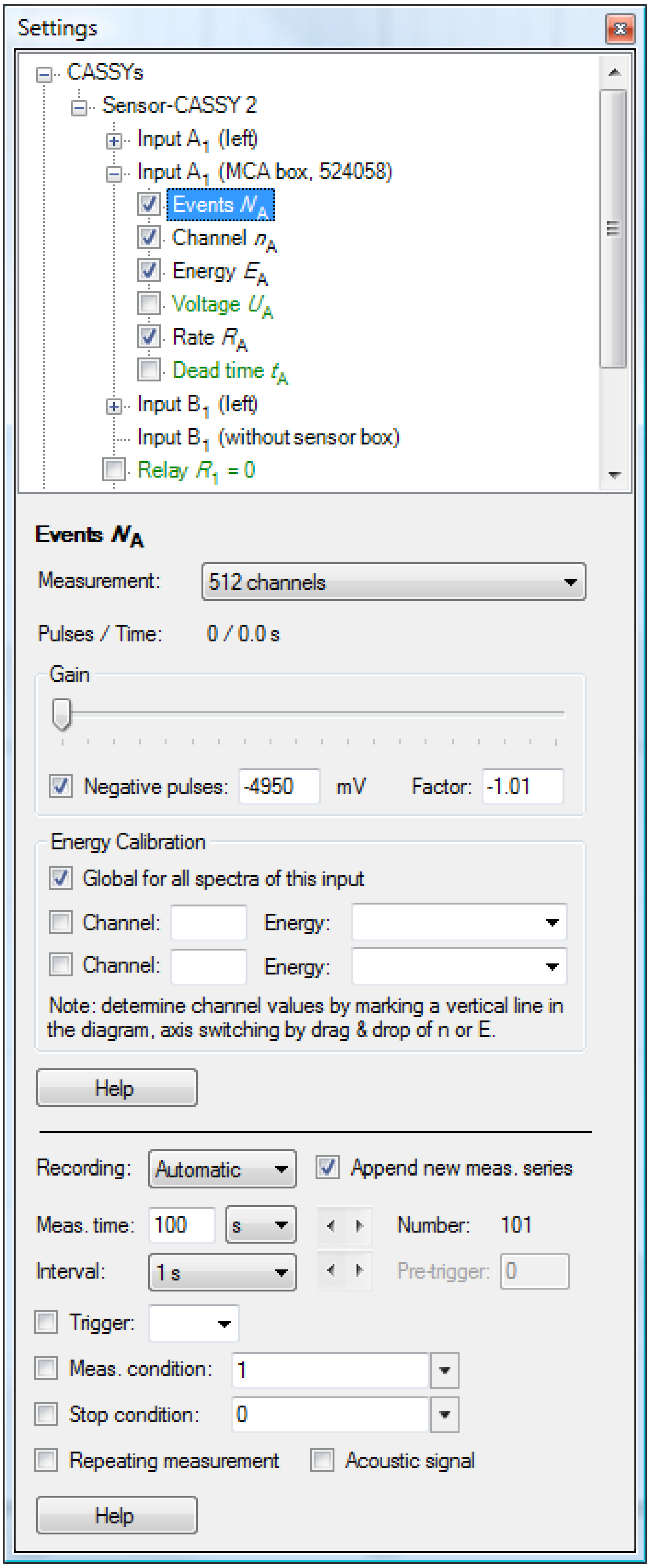
Settings

- CASSYs
  - Sensor-CASSY 2
    - Input $A_1$ (left)
      - ☐ Voltage $U_{A1}$
      - ☑ Current $I_{A1}$
    - Input $A_1$ (without sensor box)
    - Input $B_1$ (left)
      - ☑ Voltage $U_{B1}$
      - ☑ Power factor cos $\varphi_1$
    - Input $B_1$ (without sensor box)
    - ☐ Relay $R_1$ = 0
    - ☐ Voltage source $S_1$ = 1
- Calculator
- Displays

**Power factor cos $\varphi_1$**

The power factor and the phase shift can only be activated and de-activated. Other settings are not possible.

## Settings MCA box



Settings

CASSYs
Sensor-CASSY 2
Input $A_1$ (left)
Input $A_1$ (MCA box, 524058)
☑ Events $N_A$
☑ Channel $n_A$
☑ Energy $E_A$
☐ Voltage $U_A$
☑ Rate $R_A$
☐ Dead time $t_A$
Input $B_1$ (left)
Input $B_1$ (without sensor box)
☐ Relay $R_1$ = 0

**Events $N_A$**

Measurement: 512 channels

Pulses / Time: 0 / 0.0 s

Gain

☑ Negative pulses: -4950 mV Factor: -1.01

Energy Calibration

☑ Global for all spectra of this input
☐ Channel: Energy:
☐ Channel: Energy:

Note: determine channel values by marking a vertical line in the diagram, axis switching by drag & drop of n or E.

Recording: Automatic ☑ Append new meas. series
Meas. time: 100 s Number: 101
Interval: 1 s Pre-trigger: 0
☐ Trigger:
☐ Meas. condition: 1
☐ Stop condition: 0
☐ Repeating measurement ☐ Acoustic signal

Here the settings for the MCA box are made. In principle there are two operating modes:

### Multichannel measurement

Under **Measurement** the number of desired channels is selected. The amplification is located below. The best result is achieved if the amplification is set to 1, 2, 5 or 10, or somewhat more.

The measuring time is as usual provided in the measuring parameters attached below.

### Coincidence measurement

A coincidence measurement is only sensible if two MCA boxes are used, the first of which measures as normal and the second of which provides the coincidence trigger for the first box.

To do this the second MCA box requires a coincidence window which decides whether an event is to trigger the other box or not. This coincidence window can be set if, under measurement, **Coincidence trigger for other box** or **Anti-coincidence trigger for other box** is selected. In the first case, the other MCA box only makes a measurement when an event has been registered in this window. In the second case, the other MCA box only makes a measurement when an event outside of this window has been registered.

The time window for coincidences has a fixed default value of 4 κs.

### Energy calibration

Recorded spectra are first divided into channels. If one or two channels are assigned to a known energy, a spectrum can be displayed in terms of energy.

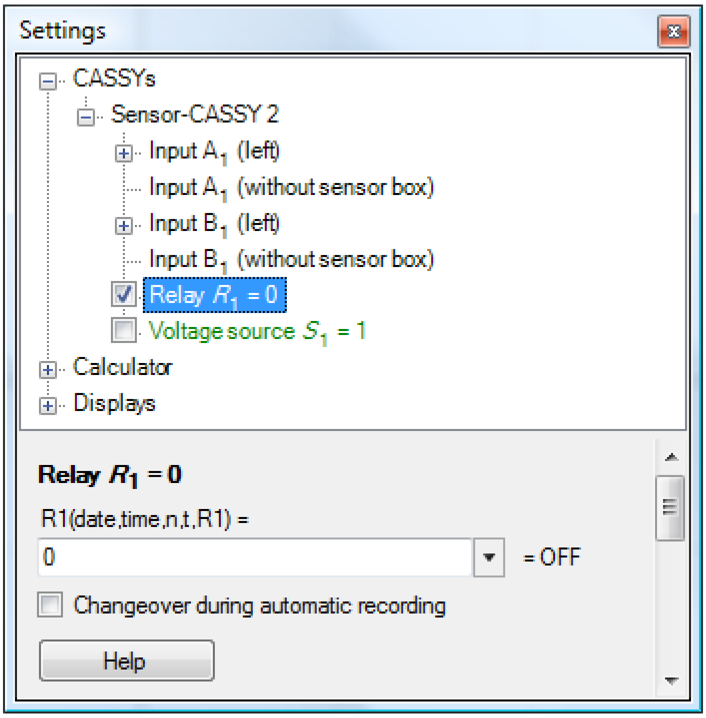
To do this, a vertical line simply has to be entered in the spectrum or a Peak center calculated. If no energy calibration has been carried out, the channel values of the vertical line or of the peak center are automatically entered in the corresponding input field. Alternatively, the values can be entered manually. As a third possibility, a Gaussian curve can be fitted. The result is then dragged from the status line into a **Channel** edit field using drag and drop. The two boxes for choosing the energies already contain default values for the customary radioactive preparations.

After one or two channels have been allocated to their energies, the channel E is allocated to the calibrated x-axis. The current channel x-axis can most simply be switched to the calibrated energy x-axis by drag & drop. To do this, the mouse is used to e.g. drag the channel button E into the diagram.

If the option **Global for all spectra of this input** has been chosen, the entered values are valid for all spectra recorded so far and also for all following spectra of this input. If this option has not been chosen, the calibration is valid for the current spectrum and all following spectra of this input.

## Relay/voltage source settings

Sensor-CASSY and Sensor-CASSY 2 are equipped with a relay R and a voltage source S which can be adjusted using the knob. Both can be switched by the software. They must first be activated by clicking on them in the CASSY arrangement.



**Relay $R_1$ = 0**

R1(date,time,n,t,R1) = 0 = OFF

☐ Changeover during automatic recording

The easiest way to do this is to synchronize the relay with the start of a measurement (e.g. for a holding magnet at voltage source S). Simply activate **Changeover During Automatic Recording**.

However, you can also define the switching state using a formula. A formula can depend on any and all quantities that appear in the displayed list, and must be entered using the correct formula notation (see also the examples). A formula result not equal to 0 means ON="switched on", while a result equal to 0 means OFF="switched off". This formula is not evaluated during the measurement when **Changeover During Automatic Recording** is switched on.

As these formulas are calculated by the PC and their results are transmitted to the CASSY, in the best case changes at the relay and the voltage source are only possible every 10 ms.

### PWM analog output

The voltage source S of Sensor-CASSY is actually a pulse width-modulated analog output. You can set the maximum voltage using the knob. The formula then controls not only OFF (=0) or ON (=1), but also allows intermediate values (e.g. 0.41 = alternately ON 41 % of the time and OFF 59 % of the time over a period of 10 ms). The function **Changeover During Automatic Recording** has no effect for these intermediate values.

Thus, this analog output lets you control modules for which only the average or the RMS value of the output voltage is relevant (e.g. the formula **saw(time/10)** would cause a small light bulb to become brighter for 5 s and then darker for 5 s).

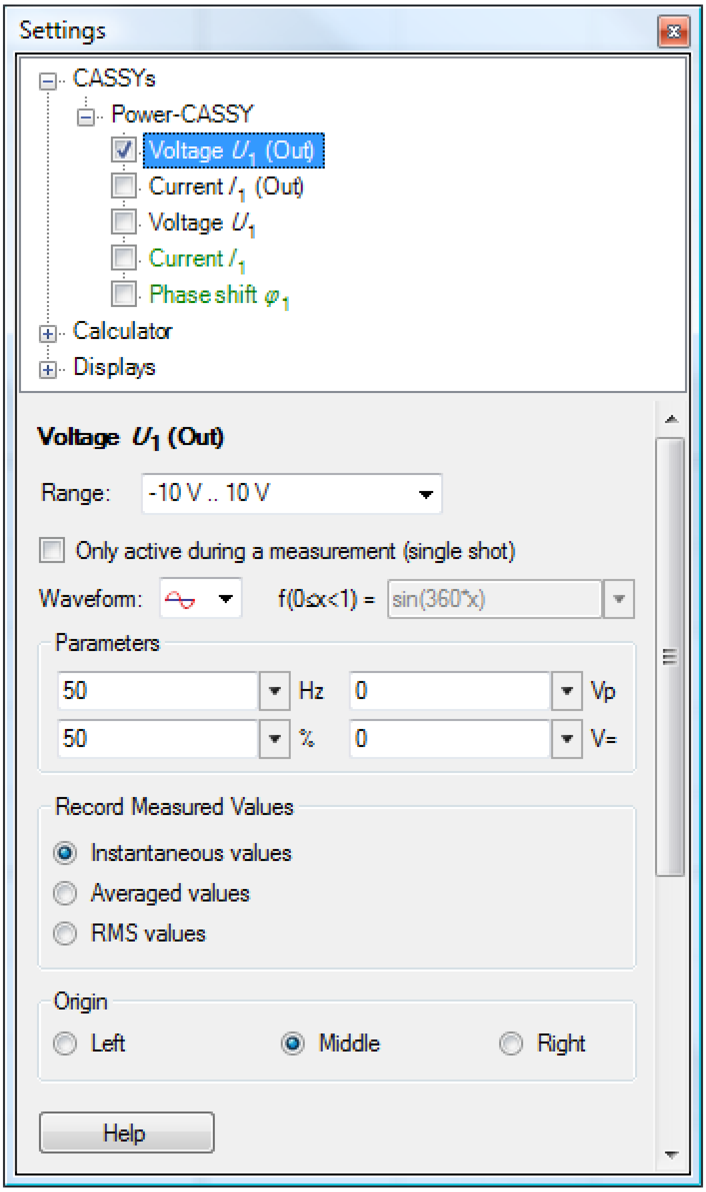
Sensor-CASSY 2 offers a real analog output which outputs fractions of the set maximum voltage as a constant voltage (without PWM).

An analog function generator output is provided by the Power-CASSY and the Profi-CASSY.

## Function generator settings

Power-CASSY is a computer-controlled power function generator. The manipulated variable of the function generator is either the voltage U (voltage source) or the current I (current source). The device simultaneously measures the current I when used as a voltage source and the applied voltage U when used as a current source. The control and measuring ranges are user-definable.

The Profi-CASSY also is a computer-controlled function generator at output X.



- ☑ Voltage $U_1$ (Out)
- ☐ Current $I_1$ (Out)
- ☐ Voltage $U_1$
- ☐ Current $I_1$
- ☐ Phase shift $\varphi_1$

**Voltage $U_1$ (Out)**

Range: -10 V .. 10 V

☐ Only active during a measurement (single shot)

Waveform: ∿ f(0≤x<1) = sin(360*x)

Parameters

50 Hz 0 Vp

50 % 0 V=

Record Measured Values

● Instantaneous values

○ Averaged values

○ RMS values

Origin

○ Left ● Middle ○ Right

The output of the function generator can be actively limited to the actual measuring time **while a measurement is active (single shot)**. The function generator is then inactive between two measurements, so that no determination of mean or RMS values is possible then either.

The output curve form, frequency f (in Hz or kHz), amplitude A (in Vp or Ap), DC voltage offset O (in V= or A=) and duty factor (in %) can be set in specific ranges:

**Power-CASSY**

| **Curve form** | **Frequency f** | **Amplitude A** | **Offset O** | **Duty factor r** |
|---|---|---|---|---|
| DC | - | - | -10 V..10 V / -1 A..1 A | - |
| ∿ | 0.01 Hz - 10 kHz | -10 V..10 V / -1 A..1 A | -10 V..10 V / -1 A..1 A | 0 % ..100 % |
| ⊓, ⊔ | 0.01 Hz - 10 kHz | -10 V..10 V / -1 A..1 A | -10 V..10 V / -1 A..1 A | 0 % ..100 % |
| △, △ | 0.01 Hz - 10 kHz | -10 V..10 V / -1 A..1 A | -10 V..10 V / -1 A..1 A | 0 % ..100 % |
| f(x) | 0.01 Hz - 10 kHz | -10 V. 10 V / -1 A..1 A | -10 V..10 V / -1 A..1 A | - |

**Profi-CASSY**

| Curve form | Frequency f | Amplitude A | Offset O | Duty factor r |
|---|---|---|---|---|
| DC | - | - | -10 V .. 10 V | - |
| ∿ | 0.01 Hz - 1000 Hz | -10 V .. 10 V | -10 V .. 10 V | 0 % .. 100 % |
| ⊓, ⊔ | 0.01 Hz - 1000 Hz | -10 V .. 10 V | -10 V .. 10 V | 0 % .. 100 % |
| ⋀, △ | 0.01 Hz - 1000 Hz | -10 V .. 10 V | -10 V .. 10 V | 0 % .. 100 % |
| f(x) | 0.01 Hz - 1000 Hz | -10 V .. 10 V | -10 V .. 10 V | - |

Square and triangular waves can be generated in two variations. The symmetrical curve form is between –A and +A. The asymmetrical curve from is between 0 and +A.

Negative amplitudes of A are allowed and mirror the signal through 0. The duty factor determines the ratio between the rising and falling curve sections. Thus, e.g. it is easy to convert a triangular signal (50 %) into a sawtooth signal (100 %).

In addition to the usual curve forms, the CASSY also offers a user-programmable curve form. To generate this, you need to enter a formula f(x) that describes that curve form. To determine the curve form, this function is evaluated in the variable x in the interval [0,1] and output with the specified frequency f, amplitude A and offset O. Formula entry is governed by the standard rules. In addition, the function **synth(a:b:c:...)** permits definition of a harmonic synthesis according to **a*sin(360*x) + b*sin(2*360*x) + c*sin(3*360*x) + ....** The signal is also output with the specified frequency f, amplitude A and offset O (see also the example sonic synthesis).

The formula input box is relatively small. You can use any standard text editor to generate longer formulas and then cut and paste these into the input box (right mouse button).

The values can be displayed as instantaneous values, averaged over multiple measured values or calculated as the RMS value. Normally, display of **instantaneous values** without averaging will be sufficient. When CASSY is active continuously (and not just during a measurement), it is also possible to display **averaged values** or **RMS values**. If the time interval is less than 10 ms, the measured values recorded in the table and the diagram will deviate from those shown in the display instruments in the latter two cases. This means that it is possible to display the curve form and the RMS values simultaneously.

### Hint

Instead of fixed numerical values, you can specify formulas for frequency, amplitude, offset and duty factor. Thus, for example, the frequency of a sinusoidal oscillation or the output voltage can be controlled flexibly (e.g. for recording resonance curves or operating control systems). However, the initialization of the output of a new frequency (or amplitude, offset or duty factor) in CASSY may take a few 100 ms. The parameters can thus only be increased in steps, and not continuously.

## Analog output Y settings

Apart from the analog output X, which can be used as a function generator, the Profi-CASSY provides another analog output Y, whose output level can be controlled via a program if a formula is assigned to it.

As this formula is calculated by the PC and its result is transmitted to the CASSY, in the best case changes at the analog output are only possible every 10 ms.

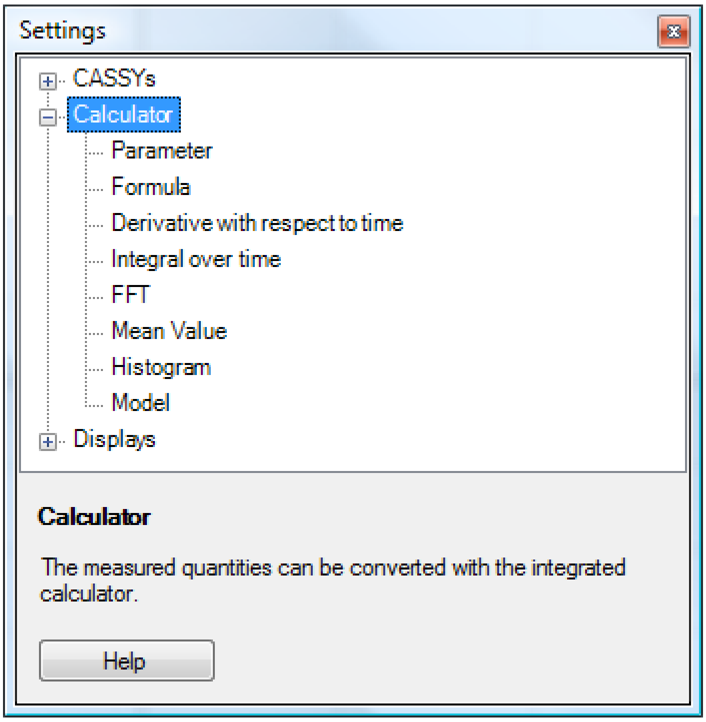
## Digital input/output settings

The Profi-CASSY has 16 digital input and 16 digital outputs, which can be activated in groups of 8 inputs or outputs.

The inputs $I_0$ to $I_{15}$ render the current input levels. To the outputs $Q_0$ to $Q_{15}$ formulas can be assigned, whereby the output levels are controlled via a program.

As these formulas are calculated by the PC and their results are transmitted to the CASSY, in the best case changes at the digital output are only possible every 10 ms.

## Settings Calculator



**Calculator**

The measured quantities can be converted with the integrated calculator.

Some quantities cannot be measured directly using CASSY, and are thus not available as a CASSY channel. If you need to include these quantities in a table or diagram, you must define these quantities here.

**New** generates a new (data) record which begins with the name of the quantity. The new quantity must contain a symbol with which it can be addressed. This symbol should consist of as few (meaningful) letters as possible and may also consist of the & character followed by a letter. In this case, the corresponding Greek letter will be displayed (otherwise the Latin letter will be displayed). Apart from that, the values proposed for the measuring range and the scaling of the axes (important for analogue and graphical representations) and the number of significant decimal positions (important for digital and tabulated representations) have to be adapted to individual requirements.

### Greek symbols

| | | | | | | | | | | | | | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| &a | &b | &c | &d | &e | &f | &g | &h | &i | &j | &k | &l | &m | &n | &o | &p | &q | &r | &s | &t | &u | &v | &w | &x | &y | &z |
| α | β | τ | δ | ε | ϕ | γ | ε | η | θ | θ | ι | κ | λ | ο | π | ζ | ρ | ζ | η | σ | ϖ | φ | μ | υ | δ |
| &A | &B | &C | &D | &E | &F | &G | &H | &I | &J | &K | &L | &M | &N | &O | &P | &Q | &R | &S | &T | &U | &V | &W | &X | &Y | &Z |
| A | B | τ | Γ | Δ | Φ | Γ | Z | H | ϑ | K | Λ | M | N | O | Π | Θ | P | Σ | Σ | T | ς | Ω | Ξ | Ψ | E |

### Parameter

The current value of a parameter is either entered in the settings window or by dragging the pointer of a display instrument. By setting the range to 0-1 and the number of decimal positions to 0, binary constants (switches) can be defined as well, which can be changed over by clicking on the display instrument. In order that parameters and constants can be easily distinguished from other channels, their pointers are magenta.

There are three different types of parameters:

- Constant (without table column)
- Manually into table
- Automatically into table

A constant is a quantity whose value can be accessed in formulas and models via the dedicated symbol of this constant. This provides an easy possibility of varying formulas or models, for example so that the result of the calculation agrees as accurately as possible with the measurement. If the value of a constant is modified this will apply to all measurement series - even retrospectively.

Manual parameters can only be entered in the table by hand via the keyboard or by drag & drop, and they are necessary whenever one wants to fill one's own table only with the evaluation results of other measurements.

Automatic parameters are automatically entered in their table column during a measurement; they can also be entered manually via the keyboard or by drag & drop. It is a good idea to enter the parameter **before** measuring, so that the right measurement points appear in the diagram immediately in manual mode and the old parameter value does not have to be used again.

Automatic and manual parameters can therefore have a different value in each table row and are usually not constant. For this reason the model cannot make use of them.

### Formula

It is possible to define a new measurement quantity using a mathematical formula, regardless of known quantities. The known quantities are addressed via their symbols, which appear in the list the program displays. When entering the formula itself, be sure to observe the correct formula notation (see also the examples). In order that converted quantities can be easily distinguished from other channels, their pointers are violet.

### Derivation, Integral, FFT (Fourier transform), Mean Value, Histogram

For time derivation, integral of time and FFT (Fourier transform), simply select the channel you wish to transform. To calculate the mean value, you additionally need to specify the time interval over which values are to be averaged. Meaningful mean values can only be generated when the interval over which the mean is taken is greater than the measuring interval. For the histogram, the channel width has to be specified in addition. For FFT, the software automatically generates the **frequency spectrum**, and for the histogram the software automatically generates the **frequency distribution** as a further display mode; this can be activated using the display tabs. In order that converted quantities can be easily distinguished from other channels, their pointers are violet.

### Notes

A derivation impairs the resolution for shorter time intervals Γt. For example, if the resolution of a path measurement is Γs = 1 mm and the measurement uses a time interval of Γt = 100 ms, the first derivation v(i) = (s(i+1)-s(i-1))/2Γt has a resolution of Γv = 0.005 m/s and the second a resolution of Γa = 0.025 m/s$^2$. At a time interval of Γt = 50 ms these errors increase to Γv = 0.01 m/s and Γa = 0.1 m/s$^2$. Thus, Γt should be set as high as possible (e.g. 200 ms for motions on a track or 50 ms for oscillating springs).

The maximum frequency of an FFT is half the scanning rate. Thus, if a time interval Γt = 10 κs (f = 100 kHz) is used for measuring, the frequency range of FFT extends to 50 kHz. The resolution in this frequency range, on the other hand, depends on the number of measured values. The more original measurement points are recorded, the better is the frequency resolution in the frequency spectrum.

### Modeling

The modeling tool enables values measured on real objects to be compared with a mathematical model. In particular, suitable constants can be chosen and varied such that the model agrees with reality as accurately as possible. In contrast to a fit (e.g. free fit), where the equation that defines the function has to be known from the beginning, modeling just requires first order differential equations as an input.

For the mathematical definition of the model, the initial values at the time $t_0$ and the differential equations are specified. These numerical values or formulas have to be entered, whereby the correct formula notation has to be observed. Each formulas may depend on constants, whose values can be varied afterwards by dragging the pointer of the display instrument. In addition, the differential equations may depend on the measuring time t, on the defined model quantities and on formulas, which, in turn, may only depend on constants or on the measuring time t. All allowed dependencies of the differential equations are listed in front of their entry field. In order that model quantities can be easily distinguished from other channels, their pointers are blue.

The model can only calculate first order differential equations. If a higher order differential equation is to be calculated, the differential equation must be split up into several first order differential equations (see example).

The **start time** $t_0$, the **accuracy** and the **computing time** are properties for all of the modeling quantities and are for this reason directly set at the modeling node of the tree diagram.

The selectable **Accuracy** gives the truncation criterion, which determines when the numerical integration of the differential equations is terminated. A lower accuracy leads to a shorter computation time, but also to a greater error of the result.

The selectable **Computation Time** determines the maximum time available for the numerical integration of the differential equation. If the computation time selected is too short with regard to the specified accuracy, the calculated values start at the selected starting time, but stop too early.

### Examples

The best-known example of a second order differential equation is certainly Newton's equation of motion F=m·a or s''=F(s,v,t)/m. In this case, the two model quantities are the path s and the velocity v, and the first differential equation is s'=v. The accelerating force F from the second differential equation s''=v'=($F_1$+$F_2$+$F_3$)/m depends on the particular experiment and is, e.g.:

$F_1$ = –m·g for free-fall experiments
$F_1$ = –D·s for oscillations of a spring

In addition, several types of friction may occur, which cause additional forces:

$F_2$ = –c·sgn(v) for Coulomb friction (e.g. solid friction)
$F_2$ = –c·sgn(v)·|v| for Stokes friction (e.g. laminar fluid friction)
$F_2$ = –c·sgn(v)·$|v|^2$ for Newton friction (e.g. aerodynamic drag, turbulent fluid friction)

In forced oscillations (resonance), an exciting force is added, e.g.:

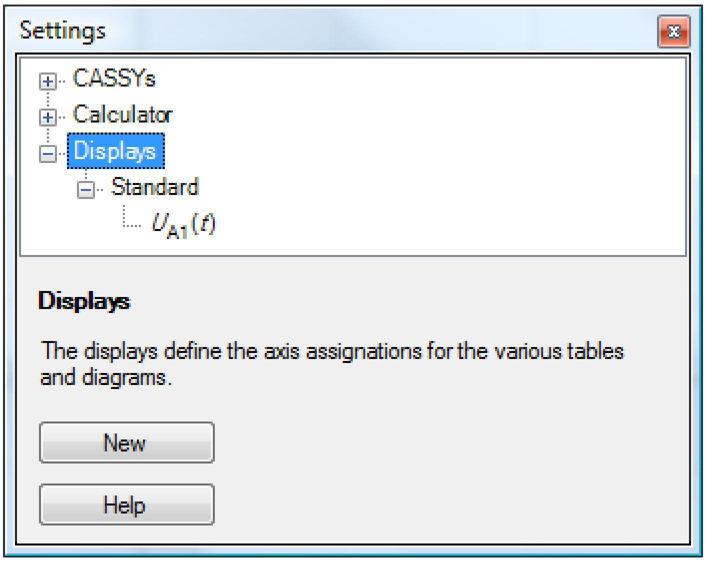
$F_3$ = A·sin(360·f·t), sin calculates the sine of the argument in degrees
$F_3$ = A·rsin(φ·t), rsin calculates the sine of the argument in radian measure

Further examples that suggest themselves are charging and discharging of a capacitor, high-pass and low-pass filters, all of which can be described by a first order differential equation Q'=($U_0$–Q/C)/R for the charge Q of the capacitor.

In the experiment examples, modeling is applied in several cases:

- Free fall with g-ladder (with modeling)
- Oscillations of a spring pendulum (with modeling)
- Oscillations of a spring pendulum with solid friction (with modeling)
- Oscillations of a spring pendulum with lubricant friction (with modeling)
- Oscillations of a spring pendulum with laminar liquid friction (with modeling)
- Oscillations of a spring pendulum with turbulent liquid friction/air friction (with modeling)
- Three-body problem (with modeling)
- Charging and discharging of a capacitor (with modeling)
- Damped oscillator (with modeling)
- Forced oscillations (resonance, with modeling)
- Low-pass filter (with modeling)
- High-pass filter (with modeling)

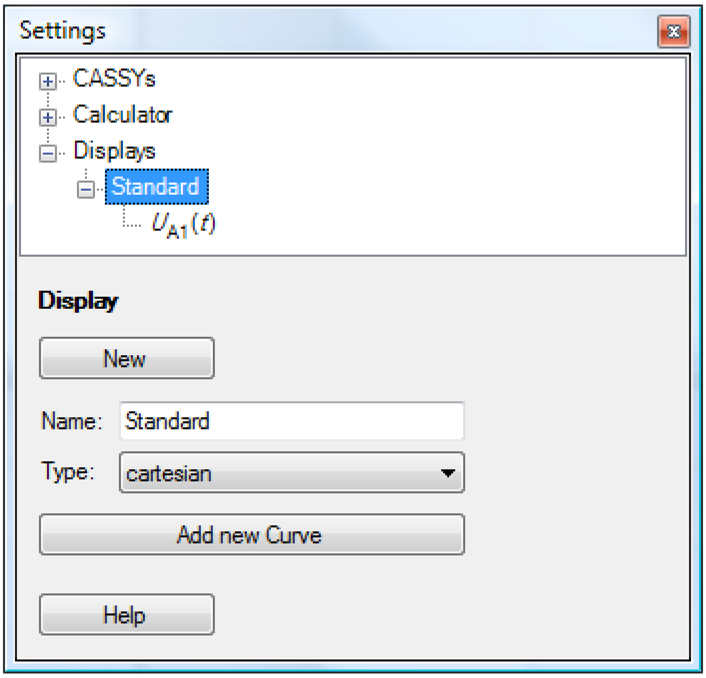
## Settings Display



**Displays**

The displays define the axis assignations for the various tables and diagrams.

If one display is not enough, you can generate additional displays using the **New** function; the name you give the new display appears on the new tab in the main window beneath the channel buttons. This lets you navigate easily between the individual displays using the mouse.



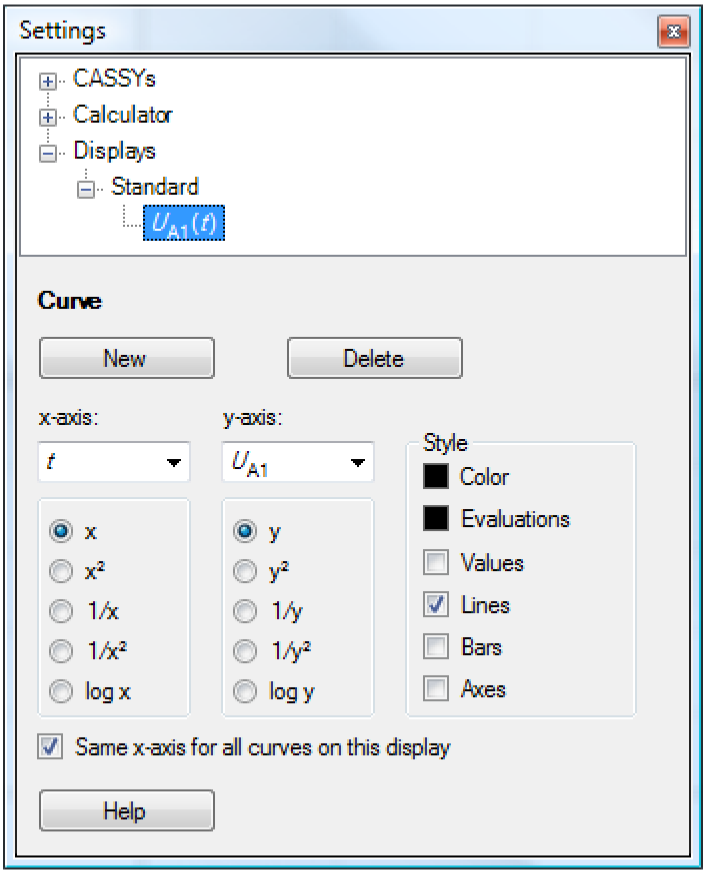
**Display**

Name: Standard

Type: cartesian

For each display a choice can be made between Cartesian and polar coordinates. In polar diagrams an angle (range 0° to 360°) has to be chosen as x-coordinate. Then every y-coordinate is interpreted as the magnitude of a complex number, which is displayed with the corresponding angle. Here the origin need not be at r = 0 but can be negative as well (e.g. for the representation of polar diagrams of antennas in dB).

**Add new Curve** creates a new curve in the current display.



x-axis: $t$

y-axis: $U_{A1}$

● x
○ x²
○ 1/x
○ 1/x²
○ log x

● y
○ y²
○ 1/y
○ 1/y²
○ log y

■ Color
■ Evaluations
☐ Values
☑ Lines
☐ Bars
☐ Axes

☑ Same x-axis for all curves on this display

**New** creates a new curve in the current display. Any number of curves can be defined in a single display.

You can assign each measurement quantity to the x- or the y-axis, and convert them where necessary ($x^2$, 1/x, $1/x^2$, log x). Three additional quantities are pre-defined for the x-axis: n (table row), t (time), f (frequency for FFT).

If more than one y-axis is to be displayed, the visible y-axis scaling in the diagram can be toggled using the corresponding button.

Usually all of the curves are plotted on the same x-axis. If this is not desired, it can be switched off by unticking **Same x-axis for all curves on this display**.

The style of every curve is normally allocated by your display, but it can be modified individually. This also includes the color of the curve and the color of its evaluations.

### Notes

Alternatively, the displayed channels can also be dragged back and forth from the channel buttons to the table and the diagram (drag and drop).

When the mouse pointer is over the rulers, you can mathematically convert the axes ($x^2$, 1/x, $1/x^2$, log x) and change the scale maximum and minimum via the right mouse button. You can also move the rulers by grabbing them with the left mouse button.

## Formula notation

### Formula variables f(time,date,n,t,...)

A formula f(…) can depend on all channels listed below. To realize this, use the name of the channel as the variable name. For example, the result of the formula **UA1 > 5** is 1 when the voltage is greater than 5 V, otherwise 0.

| **Formula for** | **can depend on** |
|---|---|
| Measuring condition | all channels |
| Formula | inputs, serial measuring instruments, parameters and formulas |
| Relay/voltage source | inputs, serial measuring instruments, parameters and formulas |
| Analog output | inputs, serial measuring instruments, parameters and formulas |
| Digital output | inputs, serial measuring instruments, parameters and formulas |
| Model | Model quantities, constants and formulas that depend only on constants and on the time t |

In addition, formulas can also depend on the **time** in seconds, the **date**, the measuring time **t** in seconds and the number of recorded measured values **n**. You can add a comment at the end of the formula by separating it with a semicolon.

Symbols can consist of a & character followed by a letter. The software displays these as the corresponding Greek letter (otherwise only Latin letters). You need to enter the & character in the formula.

### Index access and access to other measuring series

Via […] any element in a table belonging to the current measuring series can be accessed, e.g. UA1[1] will always deliver the first measured value of the measuring quantity UA1 or UA1[n-1] the preceding value.

UA1[0] is not defined. In order to avoid definition gaps during the utilization of UA1[n-1], one can write (n>1)*UA1[n-1].

Via # a different measuring series can be accessed, e.g. NA1-NA1#1 calculates the difference between the current spectrum and the first spectrum (background correction).

### Functions of a formula

Within a formula, you can use the following functions. The function arguments must be put in brackets when they are compounded, e.g. in **square(t/10)**.

| | |
|---|---|
| **ramp** | Ramp (sawtooth between 0 and 1, ramp(x) = frac(x)) |
| **square** | Square-wave function (between 0 and 1, square(x) = ramp(x) < 0.5) |
| **saw** | Triangle (between 0 and 1) |
| **shift** | Single ramp (is 0 if argument < 0, 1 if argument > 1, otherwise equal to argument) |
| **sin** | Sinus in degrees (period 360°) |
| **cos** | Cosine in degrees (period 360°) |
| **tan** | Tangent in degrees (period 360°) |
| **arcsin** | ArcSine in degrees |
| **arccos** | ArcCosine in degrees |
| **arctan** | ArcTangent in degrees |
| **rsin** | Sine of the argument in radian measure (period 2π) |
| **rcos** | Cosine of the argument in radian measure (period 2π) |
| **rtan** | Tangent of the argument in radian measure (period 2π) |
| **rarcsin** | Arc sine in radian measure |
| **rarccos** | Arc cosine in radian measure |
| **rarctan** | Arc tangent in radian measure |
| **delta** | Change with respect to last recorded measured value |
| **new** | Is 1 if the argument has changed, otherwise 0 |
| **random** | Random number (0 <= random(x) < x) |
| **sqr** | Square root |
| **exp** | Exponential function |
| **ln** | Natural logarithm |
| **log** | Decadic logarithm |
| **int** | Integer function (next lowest whole number) |
| **frac** | Integer function (next lowest whole number) |
| **abs** | Absolute value |
| **sgn** | Signum (is 1 if argument > 0, -1 if argument < 0, 0 if argument = 0) |
| **odd** | Is 1 if argument is odd, 0 if argument is even |
| **even** | Is 1 if argument is even, 0 if argument is odd |

| | |
|---|---|
| **not** | Logical inversion (is 1 if argument equals 0, otherwise 0) |
| **defined** | Is 1 if argument is defined, 0 if argument is not defined |
| **sec** | Rounds off the time to the nearest full second (sec(x) = int(x)) |
| **min** | Rounds off the time to the nearest full minute (min(x) = 60*int(x/60)) |
| **day** | Returns the day of the week (1 = Monday,...) |

### Linking variables and functions

All variables (or entered numerical values) can be linked using the usual mathematical operations.

The operators have different priorities. The higher an operation stands in the following list, the higher is its priority in evaluating the formula ("dots before dashes"). To force a different evaluation order, place the respective expressions in brackets.

| | | |
|---|---|---|
| 1) | ^ | Powers |
| 2) | * | Multiplication |
| | / | Division |
| 3) | + | Addition |
| | - | Subtraction |
| 4) | = | Test for equality |
| | <> | Test for inequality |
| | > | Test for greater than |
| | >= | Test for greater than or equal to |
| | < | Test for less than |
| | <= | Test for less than or equal to |
| 5) | and | Logical AND operation |
| 6) | or | Logical OR operation |

### Examples for using the variables time, date, n and t

**t <= 100**

has the value of 1 during the first 100 s of the measurement, then 0. You can use this formula e.g. for the time window to stop the measurement after 100 s.

**time >= 12:30:35**

has the value 1 starting at the time 12:30:35, and 0 prior to that. It must be used with the operator >=, as exact equality is only valid for 1/100 s, and is thus practically unattainable.

**min(time) = 11:45 and date = 18.3.1997**

is only true during the single minute on 18 March 1997 at 11:45 hours (value 1), and otherwise false (value 0).

**0.5 * (n– 1)**

calculates e.g. a volume from the number of the present measurement. In this case, a measured value is recorded every 0.5 ml, so that the volume is calculated from n. In the first table line n has the value 1.

### Examples for generating frequencies

**ramp(t/10)**

generates a ramp with a period of 10 seconds (t is the measuring time in seconds and starts at 0 when the measurement is started). The ramp starts at 0 and ends at 1. If other amplitudes are required, you must additionally multiply this by the desired amplitude.

**saw(t/5)**

generates a triangular ("sawtooth") wave form with a period of 5 seconds.

**square(t/5)**

generates a square wave form with a period of 5 seconds, similar to the previous example. It switches from 0 to 1 and back every 2.5 seconds.

**10*(ramp(t/10) < 0.4)**

also generates a square wave form. However, here the amplitude is 10 and the duty factor is 40%. 40% of the time, the expression in brackets is 1 (true); the remaining 60% of the time it is 0 (false).

**shift((time-12:30)/100)**

generates a single ramp starting at the time 12.30 hours with a period of 100 seconds. In this period, the value of the formula rises continuously to 1.

**sin(360*t/7)**

generates a sinusoidal oscillation with a period of 7 seconds and an amplitude of 1.

### Examples for the priority of arithmetic expressions

**x+y^z*2**

contains the operator order ^,* and +. As a result, y^z is evaluated first, the result multiplied by two, and then x is added. To suppress the given operator order, place the respective expressions in brackets.

**(x+y)^(z*2)**

Unlike the previous example, here the addition x+y and the multiplication z*2 are performed first. The first result is not raised to the power of the second until the final step.

### Examples for the evaluation of Boolean expressions

**x < 5**

can have either the value 0 (false, for x >= 5) or 1 (true, for x < 5).

**x1 < 5 and x2 > 0**

has the value 1 (true when x1 < 5 and x2 > 0 simultaneously), otherwise 0. You do not need to use any brackets, as the operator and has a lower priority than < and >.

**5*(T < 20)**

has only the values 0 (false) and 1 (true) in the brackets. However, these values are multiplied by 5. A formula of this type is thus only useful for analog outputs. In this case the analog output would output a voltage of 5 V when T is less than 20 (e.g. a temperature).

**time >= 12:30**

has the value 1 as of 12:30 hours and 0 prior to that. It must be used with the operator >=, as exact equality is only valid for 1/100 s, and is thus practically unattainable.

**sec(time) = 11:45:07 and date = 18.3.1997**

is only true during the single second on 18 March 1997 at 11:45:07 AM hours (value 1), and otherwise false (0).

**day(date) = 1**

is true every Monday (value 1) and otherwise false (value 0).

## Formula examples

### Simple controller: ϑA11<25

(ϑ entered as &J) is 1 when the temperature is less than 25 °C and otherwise 0 (e.g. for controlling a heater).

### Two-position controller: ϑA11<25 or (ϑA11<27 and old) ; R1 is the symbol of the formula

(ϑ entered as &J) is 1 when the temperature is less than 25 °C or – for the case that the value was already 1 – 27 °C, and otherwise 0 (e.g. for two-position control of a heater). The controller thus switches on below 25 °C and off again above 27 °C.

### Ramp: 8*ramp(t/10)

generates a ramp from 0 to 8 with a period of 10 s (0.1 Hz).

### Square wave with user-defined duty factor: ramp(t/10) < 0.8

generates a square wave from with a period of 10 s (0.1 Hz). The square wave is 1 for 80% of the period and otherwise 0.

### Temperature compensation pH: 7+(pHA1-7)*(25+273)/(ϑB1+273)

(ϑ entered as &J) corrects the pH value $pH_{A1}$ calibrated at 25 °C for the new temperature $\vartheta_{B1}$.

### Temperature compensation conductivity: CA1/(1+(ϑB1-25)/45)

(ϑ entered as &J) corrects the conductivity value $C_{A1}$ calibrated at 25 °C for the new temperature $\vartheta_{B1}$.

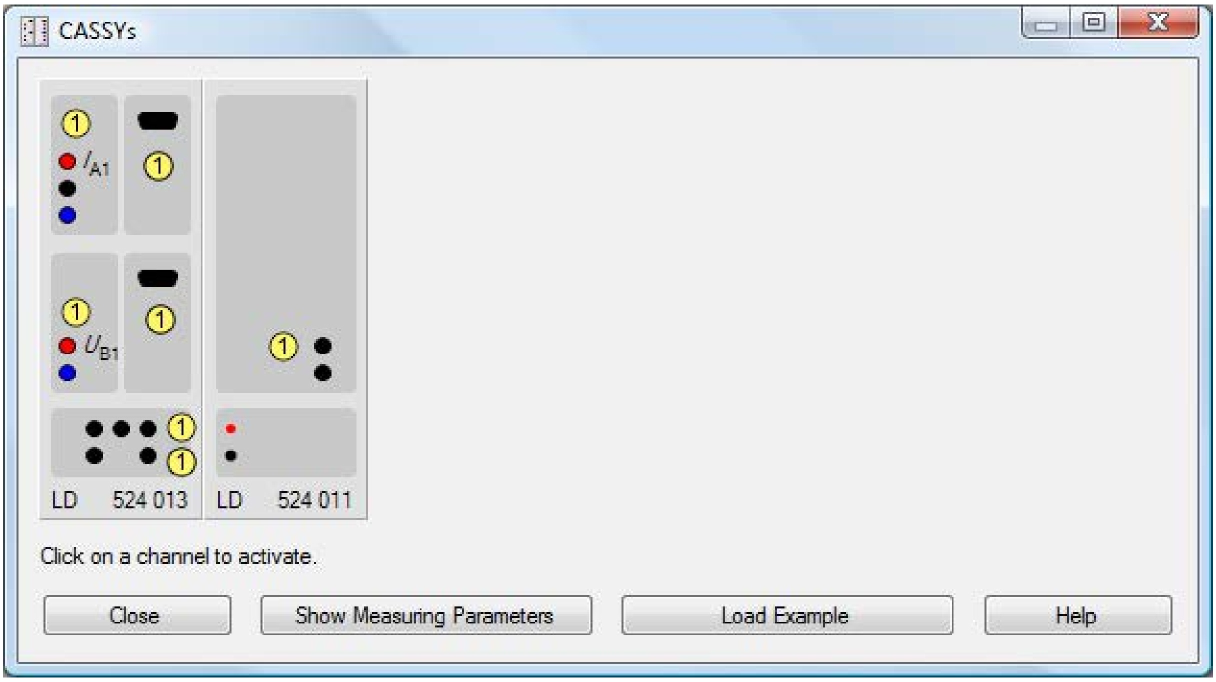
## CASSYs

### Window → Show CASSY Modules (F5)

This displays the current arrangement of the CASSY modules and sensor boxes. When this arrangement is altered (e.g. by adding a new module or sensor box) this change also appears in the display. The following devices are displayed:

- Sensor-CASSY (524 010)*
- Sensor-CASSY 2 (524 013)*
- Power-CASSY (524 011)*
- Profi-CASSY (524 016)*
- CASSY-Display (524 020)*
- Pocket-CASSY (524 006)*
- Mobile-CASSY (524 009)*
- Joule and Wattmeter (531 831)
- Universal measuring instrument physics (531 835)
- Universal measuring instrument chemistry (531 836)
- Universal measuring instrument biology (531 837)

Devices marked with an * require for the unrestricted utilisation the input of a valid activation code.



Click on a channel to activate.

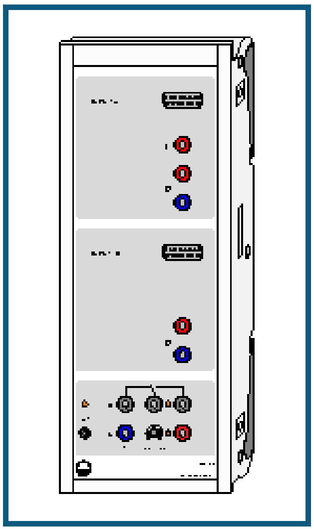
You can activate and configure this by clicking on a channel ①. The available quantities depend on the CASSY module and the attached sensor box. During measurement, the software includes measured values in the table and the diagram for each active channel. You can also decide how these are to be displayed (column and axis assignment).

For channels already activated, the activated arrangement is displayed and any deviations to the actual arrangement are crossed through with two red lines. Thus, for example, after loading a measurement file, it is easy to recreate the arrangement of CASSY modules and sensor modules which were used to capture that data.

If the current arrangement is not displayed the arrangment can be updated by deleting the invalid channels (either one by one or all at the same time, by pressing **File → New**).

**Show Measuring Parameters** opens the measuring parameter window.

## Sensor-CASSY



### Introduction

Sensor-CASSY (USB or serial respectively) is a cascadable interface device for recording measurement data:

- For connection to the USB port of a computer or to the RS-232 serial interface respectively, another CASSY module or the CASSY display.
- 4-fold electrical isolation (inputs A and B, relay R, voltage source S).
- Cascading of up to 8 CASSY modules possible (to expand the inputs and outputs)
- Up to 8 analog inputs per Sensor-CASSY retrofittable using sensor boxes
- Automatic sensor box detection by CASSY Lab (plug and play)
- Microprocessor-controlled with CASSY operating system (easily updatable via software for function enhancements).
- For use as a benchtop, console or demonstration unit (also in CPS/TPS panel frames)
- Voltage supply 12 V AC/DC via cannon plug or adjacent CASSY module.

Developer information for your own software development available on the Internet

### Safety note

- For your own protection, do not connect Sensor-CASSY to voltages over 100 V.
- Transport multiple cascaded CASSY modules only in the panel frame or individually (the mechanical stability of the connections without panel frame is sufficient for experimenting only, and not for transport).
- Use only the enclosed plug-in supply unit (12 V / 1.6 A) to power the CASSY modules.
- A Sensor-CASSY can also supply an adjacent module with a voltage as long as the total current consumption does not exceed 1.6 A (sufficient for up to 2 modules; overload trips automatic cutout). If using additional Sensor-CASSYs, supply these separately.

## Technical data

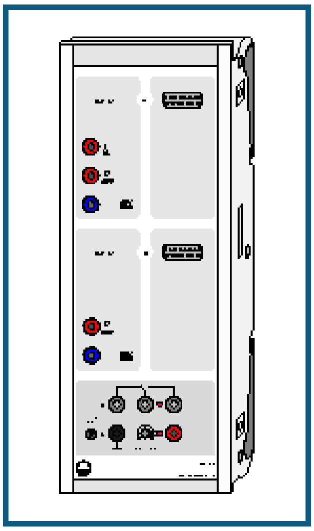
- 5 Analog inputs (any two inputs A and B usable simultaneously)
  - 2 Analog voltage inputs A and B on 4-mm safety sockets
    - Resolution: 12 bits
    - Measuring ranges: ±0.3/1/3/10/30/100 V
    - Measuring error: ± 1 % plus 0.5 % of range end value
    - Input resistance: 1 MΩ
    - Scanning rate: max. 200,000 values/s (= 100,000 values/s per input)
    - No. of meas. values: virtually unlimited (PC dependent) up to 100 values/s, at a higher measurement rate max. 32,000 values (= 16,000 values per input)
  - 1 Analog current input A on 4-mm safety sockets
    - Measuring ranges: ±0.1/0.3/1/3 A
    - Measuring error: voltage error plus 1 %
    - Input resistance: < 0.5 Ω (except under overload)
    - See voltage inputs for further data
  - 2 Analog inputs at sensor box connector sites A and B (All CASSY sensor boxes and sensors can be connected)
    - Measuring ranges: ±0.003/0.01/0.03/0.1/0.3/1 V
    - Input resistance: 10 kΩ
    - See voltage inputs for further data
    - The technical data will change depending on a connected sensor box. In this case CASSY Lab automatically detects the possible measurement quantities and ranges when a sensor box is attached.
- 4 Timer inputs with 32-bit counters at sensor box sites A and B (e.g. for BMW box, GM box or timer box)
  - Counter frequency: max. 100 kHz
  - Time resolution: 0.25 µs
  - Measuring time between two events at same input: min. 100 µs
  - Measuring time between two events at different inputs: min. 0.25 µs
  - Memory: max. 10,000 time points (= 2,500 values per input)
- 1 Changeover relay (switching indication via LED)
  - Range: max. 100 V / 2 A
- 1 Analog output (PWM-output) (**p**ulse-**w**idth **m**odulated, switchable voltage source, LED switching state indicator, e.g. for holding magnet or supplying experiment)
  - Variable voltage range: max. 16 V / 200 mA (load ≥ 80 Ω)
  - PWM range: 0 % (off), 5-95 % (1 %resolution), 100 % (on)
  - PWM frequency: 100 Hz
- 12 Digital inputs (TTL) on sensor box sites A and B (at present only used for automatic sensor box detection)
- 6 Digital outputs (TTL) on sensor box sites A and B (at present only used for automatic switching of a sensor box measuring range)
- 1 USB port (USB version), respectively serial interface RS232 (subD-9) for connection to a computer
- 1 CASSY bus for connecting additional CASSY modules or the CASSY display

Dimensions (WxHxD): 115 mm x 295 mm x 45 mm
Weight: 1 kg

### Scope of supply

- 1 Sensor-CASSY
- 1 CASSY Lab 2 software, without activation code, for Windows XP/Vista/7 with comprehensive help function (16 full-functionality sessions free, then usable as demo version)
- 1 Installation guide
- 1 USB cable or serial cable (subD-9)
- 1 Plug-in supply unit 12 V / 1.6 A

## Sensor-CASSY 2



### Introduction

Sensor-CASSY 2 is a cascadable interface device for recording measurement data:

- For connection to the USB port of a computer, another CASSY module or the CASSY-Display.
- 3-fold electrical isolation (inputs A and B, relay R).
- Measurement possible parallel at 4-mm-inputs and sensor box connector sites (4 channels)
- Cascading of up to 8 CASSY modules possible (to expand the inputs and outputs)
- Up to 8 analog inputs per Sensor-CASSY retrofittable using sensor boxes
- Automatic sensor box detection by CASSY Lab (plug and play)
- Microprocessor-controlled with CASSY operating system (easily updatable via software for function enhancements).
- For use as a benchtop, console or demonstration unit (also in CPS/TPS panel frames)
- Voltage supply 12 V AC/DC via cannon plug or adjacent CASSY module.

▫ Developer information for your own software development available on the Internet

### Safety note

- For your own protection, do not connect the 4-mm inputs of Sensor-CASSY 2 to voltages over 250 V (CAT II).
- Transport multiple cascaded CASSY modules only in the panel frame or individually (the mechanical stability of the connections without panel frame is sufficient for experimenting only, and not for transport).
- Use only the enclosed plug-in supply unit (12 V / 1.6 A) to power the CASSY modules.
- A Sensor-CASSY can also supply an adjacent module with a voltage as long as the total current consumption does not exceed 1.6 A (sufficient for up to 2 modules; overload trips automatic cutout). If using additional Sensor-CASSYs, supply these separately.

## Technical data

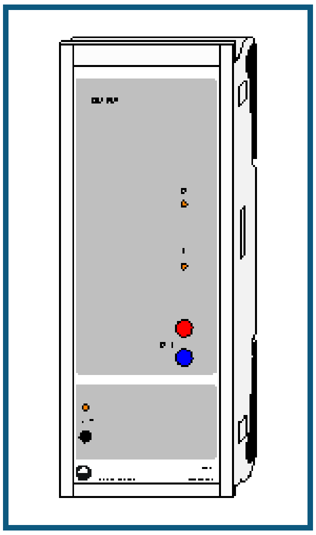
- 5 Analog inputs
  - 2 Analog voltage inputs A and B on 4-mm safety sockets
    - Resolution: 12 bits
    - Measuring ranges: ±0.1/0.3/1/3/10/30/100/250 V
    - Measuring error: ± 1 % plus 0.5 % of range end value
    - Input resistance: 1 MΩ
    - Scanning rate: max. 2,000,000 values/s (= 1,000,000 values/s per input)
    - No. of meas. values: virtually unlimited (PC dependent) up to 10,000 values/s, at a higher measurement rate max. 200,000 values
    - Pre-trigger: max. 50,000 values
  - 1 Analog current input A on 4-mm safety sockets (alternatively to voltage input A)
    - Measuring ranges: ±0.03/0.1/0.3/1/3 A
    - Measuring error: voltage error plus 1 %
    - Input resistance: < 0.5 Ω (except under overload)
    - See voltage inputs for further data
  - 2 Analog inputs at sensor box connector sites A and B (All CASSY sensor boxes and sensors can be connected)
    - Measuring ranges: ±0.003/0.01/0.03/0.1/0.3/1 V
    - Input resistance: 10 kΩ
    - Scanning rate: max. 1,000,000 values/s (= 500,000 values/s per input)
    - See voltage inputs for further data
    - The technical data will change depending on a connected sensor box. In this case CASSY Lab automatically detects the possible measurement quantities and ranges when a sensor box is attached.
- 4 Timer inputs with 32-bit counters at sensor box sites A and B (e.g. for BMW box, GM box or timer box)
  - Counter frequency: max. 1 MHz
  - Time resolution: 20 ns
- 5 LED status indicators for analog inputs and USB-port
  - Colors: red and green, according to status
  - Light intensity: adjustable
- 1 Changeover relay (switching indication via LED)
  - Range: max. 250 V / 2 A
- 1 Analog output (LED switching state indicator, e.g. for holding magnet or supplying experiment)
  - Variable voltage range: max. 16 V / 200 mA (load ≥ 80 Ω)
- 12 Digital inputs (TTL) on sensor box sites A and B (at present only used for automatic sensor box detection)
- 6 Digital outputs (TTL) on sensor box sites A and B (at present only used for automatic switching of a sensor box measuring range)
- 1 USB port for connection to a computer
- 1 CASSY bus for connecting additional CASSY modules or the CASSY display

Dimensions (WxHxD): 115 mm x 295 mm x 45 mm
Weight: 1 kg

### Scope of supply

- 1 Sensor-CASSY 2
- 1 CASSY Lab 2 software, without activation code, for Windows XP/Vista/7 with comprehensive help function (16 full-functionality sessions free, then usable as demo version)
- 1 Installation guide
- 1 USB cable
- 1 Plug-in supply unit 12 V / 1.6 A

## Power-CASSY



### Introduction

Power-CASSY (USB or serial respectively) is a cascadable interface device which can be used as a programmable voltage or current supply (power function generator) with integrated current or voltage measurement.

- For connection to the USB port of a computer or to the RS-232 serial interface respectively, another CASSY module or the CASSY display.
- Electrically isolated.
- Cascading of up to 8 CASSY modules possible (to expand the inputs and outputs)
- Microprocessor-controlled with CASSY operating system (easily updatable via software for function enhancements).
- For use as a benchtop, console or demonstration unit (also in CPS/TPS panel frames)
- Voltage supply 12 V (AC only) via cannon plug.

Developer information for your own software development available on the Internet

### Safety note

- Transport multiple cascaded CASSY modules only in the panel frame or individually (the mechanical stability of the connections without panel frame is sufficient for experimenting only, and not for transport).
- Use only the enclosed plug-in supply unit (12 V / 1.6 A) to power the CASSY modules.

## Technical data

1 Programmable voltage source with simultaneous current measurement
(e.g. for recording characteristics)
Resolution: 12 bits
Control range: ±10 V
Measuring range: ±0.1/0.3/1 A
Voltage error: ± 1 % plus 0.5 % of range end value
Current error: voltage error plus ±1 %
Scanning rate: 200,000 values/s(= 100,000 values/s each for voltage and current)
No. of meas. values: virtually unlimited (PC dependent) up to 100 values/s, at a higher measuring rate max. 32,000 values(= 16,000 values/s each for voltage and current)

1 Programmable current source with simultaneous voltage measurement
(as alternative to voltage source)
Control range: ±1 A
Measuring range: ±1/3/10 V
For further data see voltage source

1 USB port (USB version), respectively serial interface RS232 (subD-9) for connection to a computer

1 CASSY bus for connecting additional CASSY modules or the CASSY display

Dimensions (WxHxD): 115 mm x 295 mm x 45 mm
Weight: 1.0 kg

### Scope of supply

1 Power-CASSY
1 CASSY Lab 2 software, without activation code, for Windows XP/Vista/7 with comprehensive help function (16 full-functionality sessions free, then usable as demo version)
1 Installation guide
1 USB cable or serial cable (subD-9)
1 Plug-in supply unit 12 V / 1.6 A

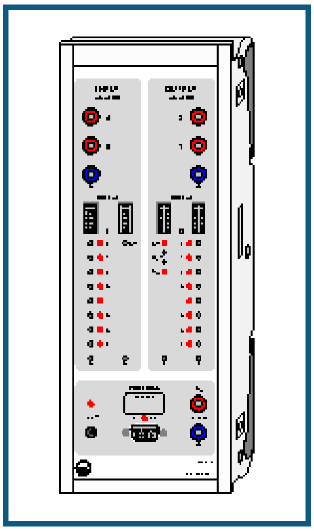
### Notes on the power limit

Due to the rating of the supplied plug-in power supply unit, Power-CASSY can not always guarantee a DC current of 1 A at 10 V. In such marginal cases, Power-CASSY only has sufficient power reserves when a second plug-in unit (not included) is used.

The scanning frequency of 100 kHz for the output channel limits the output frequency to a maximum value of 10 kHz. Here, the signal form is resolved with 10 κs, and thus consists of at least 10 points per period, each 10 κs apart. If it is not possible to achieve the set frequency or duty factor exactly by this means, the system attempts to achieve both set values as exactly as possible by averaging over a longer period.

When Power-CASSY is used as a current source, the maximum frequency is additionally reduced by a virtual output capacitance of up to 10 κF. For an ohmic load of R = 100 Ω, the output capacitance results in a time constant of R*C = 1 ms, and thus a cut-off frequency of around 1000 Hz. For inductive loads, the cut-off frequency is much lower (a resistor connected in series with the inductance can help). For capacitative loads the effective capacitance is up to 10 κF higher.

## Profi-CASSY



### Introduction

Profi-CASSY is an intelligent interface for all fields of electrical engineering

- For connection to the USB port of a computer.
- Electrically isolated from the computer.
- Cascadable with Sensor-CASSY or Power-CASSY (to expand the inputs and outputs).
- Microprocessor-controlled with CASSY operating system (easily updatable via software for function enhancements).
- For use as a benchtop, console or demonstration unit (also in CPS/TPS panel frames)
- Voltage supply 12 V (AC only) via cannon plug.

▨ Developer information for your own software development available on the Internet

### Safety note

- Transport multiple cascaded CASSY modules only in the panel frame or individually (the mechanical stability of the connections without panel frame is sufficient for experimenting only, and not for transport).
- Use only the enclosed plug-in supply unit (12 V / 1.6 A) to power the CASSY modules.
- A Profi-CASSY can also supply an adjacent module with a voltage as long as the total current consumption does not exceed 1.6 A (sufficient for up to 2 modules; overload trips automatic cutout). If using additional CASSYs, supply these separately.

## Technical data

2 Analog voltage inputs A and B on 4-mm safety sockets
- Resolution: 12 bits
- Measuring range: ±10 V
- Measuring error: ± 1 % plus 0.5 % of range end value
- Input resistance: 1 MΩ
- Scanning rate: 20,000 values/s (= 10,000 values/s per input)
- No. of meas. values: virtually unlimited (PC dependent) up to 100 values/s, at a higher measurement rate max. 16,000 values (= 8,000 values per input)

2 Analog voltage outputs X and Y on 4-mm safety sockets
- Resolution: 12 bits
- Control range: ±10 V
- Error: ± 1 % plus 0.5 % of range end value
- Output current: max. 100 mA per output
- Scanning rate: 10,000 values/s for output X<br>max. 100 values/s for output Y (PC dependent)
- No. of meas. values: virtually unlimited (PC dependent) up to 100 values/s, at a higher measuring rate max. 8,000 values (output X only)

16 Digital inputs I0 to I15
- Logic: 5 V or 24 V
- Scanning rate: max. 100 values/s (PC dependent)

The digital inputs are each equipped with two 10-pole plug-in connectors for direct connection to automation devices. In addition, eight of them are equipped with 2-mm sockets and status LEDs.

16 Digital outputs Q0 to Q15
- Logic: 5 V or 24 V
- Output current: 10 mA for internal supply with 5 V<br>500 mA for external power supply with up to 30 V
- Total current: 2 A
- Scanning rate: max. 100 values/s (PC dependent)

The digital outputs are each equipped with two 10-pole plug-in connectors for direct connection to automation devices. In addition, eight of them are equipped with 2-mm sockets and status LEDs.

1 PROFIBUS connection with 9-pole subD socket
passive station (slave) at the PROFIBUS-DP fieldbus with 16 digital inputs and outputs and a bit rate of up to max. 3 Mbit/s
address can be set via CASSY Lab

1 USB port for connection to a computer

1 CASSY bus for connecting Sensor-CASSYs or Power-CASSYs

Dimensions (WxHxD): 115 mm x 295 mm x 45 mm

Weight: 1.0 kg

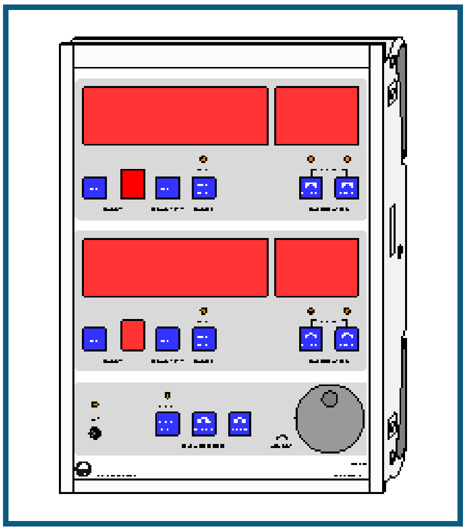
### Scope of supply

1 Profi-CASSY
1 CASSY Lab 2 software, without activation code, for Windows XP/Vista/7 with comprehensive help function (16 full-functionality sessions free, then usable as demo version)
1 Installation guide
1 USB cable
1 Plug-in supply unit 12 V / 1.6 A
1 GSD file LD066F.GSD for easy parameterization of the PROFIBUS on the CASSY Lab-CD

### Applications

- CBS9 plant simulator for PLC, COM3LAB, digital technology and MFA
- CASSY® Lab for recording and evaluating measuring data
- WinFACT® for applications in control engineering

## CASSY-Display



### Introduction

CASSY-Display (USB or serial respectively) is a two-channel instrument for displaying measured values without a computer.

- Microprocessor-controlled with CASSY operating system (easily updatable via software for function enhancements).
- For use as a benchtop, console or demonstration unit (also in CPS/TPS panel frames)
- Supports up to 8 Sensor-CASSY units (for 16 measuring channels)
- Values are measured using Sensor-CASSY or a sensor box connected there
  (see Sensor-CASSY for measurement quantities and ranges).
- Measured values can be toggled and calibrated individually. Measurement quantity and unit change automatically when a sensor box is added or moved.
- With integrated real-time clock and data logger.
  Data storage for up to 32,000 measured values is retained when the device is switched off, enabling these to be read out by a computer via the USB port or via the serial interface respectively.
- Voltage supply 12 V AC/DC via cannon plug.

### Safety note

- Transport multiple cascaded CASSY modules only in the panel frame or individually (the mechanical stability of the connections without panel frame is sufficient for experimenting only, and not for transport).
- Use only the plug-in supply unit (12 V / 1.6 A) to power the CASSY modules.

## Data logger

CASSY-Display is equipped with an integrated memory function for storing measurement data. This data is retained when the power supply is switched off and can later be read from the memory by CASSY Lab. When the CASSY-Display is connected to a computer, it is displayed in the current arrangement of CASSY modules. To read out the data, simply click on **Read Out Data**.

Alternatively the data can be read in the Settings CASSYs screen. The option is also available there to set the real-time clock of the CASSY-Display.

Please refer to the CASSY-Display Instruction Sheet for more information on using the device.

## Pocket-CASSY

### Introduction

Pocket-CASSY is an interface device for recording measurement data:

- For connection to the USB port of a computer or to an active hub.
- Compatible with USB 1.x and 2.0 (Full speed)
- Up to 8 analog inputs per Pocket-CASSY available using sensor boxes
- Up to 8 Pocket-CASSYs can be used at different USB ports (to expand the inputs even more)
- Automatic sensor box detection by CASSY Lab (plug and play)
- Power supply via USB port (500 mA).

▪ Developer information for your own software development available on the Internet

### Safety note

- For your own protection, do not connect sensors and sensor boxes to voltages over 30 V.
- Mind possible ground connections between the sensors and the computer.

## Technical data

1 Analog input at sensor connector site (all CASSY sensor boxes and sensors can be connected)

| | |
|---|---|
| Resolution: | 12 bits |
| Measuring ranges: | ±0.003/0.01/0.03/0.1/0.3/1 V |
| Measuring error: | ± 1 % plus 0.5 % of range end value |
| Input resistance: | 10 kΩ |
| Scanning rate: | max. 7,800 values/s |
| No. of meas. values: | virtually unlimited (PC dependent) up to 100 values/s, at a higher measurement rate max. 16,000 values |

The technical data will change depending on a connected sensor box.
In this case CASSY Lab automatically detects the possible measurement quantities and ranges when a sensor box is attached.

2 Timer inputs at sensor connector site (e.g. for BMW box, GM box or timer box)

| | |
|---|---|
| Counter frequency: | max. 10 kHz |
| Time resolution: | 1 µs |
| Measuring time between two events: | min. 100 µs |
| Memory: | max. 5,000 time points (= 2,500 values per input) |

6 Digital inputs (TTL) at sensor connector site
(at present only used for automatic sensor box detection)

3 Digital outputs (TTL) at sensor connector site
(at present only used for automatic switching of a sensor box measuring range)

1 USB port for connection to a computer and for power supply (500 mA)

| | |
|---|---|
| Dimensions (WxHxD): | 50 mm x 25 mm x 60 mm |
| Weight: | 0.1 kg |

### Scope of supply

1 Pocket-CASSY
1 CASSY Lab 2 software, without activation code, for Windows XP/Vista/7 with comprehensive help function (16 full-functionality sessions free, then usable as demo version)
1 Installation guide
1 USB cable

## Use of Pocket-CASSY

Pocket-CASSY is an interface designed as a low-cost device for students' practice. Therefore some features of the Sensor-CASSY have been renounced. However, most of the experiments described can also be carried out using Pocket-CASSY. These experiments are labeled with the Pocket-CASSY logo. The subsequent description and equipment list nevertheless refer to the use of Sensor-CASSY.

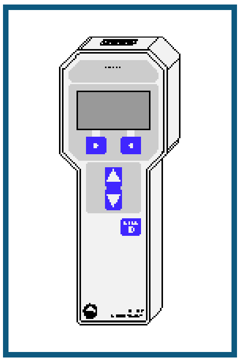
### Carrying out an experiment intended for Sensor-CASSY using the Pocket-CASSY

- For voltage and current measurements the UI sensor S (524 062) or the UIP sensor S (524 0621) is required if the Pocket-CASSY is used.
- If both analog inputs A and B of the Sensor-CASSY are used, two Pocket-CASSYs have to be employed instead (maybe in conjunction with two UI sensors S). In the case of a combined voltage and current measurement, a single Pocket-CASSY with a UIP sensor S is sufficient.
- The symbols of the measurement quantities have one index less than those given in the experiment descriptions as, in the case of the Pocket-CASSY, no distinction has to be made between input A and input B. For example, you have $U_1$ and $U_2$ (two Pocket-CASSYs) instead of $U_{A1}$ and $U_{B1}$ (one Sensor-CASSY).

### Limitations of Pocket-CASSY as compared with Sensor-CASSY

- There is only one sensor input. If there are enough USB ports available, several sensor inputs can be realized by using several Pocket-CASSYs. As there is no direct signal transmission between several Pocket-CASSYs, trigger time errors of up to 5 ms may arise.
- There are no voltage and current inputs on 4-mm sockets. These can be made available by means of the UI sensor S or the UIP sensor S. However, the UI sensor S has only 7 measuring ranges. It lacks the ranges ±250 V, ±100 V, ±0.1 V, ±3 A, ±0.1 A, ±0.03 A. Moreover, it cannot be used to record U and I simultaneously. The UIP sensor S only lacks the ranges ±250 V, ±100 V, ±0.03 A.
- Time resolutions Γt < 100 µs cannot be selected. Internally Pocket-CASSY scans at Γt >= 128 µs so that an interpolation has already to be made for Γt = 100 µs.
- There is no relay R and no voltage source S.
- The timer inputs only have 1 µs resolution - a variable latency of up to 10 µs may arise in addition. The maximum measurable frequency is approx. 10 kHz.
- Pocket-CASSY is not isolated. Depending on the sensor connected, a continuous ground connection may exist between the sensor and the computer. If two Pocket-CASSYs are used simultaneously at the same computer, even an electrical connection between two sensors may occur. In order to compensate this disadvantage, the UI sensor S (524 062) and the UIP sensor S (524 0621), which are often employed, have been designed as difference amplifiers. Their input sockets are only connected to the ground via high resistances.

## Mobile-CASSY



### Introduction

Mobile-CASSY is a universal hand-held measuring instrument:

- For almost all CASSY sensors and sensor boxes
- Automatic sensor box detection (plug and play)
- Up to 8 analog inputs per Mobile-CASSY available using sensor boxes
- Power supply via 4 mignon cells (AA, batteries or accumulators) or plug-in power supply 12 V AC/DC
- With integrated data logger for up to 16,000 measured values
- Can be connected to the USB port of a computer for reading the data logger or for displaying the measured values on a large screen
- Compatible with USB 1.x and 2.0
- Up to 8 Mobile-CASSYs can be used at different USB ports
- Electrically isolated from the computer.

Developer information for your own software development available on the Internet

### Safety note

- For your own protection, do not connect sensors and sensor boxes to voltages over 30 V.

## Technical data

1 Analog input at sensor connector site (almost all CASSY sensor boxes and sensors can be connected)
Resolution: 12 bits
Measuring ranges: ±0.003/0.01/0.03/0.1/0.3/1 V
Measuring error: ± 1 % plus 0.5 % of range end value
Input resistance: 10 kΩ
Scanning rate: max. 5 values/s
No. of meas. values: 16,000 in the integrated data logger or virtually unlimited (depending on the PC) if the measurements a made with a PC

The technical data will change depending on a connected sensor box. When a sensor box is attached, the possible measurement quantities and ranges are detected automatically.

1 Display for simultaneously displaying up to four values in various character sizes
1 USB port for connection to a computer
Dimensions (WxHxD): 87 mm x 215 mm x 30 mm
Weight: 0.25 kg

### Scope of supply

1 Mobile-CASSY
1 CASSY Lab 2 software, without activation code, for Windows XP/Vista/7 with comprehensive help function (16 full-functionality sessions free, then usable as demo version)
1 Instruction sheet
1 USB cable

## Use of Mobile-CASSY

Mobile-CASSY is an interface designed for mobile use. Therefore many features of the Sensor-CASSY have been renounced, and a data logger has been integrated instead. However, some of the experiments described can also be carried out using the Mobile-CASSY. These experiments are labeled with the Mobile-CASSY logo. The subsequent description and equipment list nevertheless refer to the use of Sensor-CASSY.

### Carrying out an experiment intended for Sensor-CASSY using the Mobile-CASSY

- For voltage and current measurements the UI sensor S (524 062) or the UIP sensor S (524 0621) is required if the Mobile-CASSY is used.
- If both analog inputs A and B of the Sensor-CASSY are used, two Mobile-CASSYs have to be employed instead (maybe in conjunction with two UI sensors S). In the case of a combined voltage and current measurement, a single Mobile-CASSY with a UIP sensor S is sufficient.
- The symbols of the measurement quantities have one index less than those given in the experiment descriptions as, in the case of the Mobile-CASSY, no distinction has to be made between input A and input B. For example, you have $U_1$ and $U_2$ (two Mobile-CASSYs) instead of $U_{A1}$ and $U_{B1}$ (one Sensor-CASSY).

### Limitations of Mobile-CASSY as compared with Sensor-CASSY

- There is only one sensor input. If there are enough USB ports available, several sensor inputs can be realized by using several Mobile-CASSYs.
- There are no voltage and current inputs on 4-mm sockets. These can be made available by means of the UI sensor S or the UIP sensor S. However, the UI sensor S has only 7 instead of 10 measuring ranges. It lacks the ranges ±100 V, ±3 A, ±0.1 A. Moreover, it cannot be used to record U and I simultaneously. The UIP sensor S only lacks the range ±100 V.
- Time resolutions Γt < 200 ms cannot be selected.
- There is no relay R and no voltage source S.
- Support of the timer inputs is very limited.

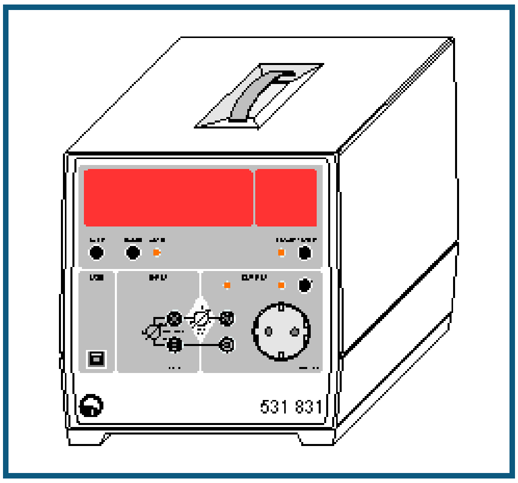
### Data logger

The Mobile-CASSY is equipped with an integrated data memory, where measurement data can be stored. This data is retained when the power supply is switched off and can later be read from the memory by CASSY Lab. When the Mobile-CASSY is connected to a computer, it is displayed in the current arrangement of CASSY modules. To read out the data, simply click on **Read Out Data**.

Alternatively the data can be read in the Settings CASSYs screen. The option is also available there to set the real-time clock of the Mobile-CASSY.

Please refer to the Mobile-CASSY Instruction Sheet for more information on using the device.

## Joule and wattmeter



### Introduction

The Joule and wattmeter is a universal multimeter with a wattmeter

- for measuring and displaying effective voltages U and effective currents I for voltages and currents of any shape
- for displaying the nonreactive power P determined from U and I and the time integrals ∫ P(t) dt (work), ∫ U(t) dt (surge) and ∫ I(t) dt (charge)
- with large power range from nW to kW (12 decades)
- with large display, which can be read from great distances
- with connection of the load optionally via 4 mm safety sockets or grounded socket (front panel)
- with possibility of connecting to the USB port of a computer for reading the time-resolved curve shapes U(t), I(t) and P(t) and their effective values
- Compatible with USB 1.x and 2.0 (Full speed)
- Electrically isolated from the computer.

Developer information for your own software development available on the Internet

### Safety note

The device complies with the safety requirements for electrical measuring, control and laboratory equipment in accordance with DIN EN 61010 part 1. It is intended for use in dry rooms, which are suitable for electrical equipment and devices.

If the device is used as prescribed, it's safe operation is guaranteed. However, safety is not guaranteed if the device is improperly used or carelessly handled. If it has to be assumed that safe operation is no longer possible (e.g. in the case of visible damage), shut the device down immediately.

When putting the device into operation for the first time:

- Check whether the value for the mains voltage indicated on the rating plate agrees with the local value.
- Look for the instruction sheet of the device on the enclosed CD "Instruction Sheets" with the aid of the catalogue number, and read it.

Before putting the device into operation:

- Examine the housing for damage. In case of malfunction or visible damage, shut the device down and make sure that it is not used inadvertently.

On every operation:

- Connect the device only to sockets with grounded neutral wire.
- Never apply voltages over 250 V and currents over 10 A.
- Examine connecting leads, test leads and probes for defective insulation and bare wires.
- When carrying out experiments with hazardous-contact voltages, use only 4 mm safety connecting leads.
- The socket on the front panel may be alive even if the output is not active.
- Replace a defective fuse only with a fuse that corresponds to the original value (T 10 A / 250 V).
- Never short the fuse or the fuse holder.
- Always keep the ventilation slots of the housing free in order to ensure sufficient air circulation for cooling the internal components.

- Keep metallic objects, foreign matter and water away from the ventilation slots.
- Do not put the device into operation if objects of that kind have got into the interior of the device.
- Allow only skilled persons to open the device.
- The device must not be subjected to strong shocks.

## Technical data

1 Analog voltage input on 4 mm sockets
Resolution: 12 bits
Measuring ranges: ±5**/±50**/±500 mV / ±5/±50/±250 V
Measuring accuracy*: 1 %
Input resistance: ≥1 MΩ
Scanning rate: max. 10,000 values/s
No. of meas. values: virtually unlimited (PC dependent) up to 100 values/s, at a higher measurement rate max. 16,000 values

1 Analog voltage input for grounded socket (can be used alternatively)
Resolution: 12 bits
Measuring range: 250 V
Measuring accuracy*: 1 %
Input resistance: 2 MΩ
Scanning rate: max. 10,000 values/s
No. of meas. values: virtually unlimited (PC dependent) up to 100 values/s, at a higher measurement rate max. 16,000 values

1 Analog current input for 4 mm safety sockets and grounded socket
Resolution: 12 bits
Measuring ranges: ±0.2/±2/±20 mA / ±0.2/±2/±10 A
Measuring accuracy*: 1 %
Input resistance: 10 Ω / approx. 0.01 Ω
Scanning rate: max. 10,000 values/s
No. of meas. values: virtually unlimited (PC dependent) up to 100 values/s, at a higher measurement rate max. 16,000 values

Connection of load: optionally via 4 mm safety sockets or grounded socket (front panel)
Display: 5 digit 7 segment display for numerical value and 7x15 matrix for unit
Height of digits: 25 mm
USB-Port: USB 1.x and 2.0 (full speed), isolated
Supply: 230 V, 50/60 Hz
Dimensions (WxHxD): 20 cm x 21 cm x 23 cm
Weight: 2 kg

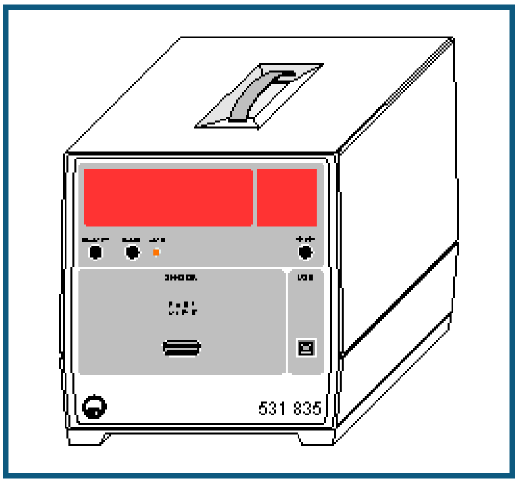
* The specified accuracy is valid at the upper limit of range for DC and for AC with a frequency of 50 to 60 Hz and a crest factor = maximum value : effective value ≤ 2.

** This range is only suited for DC (not for AC).

### Scope of supply

1 Joule and wattmeter
1 CASSY Lab 2 software without activation code for Windows XP/Vista/7 with comprehensive help (can be used for the Joule and wattmeter without limitations)
1 Instruction sheet
1 USB cable

## Universal measuring instrument physics



### Introduction

The universal measuring instrument physics is a universal multimeter

- for measuring and displaying many physical quantities
- with large display, which can be read from great distances
- with possibility of connecting to the USB port of a computer for reading the time-resolved curve shapes
- Compatible with USB 1.x and 2.0 (Full speed)
- Electrically isolated from the computer.
- Developer information for your own software development available on the Internet

### Safety note

The device complies with the safety requirements for electrical measuring, control and laboratory equipment in accordance with DIN EN 61010 part 1. It is intended for use in dry rooms, which are suitable for electrical equipment and devices.

If the device is used as prescribed, it's safe operation is guaranteed. However, safety is not guaranteed if the device is improperly used or carelessly handled. If it has to be assumed that safe operation is no longer possible (e.g. in the case of visible damage), shut the device down immediately.

When putting the device into operation for the first time:

- Check whether the value for the mains voltage indicated on the rating plate agrees with the local value.
- Look for the instruction sheet of the device on the enclosed CD "Instruction Sheets" with the aid of the catalogue number, and read it.

Before putting the device into operation:

- Examine the housing for damage. In case of malfunction or visible damage, shut the device down and make sure that it is not used inadvertently.

On every operation:

- Connect the device only to sockets with grounded neutral wire.
- Always keep the ventilation slots of the housing free in order to ensure sufficient air circulation for cooling the internal components.
- Keep metallic objects, foreign matter and water away from the ventilation slots.
- Do not put the device into operation if objects of that kind have got into the interior of the device.
- Allow only skilled persons to open the device.
- The device must not be subjected to strong shocks.

## Technical data

1 Analog sensor input at sensor connector site for many sensors S

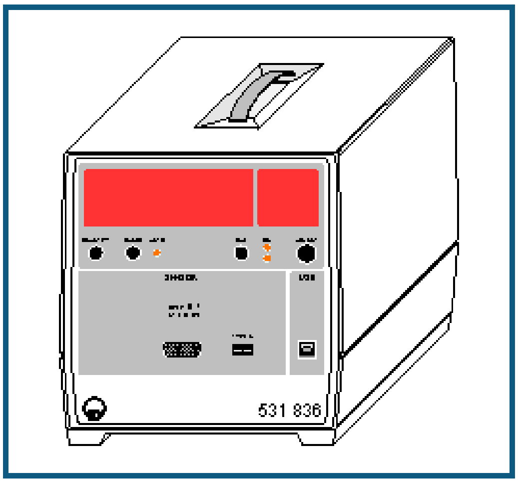
| | |
|---|---|
| Resolution: | 12 bits |
| Measuring ranges: | depending on sensor |
| Measuring error: | ±1 % plus sensor error |
| Input resistance: | 10 kΩ |
| Scanning rate: | max. 10,000 values/s |
| No. of meas. values: | virtually unlimited (PC dependent) up to 100 values/s, at a higher measurement rate max. 16,000 values |

| | |
|---|---|
| Display: | 5 digit 7 segment display for numerical value and 7x15 matrix for unit |
| Height of digits: | 25 mm |
| USB-Port: | USB 1.x and 2.0 (full speed), isolated |
| Supply: | 230 V, 50/60 Hz |
| Dimensions (WxHxD): | 20 cm x 21 cm x 23 cm |
| Weight: | 2 kg |

### Scope of supply

1 Universal measuring instrument physics
1 CASSY Lab 2 software without activation code for Windows XP/Vista/7 with comprehensive help (can be used for the Universal measuring instrument physics without limitations)
1 Instruction sheet
1 USB cable

# Universal measuring instrument chemistry



### Introduction

The universal measuring instrument chemistry is a universal multimeter

- for measuring and displaying many chemical quantities
- with large display, which can be read from great distances
- with possibility of connecting to the USB port of a computer for reading the time-resolved curve shapes
- Compatible with USB 1.x and 2.0 (Full speed)
- Electrically isolated from the computer.

▪ Developer information for your own software development available on the Internet

### Safety note

The device complies with the safety requirements for electrical measuring, control and laboratory equipment in accordance with DIN EN 61010 part 1. It is intended for use in dry rooms, which are suitable for electrical equipment and devices.

If the device is used as prescribed, it's safe operation is guaranteed. However, safety is not guaranteed if the device is improperly used or carelessly handled. If it has to be assumed that safe operation is no longer possible (e.g. in the case of visible damage), shut the device down immediately.

When putting the device into operation for the first time:

- Check whether the value for the mains voltage indicated on the rating plate agrees with the local value.
- Look for the instruction sheet of the device on the enclosed CD "Instruction Sheets" with the aid of the catalogue number, and read it.

Before putting the device into operation:

- Examine the housing for damage. In case of malfunction or visible damage, shut the device down and make sure that it is not used inadvertently.

On every operation:

- Connect the device only to sockets with grounded neutral wire.
- Always keep the ventilation slots of the housing free in order to ensure sufficient air circulation for cooling the internal components.
- Keep metallic objects, foreign matter and water away from the ventilation slots.
- Do not put the device into operation if objects of that kind have got into the interior of the device.
- Allow only skilled persons to open the device.
- The device must not be subjected to strong shocks.

## Technical data

1 Analog sensor input at sensor connector site for many sensors S

| | |
|---|---|
| Resolution: | 12 bits |
| Measuring ranges: | depending on sensor |
| Measuring error: | ±1 % plus sensor error |
| Input resistance: | 10 kΩ |
| Scanning rate: | max. 10,000 values/s |
| No. of meas. values: | virtually unlimited (PC dependent) up to 100 values/s, at a higher measurement rate max. 16,000 values |

1 Type K socket for additional connection of a NiCr-Ni thermocouple (e.g. for automatic temperature compensation of pH measurements)

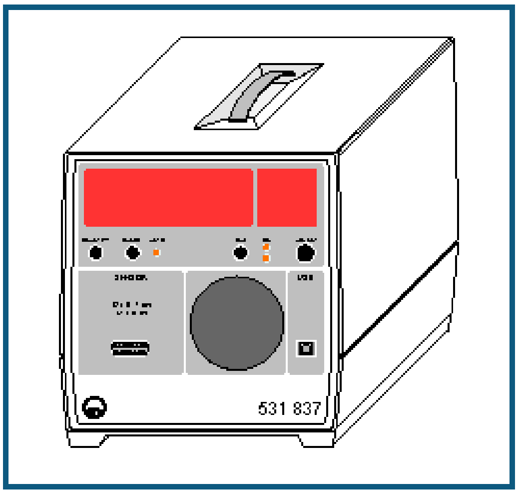
| | |
|---|---|
| Resolution: | 12 bits |
| Measuring range: | depending on sensor |

| | |
|---|---|
| Calibration: | through 1 or 2 points (stored internally for pH, conductivity, $O_2$ and $CO_2$ concentration) |
| Display: | 5 digit 7 segment display for numerical value and 7x25 matrix for unit |
| Height of digits: | 25 mm |
| USB-Port: | USB 1.x and 2.0 (full speed), isolated |
| Supply: | 230 V, 50/60 Hz |
| Dimensions (WxHxD): | 20 cm x 21 cm x 23 cm |
| Weight: | 2 kg |

### Scope of supply

1 Universal measuring instrument chemistry
1 CASSY Lab 2 software without activation code for Windows XP/Vista/7 with comprehensive help (can be used for the Universal measuring instrument chemistry without limitations)
1 Instruction sheet
1 USB cable

## Universal measuring instrument biology



### Introduction

The universal measuring instrument biology is a universal multimeter

- for measuring and displaying many physical quantities
- with large display, which can be read from great distances
- with possibility of connecting to the USB port of a computer for reading the time-resolved curve shapes
- Compatible with USB 1.x and 2.0 (Full speed)
- Electrically isolated from the computer.
- Developer information for your own software development available on the Internet

### Safety note

The device complies with the safety requirements for electrical measuring, control and laboratory equipment in accordance with DIN EN 61010 part 1. It is intended for use in dry rooms, which are suitable for electrical equipment and devices.

If the device is used as prescribed, it's safe operation is guaranteed. However, safety is not guaranteed if the device is improperly used or carelessly handled. If it has to be assumed that safe operation is no longer possible (e.g. in the case of visible damage), shut the device down immediately.

When putting the device into operation for the first time:

- Check whether the value for the mains voltage indicated on the rating plate agrees with the local value.
- Look for the instruction sheet of the device on the enclosed CD "Instruction Sheets" with the aid of the catalogue number, and read it.

Before putting the device into operation:

- Examine the housing for damage. In case of malfunction or visible damage, shut the device down and make sure that it is not used inadvertently.

On every operation:

- Connect the device only to sockets with grounded neutral wire.
- Always keep the ventilation slots of the housing free in order to ensure sufficient air circulation for cooling the internal components.
- Keep metallic objects, foreign matter and water away from the ventilation slots.
- Do not put the device into operation if objects of that kind have got into the interior of the device.
- Allow only skilled persons to open the device.
- The device must not be subjected to strong shocks.

## Technical data

1 Analog sensor input at sensor connector site for many sensors S
  Resolution: 12 bits
  Measuring ranges: depending on sensor
  Measuring error: ±1 % plus sensor error
  Input resistance: 10 kΩ
  Scanning rate: max. 10,000 values/s
  No. of meas. values: virtually unlimited (PC dependent) up to 100 values/s, at a higher measurement rate max. 16,000 values

Loudspeaker: for pulse/blood pressure/hearing threshold measurement
Display: 5 digit 7 segment display for numerical value and 7x15 matrix for unit
Height of digits: 25 mm
USB-Port: USB 1.x and 2.0 (full speed), isolated
Supply: 230 V, 50/60 Hz
Dimensions (WxHxD): 20 cm x 21 cm x 23 cm
Weight: 2 kg

### Scope of supply

1 Universal measuring instrument biology
1 CASSY Lab 2 software without activation code for Windows XP/Vista/7 with comprehensive help (can be used for the Universal measuring instrument biology without limitations)
1 Instruction sheet
1 USB cable

## Sensors and sensor boxes

The recordable measurement quantities of a sensor input depend greatly on the sensor box that is connected to the sensor input. The table below defines the correlation between sensor box, measurement quantity and sensor:

| **Sensor box** | **Quantity** | **Sensor** | **Remark** |
|---|---|---|---|
| none | Voltage | | |
| | Current | | Only input A and only for currents less than 3 A |
| Current supply box (524 031) | Resistance | | |
| | Path | Displacement transducer (529 031) | Potentiometer for measuring displacement |
| BMW box (524 032) | Path (Γs=±1 mm) | Motion sensing element (337 631*) | Top socket on BMW box with direction of motion |
| | Angle (Γs=±1 mm) | ditto | ditto<br>Enter radius also |
| | Path (Γs=±1 mm) | Pair of recording pulleys (337 16*) | Bottom socket on BMW box<br>Use only first pulley |
| | Angle (Γs=+1 cm) | ditto | ditto<br>Enter radius also |
| GM box (524 033) | Events | End-window counter (e.g. 559 01) | Enter gate time |
| | Rate | ditto | ditto with frequency distribution as alternative display |
| GM counter tube S (524 0331) | Events | integrated | Enter gate time |
| | Rate | integrated | ditto with frequency distribution as alternative display |
| Timer box (524 034) | Level | | |
| | Events | | |
| | Frequency | | Enter gate time |
| | Rate | | ditto with frequency distribution as alternative display |
| | Period | | |
| | Transit time | | of event at E to F |
| | Obscurations | Forked light barrier (337 46*) | Number of obscuration |
| | Obscuration time | ditto | Duration of obscuration |
| | Path (Γs=1 cm) | Spoked wheel (e.g. 337 461) or g-ladder (529 034) with forked light barrier (337 46*) | |
| | Angle (Γs=1 cm) | ditto | Enter radius |
| | Linear collision (v) | 2 forked light barriers (337 46*) | Enter flag width |
| | Torsion collision (φ) | ditto | Enter flag width and radius |
| pH box (524 035) | pH | pH electrode (e.g. 667 424) | Correct with two buffer solutions<br>Temperature compensation possible using formula<br>Special evaluation for equivalence point |
| | Voltage | ditto | |
| KTY box (524 036) | Temperature | KTY sensor (529 036) | |
| | Resistance | ditto | |
| Conductivity box (524 037) | Conductivity | Conductivity measuring cell (667 426) | Correct with factor k printed on measuring cell<br>Temperature compensation possible using formula |
| B box (524 038) | Magnetic flux density | Tangential B-probe (516 60*) or axial B-probe (516 61*) | Switch on box with **Box-LED** for offset calibration with → **0** ← |
| | Relative pressure (2000 hPa) | Pressure sensor (529 038*) | ditto |
| | Relative pressure (70 hPa) | Pressure sensor 70 hPa (529 040*) | ditto |
| | Absolute pressure | Absolute pressure sensor (529 042*) | ditto |

| | | | |
|---|---|---|---|
| Combination B probe S (524 0381) | Magnetic flux density (tangential or axial) | integrated | Offset calibration with<br>→ **0** ← |
| Axial B probe S, 2000 mT (524 0382) | Magnetic flux density (axial) | integrated | Offset calibration with<br>→ **0** ← |
| Axial B probe S, ±0.3 mT (524 0383) | Magnetic flux density (axial) | integrated | Offset calibration with<br>→ **0** ← |
| dU box (524 039) | Voltage | | No longer necessary thanks to electrical isolation |
| µV box (524 040) | Voltage | | Highly sensitive input (resolution to 0.5 κV) |
| Bridge box (524 041) | Force | Force sensor (314 261*) | Box-LED toggles between SMOOTHed and unsmoothed;<br>replaced by Force sensor S, ±1 N. |
| Force sensor S, ±50 N (524 042) | Force | integrated | For greater forces up to 50 N |
| | Acceleration | integrated | |
| Force plate S (524 0421) | Force | integrated | Offset calibration with<br>→ **0** ← |
| 3D acceleration sensor S (524 0422) | Acceleration in g | integrated | Offset calibration with<br>→ **0** ← |
| 30-A box (524 043) | Current | | Use only for currents greater than (otherwise without box at A) |
| Temperature sensor S (NTC) (524 044) | Temperature | integrated | |
| Temperature box (524 045) | Temperature | Temperature sensor NTC (666 212) or NiCr-Ni (666 193) | |
| | Temperature difference | 2 NiCr-Ni (666 193) | |
| Reaction test box (524 046) | Reaction time | Push button (662 148) or foot switch (662 149) | To start press key first – and again for reaction depending on the color of the pointer |
| Reaction test adapter S (524 0461) | Reaction time | Push button (662 148) or foot switch (662 149) | To start press key first – and again for reaction depending on the color of the pointer |
| Pulse box (524 047) | Pulse | integrated | Wait at least 10 s for box to stabilize |
| | Voltage | integrated | Circulation curve |
| Pulse sensor S (524 0471) | Pulse | integrated | Wait at least 10 s for sensor to stabilize |
| | Voltage | integrated | Circulation curve |
| Skin resistance box (524 048) | Skin resistance | integrated | Match measuring range individually (move axis with mouse or click on it with right mouse button) |
| Skin resistance sensor S(524 0481) | Skin resistance | integrated | Match measuring range individually (move axis with mouse or click on it with right mouse button) |
| ECG/EMG box (524 049) | 3 ECG leads | integrated | |
| | EMG | integrated | |
| EKG/EMG sensor S (524 0491) | 1 ECG lead | integrated | |
| | EMG | integrated | |
| Blood pressure box (524 050) | Blood pressure | integrated | Special evaluation for systole and diastole |
| | Pulse | integrated | blood pressure variations only |
| Blood pressure sensor S (524 0501) | Blood pressure | integrated | Special evaluation for systole and diastole |
| | Pulse | integrated | blood pressure variations only |
| Lux box (524 051) | Illuminance | Lux sensor (666 243)<br>IR sensor (666 247)<br>UV-A sensor (666 244)<br>UV-B sensor (666 245)<br>UV-C sensor (666 246) | Correct with factor F printed on sensor |

| | | | |
|---|---|---|---|
| Lux adapter S (524 0511) | Illuminance | Lux sensor (666 243)<br>IR sensor (666 247)<br>UV-A sensor (666 244)<br>UV-B sensor (666 245)<br>UV-C sensor (666 246) | Correct with factor F printed on sensor |
| Optical power sensor S (524 0512) | Optical power | integrated | |
| Oxygen box (524 052) | $O_2$ saturation | Oxygen electrode (667 458) | Correct to 100% in $O_2$ gas |
| | $O_2$ concentration | ditto | Correct with same factor as for saturation |
| | Temperature | ditto | |
| Oxygen adapter S (524 0521) | $O_2$ saturation | Oxygen electrode (667 458) | Correct to 100% in $O_2$ gas |
| | $O_2$ concentration | ditto | Correct with same factor as for saturation |
| | Temperature | ditto | |
| Electrometer box (524 054) | Voltage | | Extremely high-ohm input, e.g. for electrostatics |
| Amplifier box (524 055) | Voltage | | Replaced by κV Box |
| Spirometer box (524 056) | Volume flux | integrated | |
| Climate box (524 057) | Rel. humidity | Humidity sensor (529 057) | Calibrate with values C1 to C4 printed on sensor. |
| | Temperature | Humidity sensor (529 057) | Calibrate with values C1 to C4 printed on sensor. |
| | Temperature | Temperature sensor NTC (666 212) | |
| | Barometric pressure | integrated | |
| | Illuminance | Lux sensor (666 243) | Correct with factor F printed on sensor |
| Humidity sensor S (524 0572) | Rel. humidity | integrated | |
| | Temperature | integrated | |
| MCA box (524 058) | Pulse height distribution | Scintillation counter (559 901) with Detector output stage (559 912) or Semiconductor detector (559 92) with Discriminator preamplifier(559 93*) | α-, β-, γ- Spectroscopy |
| Microphone S (524 059) | Voltage | integrated | External microphone connectable |
| | Frequency | integrated | External microphone connectable |
| | Transit time | integrated | External microphone connectable |
| | Level | integrated | |
| Force sensor S, ±1 N (524 060) | Force | integrated | For forces up to 1 N |
| UI sensor S (524 062) | Voltage | integrated | for Pocket-CASSY and Mobile-CASSY |
| | Current | 1 Ω Shunt | for Pocket-CASSY and Mobile-CASSY |
| UIP sensor S (524 0621) | Voltage | integrated | for Pocket-CASSY and Mobile-CASSY |
| | Current | integrated | for Pocket-CASSY and Mobile-CASSY |
| Pressure sensor S, 2000 hPa (524 064) | Relative pressure | integrated | |
| Absolute pressure sensor S (524 065) | Absolute pressure | integrated | |
| Pressure sensor S, 70 hPa (524 066) | Relative pressure | integrated | |
| Chemistry box (524 067) | pH | pH sensor (667 4172) | |
| | Conductivity | Conductivity sensor (529 670) | |
| | Temperature | Conductivity sensor (529 670) | |
| | Temperature | Temperature sensor (529 676) | |
| | Temperature difference | 2 Temperature sensors (529 676) | |
| | Potential | | |

| | | | |
|---|---|---|---|
| Conductivity adapter S (524 0671) | Conductivity | Conductivity sensor (529 670) | |
| | Temperature | Conductivity sensor (529 670) | |
| pH adapter S (524 0672) | pH | pH sensor (667 4172) | |
| | Potential | | |
| NiCr-Ni adapter S (524 0673) | Temperature | Temperature sensor (529 676) | |
| | Temperature difference | 2 Temperature sensors (529 676) | |
| Centrifugal force apparatus S (524 068) | Centrifugal force | integrated | |
| Immersion photometer S (524 069) | Transmission | integrated | |
| | Extinction | integrated | |
| | Concentration | integrated | |
| Ultrasonic motion sensor S (524 070) | Path | integrated | |
| | Temperature | integrated | |
| Laser motion sensor S (524 073) | Path | integrated | |
| | Transit time | integrated | |
| Timer S (524 074) | Level | | |
| | Events | | |
| | Frequency | | Enter gate time |
| | Rate | | ditto with frequency distribution as alternative display |
| | Period | | |
| | Transit time | | of event at E to F |
| | Obscurations | Forked light barrier (337 46*) | Number of obscuration |
| | Obscuration time | ditto | Duration of obscuration |
| | Path (Γs=1 cm) | Spoked wheel (e.g. 337 461) or g-ladder (529 034) with forked light barrier (337 46*) | |
| | Angle (Γs=1 cm) | ditto | Enter radius |
| | Linear collision (v) | 2 forked light barriers (337 46*) | Enter flag width |
| | Torsion collision (φ) | ditto | Enter flag width and radius |
| | Path (Γs=±1 mm) | Combination light barrier (337 462*) with combination spoked wheel (337 464) | Connect to left socket |
| | Angle (Γs=±1 mm) | ditto | Enter radius |
| Car box i (524 076) | Rotational speed | Stand workshop TDC generator (738 989) | |
| | Ignition angle | Inductive-type pulse pick-up (738 986) | |
| | Level | | |
| | Frequency | | |
| | Duty factor | | |
| | Shut-off time | | |
| | Operating time | | |
| | Injection time | | |
| Car box Z (524 077) | Primary voltage | Capacitive-type pick-up (738 987) | |
| | Secondary voltage | | |
| | Contact closed interval | | |
| | Rotational speed | | |
| CAN bus box (524 078) | CAN bus message | integrated | |
| | CAN bus data | integrated | |
| Electric field meter S (524 080) | Electric field strength | integrated | Offset calibration with → **0** ← |
| | Voltage | integrated | Offset calibration with → **0** ← |
| LIN bus box (524 081) | LIN bus voltage | integrated | |
| | LIN bus message | integrated | |
| | LIN bus data | integrated | |

| | | | |
|---|---|---|---|
| Rotary motion sensor S (524 082) | Angle | integrated | |
| | Path | integrated | |
| | Amplitude | integrated | |
| | Period | integrated | |
| | Frequency | integrated | |
| $CO_2$ sensor S (524 083) | $CO_2$ concentration | integrated | Calibration with → **0.037 %** ← |
| Hearing threshold adapter S (524 085) | Frequency | Loudspeaker | |
| | Amplitude | Loudspeaker | |
| | Voltage | Loudspeaker | |

Sensors indicated with * require a 6-pole connecting cable (501 16) for connection to the sensor box.

## Other devices

In addition to CASSY, CASSY Lab also supports other devices. You can use them simultaneously with CASSY.These include:

- ASCII (configurable)
- Balance (various manufacturers)
- VideoCom (337 47)
- IRPD (332 11)
- Multifunction instrument MFA 2001 (727 230)
- Thermometer (666 209 / 666 454)
- Digital spectrophotometer (667 3491 / 667 3493)
- Rotating antenna platform (737 405)

The devices are selected in Settings CASSYs.

## ASCII, balance, VideoCom, IRPD, MFA 2001

In addition to balances, VideoCom (337 47), the IR position detector (332 11) and the Multifunction instrument MFA 2001 (727 230), CASSY Lab supports all devices at the serial interface as long as they transmit ASCII data (plain text, number and unit, mode 8N1 = 8 data bits, no parity, 1 stop bit or mode 7E1 = 7 data bits, even parity, 1 stop bit).

The transmission rate of VideoCom and IRPD is fixed. As balances and other devices can work with different transmission rates, this can be set.

### Troubleshooting

If no measured values are displayed, this may be due to one of several reasons:

- Serial interface not correctly defined
- Incorrect interface parameters: make sure that the device is using the same transmission rate and the same mode (8N1 = 8 data bits, no parity, 1 stop bit or 7E1 = 7 data bits, even parity, 1 stop bit). VideoCom and IRPD always fulfill this condition.
- Wrong connecting cable: depending on the device, you may need either an uncrossed (1:1) cable or a crossed (null modem) cable. VideoCom, IRPD and MFA 2001 require a 1:1 cable, balances usually need a null modem cable.

### VideoCom restrictions

VideoCom also uses the specified display range to calibrate the path, and this should thus correspond to the width of VideoCom's field of view.

The position of the first detected reflection only is displayed. The VideoCom software can still be used for multiple positions.

The measurement is not processed in synchronized form. Although VideoCom transmits 80 positions per second, the software does not synchronize measured-value recording with this rate. Therefore, you should measure with a time interval of at least 100 ms. This is sufficient for the typical VideoCom application together with CASSY (position control).

## Thermometer

CASSY Lab supports the thermometer (666 209 or 666 454). Each of the four temperatures receives its own display instrument, and these are arrayed in the speed buttons of the main window.

You can change the set measuring range at any time; this has nothing to do with the actual measuring range of the thermometer.

The thermometer is equipped with a measurement storage function which can be read out. Simply activate **Read Data**.

### Troubleshooting

If no measured values are displayed, this may be due to one of several reasons:

- Serial interface not correctly defined
- Wrong connecting cable: use an uncrossed (1:1) cable.
- Wrong device selected: compare the catalogue number of the device with that shown in the dialog. Older versions of the thermometer can be operated as **ASCII (configurable)**.
- No temperature sensor attached.

## Digital spectrophotometer

The Digital spectrophotometer (667 3491 and 667 3493) is supported. A display instrument is assigned to both the current wavelength ı and the currently measured transmission T and placed near the channel buttons in the main window.

The digital spectrophotometer (667 3493) transmits the data after the FUNC key has been pressed.

If in addition the values of the absorption (100-T) or the extinction (-log(T/100)) are to be displayed, these values can be calculated with Formulae or the settings of the corresponding Experiment example can be loaded.

### Troubleshooting

If no measured values are displayed, this may be due to one of several reasons:

- Serial interface not correctly defined
- Wrong connecting cable: use only the cable delivered together with the device.
- Wrong device selected: compare the catalogue number of the device with that shown in the dialog.
- The digital spectrophotometer (667 3493) transmits the data after the FUNC key has been pressed.

## Rotating antenna platform

The rotating antenna platform (737 405) is supported. Apart from numerous predefined experiment examples, the following parameters can be changed manually for optimum use:

- **Range from**
  Starting angle for the measurement given in degrees, e.g. –180
- **Range to**
  Target angle given in degrees, e.g. 180
- **Angular Increment**
  In this menu for the angular resolution, one of the following intervals of rotation can be selected: 0.5° / 1° / 2°.
- **Bias Current**
  Can be switched on / off. The Schottky detector diode used in the dipole antenna (737 411) requires a small DC bias current of the order of magnitude of 15 κA. Without this bias current, the sensitivity of the detector is considerably diminished.
- **Gunn Modulation**
  Superimposes a square-wave voltage of approx. 1 kHz, 1 $V_{pp}$ on the DC supply for the Gunn oscillator. Should only be switched on if no PIN modulator (737 05) is available.
- **Detector Characteristic**
  The test antennas always have to be connected to a detector (e.g. coax detector 737 03), or they have a built-in detector diode. The original antenna signal A before the detector cannot be measured directly. Only the voltage drop generated by the detector current at the measuring amplifier is measurable. In general, A is not proportional to U. There are the following choices:
  - Quadratic detector: $A \propto U^{1/2}$ (good approximation for small received voltages U < 5 mV)
  - Linear detector: $A \propto U$ (approximation for high received voltages U > 5 mV)
  - Free: $A \propto U^{1/m}$ (here the detector characteristic has to be entered, e.g. after a gauging measurement with a calibrated attenuator 737 09).
- **Far-Field Computer**
  The input is $D_T$ (greatest lateral dimension of the test antenna in mm). The extension of the of the transmitting antenna $D_Q$ (e.g. large horn antenna 737 21: $D_Q$ = 100 mm) and the wavelength ı $_0$ = 32 mm being taken into account, the minimum distance $r_0$ between the transmitting and the receiving antenna is calculated at which the far-field condition is fulfilled:
  $$r_0 \geq \frac{2(D_Q + D_T)^2}{\lambda_0}$$
- **Normalize Level**
  Forms the ratio $A = U/U_{max}$, which is 1 in the maximum. The logarithmic damping factor is a = 0 dB in the maximum.
- **Rotate Maximum to 0°**
  Sets the maximum of the measured curve to 0°. The measured curve can be rotated and shifted manually with the two screenshot keys. Important note regarding cursor operation: the measuring instruments (e.g. level A or angle $\vartheta$) display the current measured value and not the position of the cursor in the diagram or the table.
- **Approach Reference Point**
  Interrupts the current measurement and returns the rotating platform to the starting position +/-180°. This is necessary, e.g., after free movement of the rotating platform has been hindered so that errors occur in recording the position.
- **Stop Rotating Platform**
  Stops the rotating platform. Static measurements are possible, e.g. for determining the antenna gain. The rotating platform may be controlled step by step via the screenshot keys.

### Troubleshooting

If no measured values are displayed, this may be due to one of several reasons:

- Serial interface not correctly defined
- Wrong connecting cable: use an uncrossed (1:1) cable.
- Wrong device selected: compare the catalogue number of the device with that shown in the dialog.

## Experiment examples

The experiment examples fall into five main subject areas:

- STM (Science Teaching Modules)
- Physics
- Chemistry
- Biology
- Technology

Note that you can print out individual experiment examples or entire collections.

## STM (Science Teaching Modules)

The experiment examples help you in using CASSY. The measurement data or settings for the examples can be loaded directly into CASSY Lab. Simply click the symbols □ in the descriptions. New examples are labeled with a red •.

### Teacher's versions

The teacher's versions are able to load the examples with measurement data and also contain the answers to questions asked in the text. If you do NOT want to show the teacher's version, please delete the file CASSYSVN2.CHM in the installation folder.

Texts which are written in red in the teacher's versions are not found in the student's versions.

### Mechanics

- P1.3.1.3 Uniformly accelerated motion - path-time diagram
- Uniform motion between two light barriers
- Uniformly accelerated motion between a holding magnet and a light barrier
- Relation between acceleration and mass (F=constant)
- Relation between acceleration and force (m=constant)

### Electricity

- Ohm's law
- P3.2.3.1a Series connection of resistors
- P3.2.3.1b Parallel connection of resistors
- P3.2.3.2 Adjusting a voltage by means of a potentiometer
- P3.2.3.3 Principle of Wheatstone's bridge

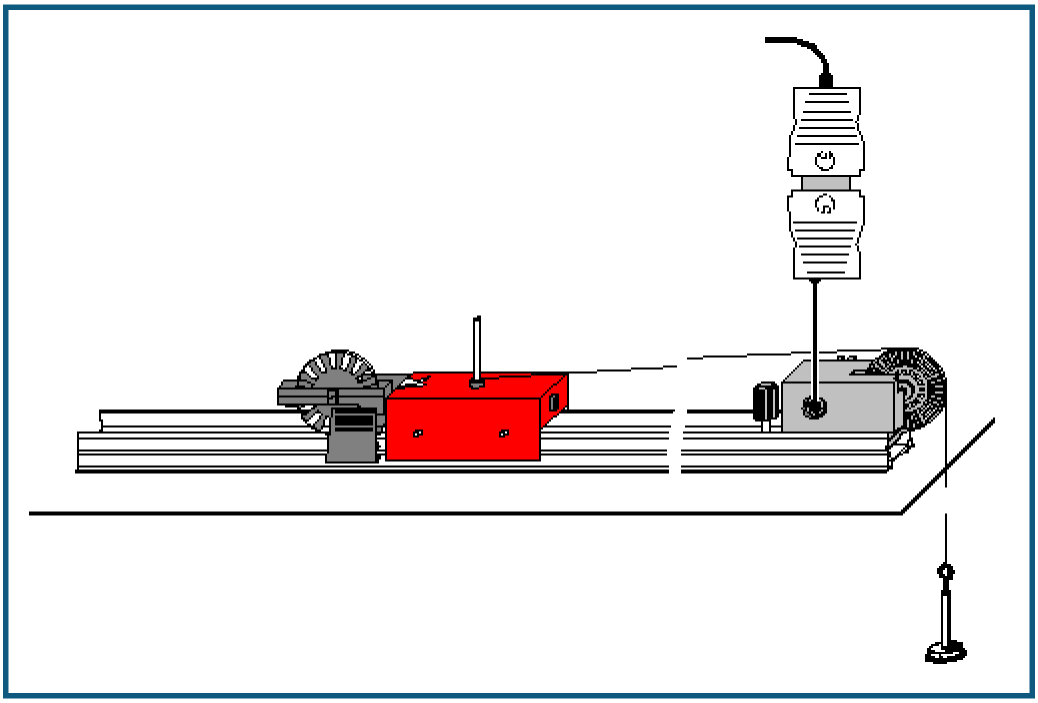
### Heat

- PS2.1.1.3p Longitudinal expansion of solid bodies
- PS2.1.2.4p Temperature change on account of thermal radiation
- PS2.1.3.1p Cooling down of water
- PS2.1.5.1p Temperature change when heat energy is supplied
- PS2.4.4.4p Specific heat capacity of water

### Atomic and Nuclear physics

- The effect of the distance between the radiation source and the end-window counter on the pulse rate

## Uniformly accelerated motion - path-time diagram



### Task

Investigate the motion of a trolley driven by a weight which is suspended from a piece of cord that runs over a pulley.

### Equipment list

| | | |
|---|---|---|
| 1 | Pocket-CASSY | 524 006 |
| 1 | CASSY Lab 2 | 524 220 |
| 1 | Timer S | 524 074 |
| 1 | Combination light barrier | 337 462 |
| 1 | Combination spoked wheel | 337 464 |
| 1 | Adapter combination light barrier for student's track | 337 465 |
| 1 | Multi-core cable, 6-pole | 501 16 |
| 1 | Precision metal rail, 1 m | 460 81 |
| 1 | Trolley, 85 g | 337 00 |
| 1 | Set of driving weights | 337 04 |
| 1 | Cord | from 686 51ET2 |
| 1 | Single pulley on clamp rider | 337 14 |
| | alternatively: 1 clamp rider | 460 95 |
| 1 | PC with Windows XP/Vista/7 | |

### Experiment setup (see drawing)

- Cut an approx. 80 cm long piece of cord, and tie loops at the ends. The length of the cord should be chosen so that the suspended weight is just over the bottom when the trolley stands at the end of the track.
- Move the trolley on the track until the suspended weight is just before the pulley without touching it. Now attach the single pulley on clamp rider (or a clamp rider) to the precision metal rail as the starting point for the trolley.
- At the beginning, only suspend the hanger (5.2 g) from the cord.

### Carrying out the experiment

■ Load settings

- Move the trolley to its starting point, keep it there, and define the zero in the window Settings Path s1 with → **0** ←. Start the measurement by clicking the ⏱ button and release the trolley.
- Lay additional weights on the hanger (each time 5 g), and repeat the experiment.

## Evaluation

- What was measured in the experiment (see table or diagram)?

- What is displayed in the diagram?

- How do the path differences covered in equal time intervals behave?

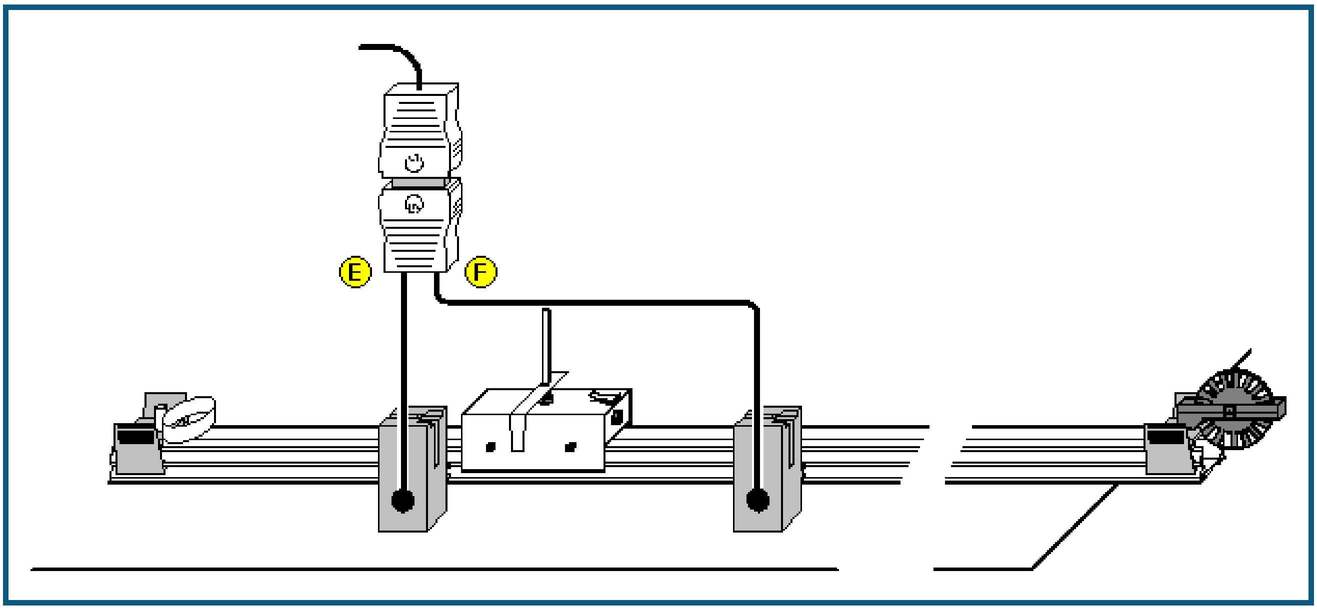
- What kind of curve is described by the measured values? Suggestion:

- Confirm the suggestion by fitting to a corresponding curve with Fit Function.
- What is your conclusion regarding the relation between the path *s* and the time *t*?

- Display the axes correspondingly in the **Check** sheet by clicking with the right mouse button. Then determine the factor of proportionality by Line through origin. The results for the three motions are:

- What is your conclusion regarding the general mathematical description of the motion (equation of motion)?

## Uniform motion between two light barriers



### Task

Investigate the relations between the path s and the time t and between the velocity v and the time t for the uniform motion of a trolley between two light barriers.

### Equipment list

| | | |
|---|---|---|
| 1 | Pocket-CASSY | 524 006 |
| 1 | CASSY Lab 2 | 524 220 |
| 1 | Timer S | 524 074 |
| 1 | Precision metal rail, 1 m | 460 81 |
| 1 | Trolley 1 | 337 00 |
| 1 | Single pulley on clamp rider | 337 14 |
| 1 | Spring and buffer | 337 03 |
| 1 | Clamp rider | 460 95 |
| 1 | Extension pin | from 686 60ET2 |
| 1 | Accessories for electronic time measurement | 337 466 |
| 2 | Combination light barriers | 337 462 |
| 2 | Multi-core cables, 6-pole, 1.5 m | 501 16 |
| 1 | PC with Windows XP/Vista/7 | |

### Experiment setup (see drawing)

- Set up the light barrier 1 at a distance of 40 cm from the beginning of the metal rail, and connect it to the input E of the timer S. Connect the light barrier 2 to the input F.
- Put the trolley with spring and interrupter flag onto the metal rail.
- Mount the clamp rider and the extension pin as a start device at the beginning of the metal rail and the single pulley as a stop device at the end of the metal rail.

### Carrying out the experiment

☐ Load settings
- Set up the light barrier 2 at a distance of 10 cm from the light barrier 1. Use the mouse to drag the pointer in the display window Path s to 10 cm.
- To start the motion press the trolley with the spring against the holding pin. The spring should be compressed by approximately 2 cm.
- Release the trolley. Take the measured values into the table with ⏱.
- Repeat the measurement increasing the path in steps of 5 cm.

When the trolley is slid back to the zero position, the light barrier 1 is interrupted and the time measurement is started. In order to stop it, the light barrier 2 has to be interrupted as well. However, it is simpler to the take the trolley off the rail and to put it back before the light barrier 1.

## Evaluation

- Draw a straight line through the origin and the measuring points in the s(t) diagram. What relation between s and $\Gamma t_1$ can be derived?

  ________________________________

- Read the slope A of the straight line.

  ________________________________

- Determine the mean value $v_m$ of the measuring points in the v(t) diagram.

  ________________________________

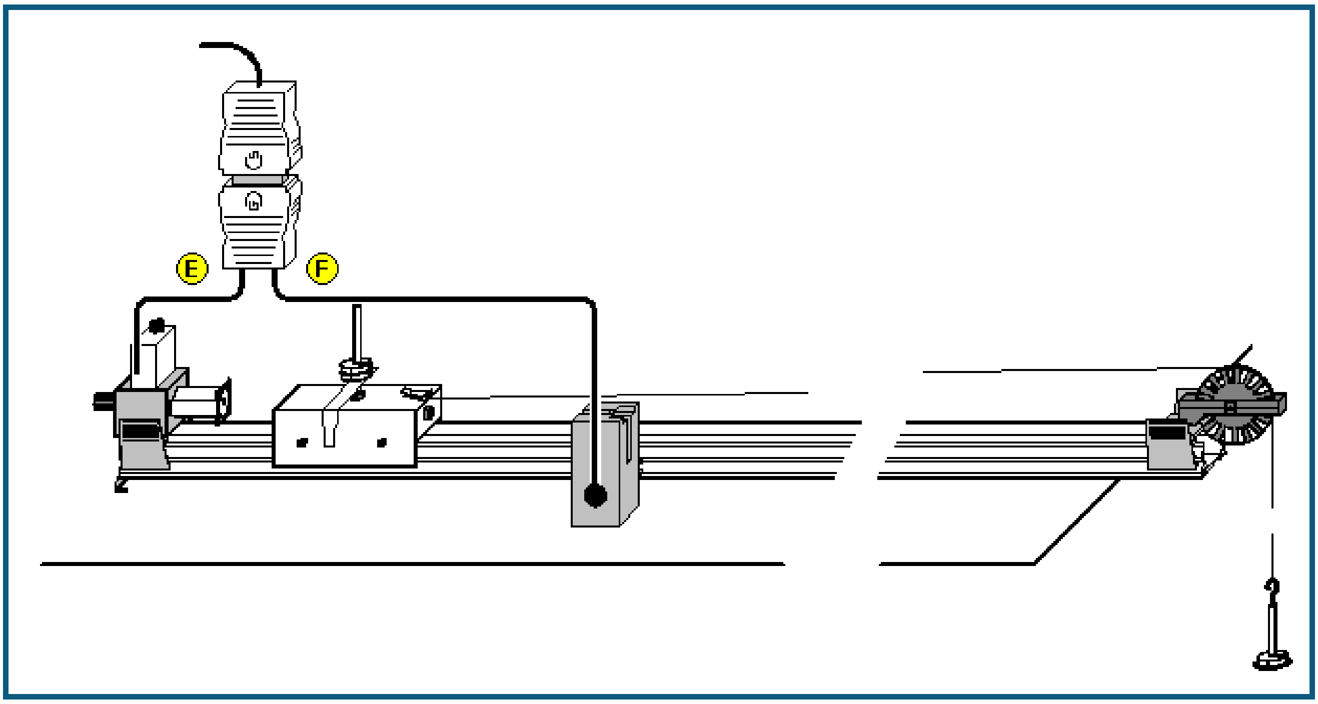
- Compare the slope A of the straight line in the s(t) diagram with the mean value $v_m$ of the velocity.

  ________________________________

- What equation of motion can be derived for the uniform motion?

  ________________________________

## Uniformly accelerated motion between a holding magnet and a light barrier



### Task

Investigate the relations between the path s and the time t and between the mean velocity $v_m$ and the time t for the uniformly accelerated motion of a trolley between a holding magnet and a light barrier.

### Equipment list

| | | |
|---|---|---|
| 1 | Pocket-CASSY | 524 006 |
| 1 | CASSY Lab 2 | 524 220 |
| 1 | Timer S | 524 074 |
| 1 | Precision metal rail, 1 m | 460 81 |
| 1 | Trolley 1 | 337 00 |
| 1 | Set of driving weights | 337 04 |
| 1 | Fishing line | from 309 48ET2 |
| 1 | Single pulley on clamp rider | 337 14 |
| 1 | Holding magnet for track | 683 41 |
| 1 | Holding magnet adapter with a release mechanism | 336 25 |
| 1 | Accessories for electronic time measurement | 337 466 |
| 1 | Combination light barrier | 337 462 |
| 1 | Multi-core cable, 6-pole | 501 16 |
| 1 | PC with Windows XP/Vista/7 | |

### Experiment setup (see drawing)

- Put the holding magnet with the holding magnet adapter onto the metal rail and connect it to the input E of the timer S.
- Set up the light barrier at a distance of 20 cm from the beginning of the metal rail and connect it to the input F.
- Put the trolley with the holding pin onto the metal track.
- Fix a piece of fishing line to the trolley, and suspend the hanger and a slotted weight from it.
- Adjust the screw of the holding magnet so that the trolley is just kept from rolling.
- Shift the trolley together with the holding magnet so that the interrupter flag on the trolley still just interrupts the light barrier (origin).

## Carrying out the experiment

☐ Load settings

- Position the light barrier at a distance s of 10 cm behind the zero just defined.
- Use the mouse to drag the pointer in the display window Path s to 10 cm.
- Start the measurement by pressing the pushbutton of the holding magnet adapter.
- Take the path s and the travel time $\Gamma t_1$ into the table with ⏱.
- Increase the distance s of the light barrier in steps of 5 cm each time repeating the measurement.

## Evaluation

- Draw a normal parabola through the measuring points of the s(t) diagram. What relation between s and $\Gamma t_1$ can be derived?

  ______________________________

- Draw a straight line through the origin and the measuring points in the $v_m$(t) diagram. What relation between the mean velocity $v_m$ and the travel time $\Gamma t_1$ can be derived?

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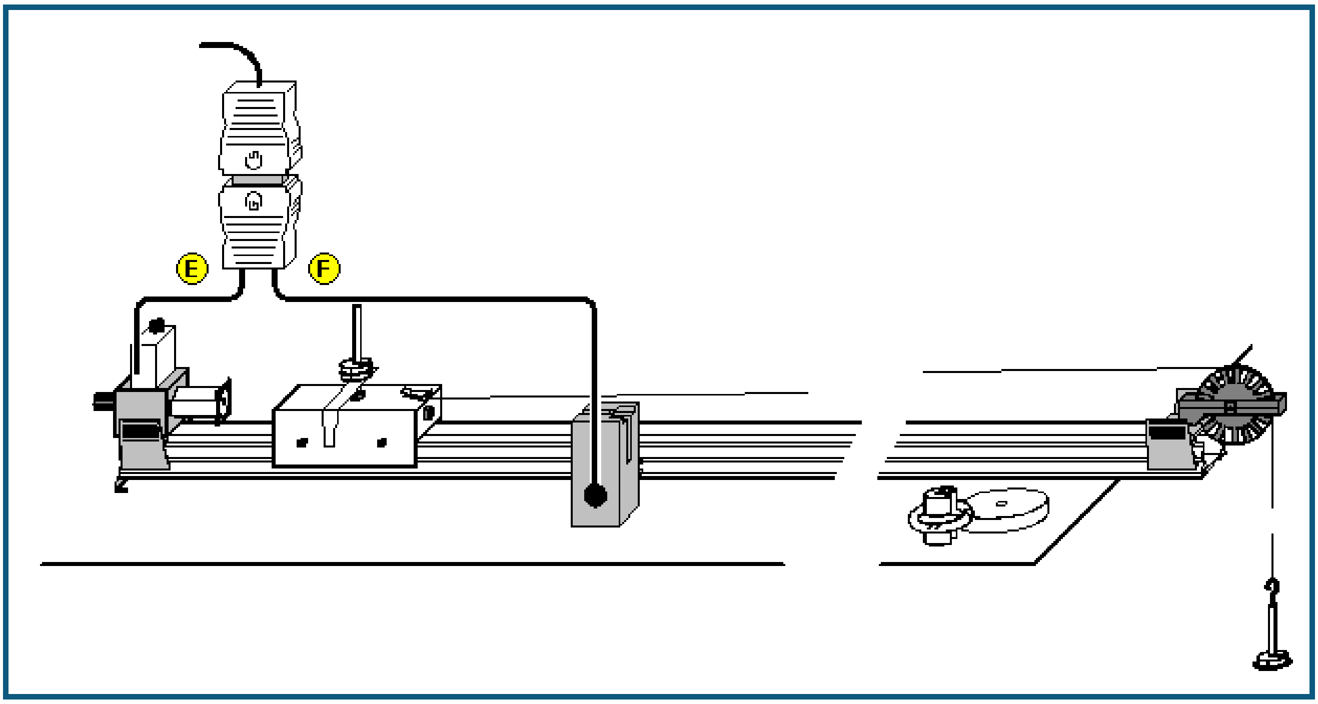
## Relation between acceleration and mass (F=constant)



### Task

Investigate the relation between the acceleration a and the mass m for the uniformly accelerated motion of a trolley between a holding magnet and a light barrier.

### Equipment list

| | | |
|---|---|---|
| 1 | Pocket-CASSY | 524 006 |
| 1 | CASSY Lab 2 | 524 220 |
| 1 | Timer S | 524 074 |
| 1 | Precision metal rail, 1 m | 460 81 |
| 1 | Trolley 1 | 337 00 |
| 1 | Set of driving weights | 337 04 |
| 1 | Additional weight 1 | 337 05 |
| 1 | Weight, 50 g | from 340 85 |
| 1 | Fishing line | from 309 48ET2 |
| 1 | Single pulley on clamp rider | 337 14 |
| 1 | Holding magnet for track | 683 41 |
| 1 | Holding magnet adapter with a release mechanism | 336 25 |
| 1 | Accessories for electronic time measurement | 337 466 |
| 1 | Combination light barrier | 337 462 |
| 1 | Multi-core cable, 6-pole | 501 16 |
| 1 | Electronic balance | 667 794 |
| 1 | PC with Windows XP/Vista/7 | |

### Experiment setup (see drawing)

- Put the holding magnet with the holding magnet adapter onto the metal rail and connect it to the input E of the timer S.
- Set up the light barrier at a distance of 20 cm from the beginning of the metal rail and connect it to the input F.
- Put the trolley with the holding pin onto the metal track.
- Fix a piece of fishing line to the trolley, and suspend the hanger and a slotted weight (F = 0.10 N) from it.
- Put the other slotted weights on the plug-in holder of the trolley.
- Adjust the screw of the holding magnet so that the trolley is just kept from rolling.
- Shift the trolley together with the holding magnet so that the interrupter flag on the trolley still just interrupts the light barrier (origin).

## Carrying out the experiment

Load settings

- Determine the mass m of the trolley (including the hanger and the slotted weights) and enter it into the table.
- Position the light barrier at the distance s = 30 cm from the zero.
- Start the measurement by pressing the pushbutton of the holding magnet adapter.
- Read the travel time $\Gamma t_1$ in the display window and accept it with ⏱ for calculating the acceleration.
- Increase the mass of the trolley in steps of 50 g and repeat the measurement.
- Before recording a new measurement series, select **Measurement → Append new Measurement Series**
- Next increase the accelerating force by putting one and two slotted weights, respectively, on the hanger, and repeat the measurements.

## Evaluation

- How can the acceleration a of the trolley be calculated from the path s and the travel time $\Gamma t_1$?

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- Enter the respective masses m (trolley, additional weights, hanger weight and slotted weights) in the table. Draw hyperbolas (1/x) through the measuring points in the a(m) diagram.
- What relation between the acceleration a and the mass m can be derived?

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- On which physical quantity does the acceleration a of the trolley depend if the mass is constant?

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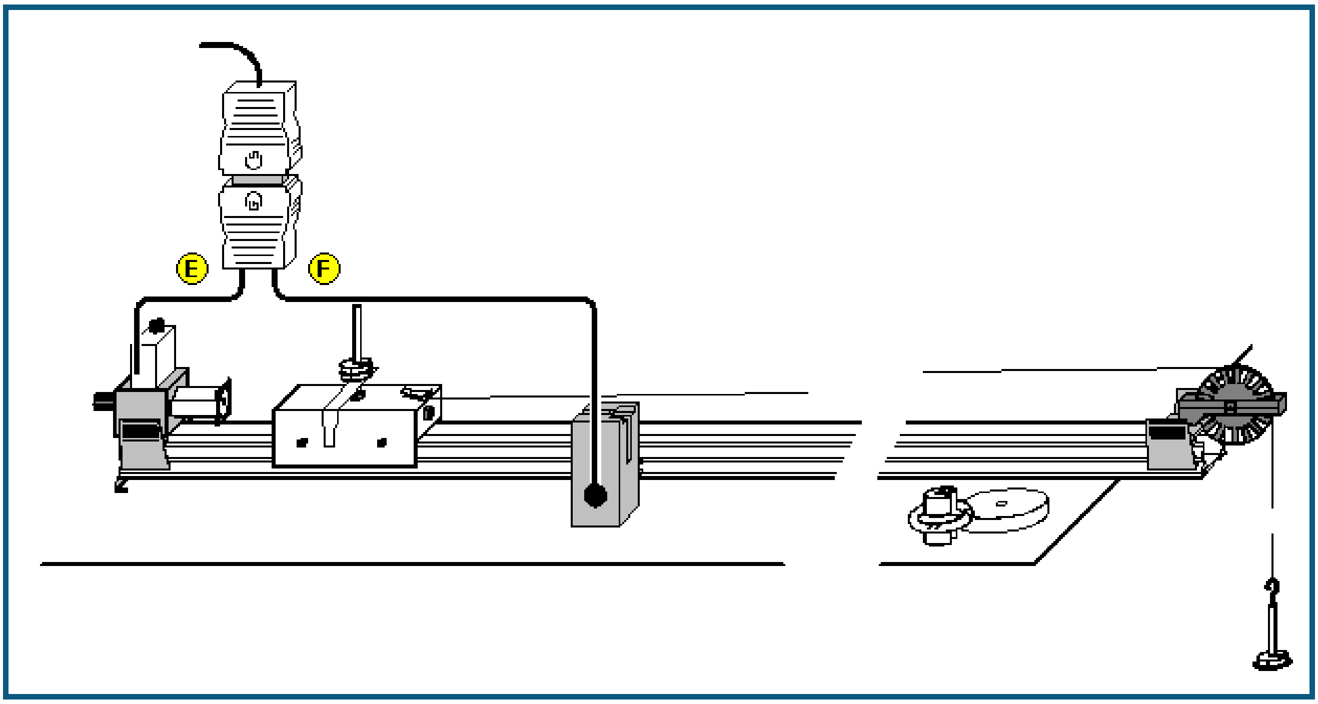
## Relation between acceleration and force (m=constant)



### Task

Investigate the relation between the acceleration and the force for the uniformly accelerated motion of a trolley between a holding magnet and a light barrier.

### Equipment list

| | | |
|---|---|---|
| 1 | Pocket-CASSY | 524 006 |
| 1 | CASSY Lab 2 | 524 220 |
| 1 | Timer S | 524 074 |
| 1 | Precision metal rail, 1 m | 460 81 |
| 1 | Trolley 1 | 337 00 |
| 1 | Set of driving weights | 337 04 |
| 1 | Additional weight 1 | 337 05 |
| 1 | Weight, 50 g | from 340 85 |
| 1 | Fishing line | from 309 48ET2 |
| 1 | Single pulley on clamp rider | 337 14 |
| 1 | Holding magnet for track | 683 41 |
| 1 | Holding magnet adapter with a release mechanism | 336 25 |
| 1 | Accessories for electronic time measurement | 337 466 |
| 1 | Combination light barrier | 337 462 |
| 1 | Multi-core cable, 6-pole | 501 16 |
| 1 | Electronic balance | 667 794 |
| 1 | PC with Windows XP/Vista/7 | |

### Experiment setup (see drawing)

- Put the holding magnet with the holding magnet adapter onto the metal rail and connect it to the input E of the timer S.
- Set up the light barrier at a distance of 20 cm from the beginning of the metal rail and connect it to the input F.
- Put the trolley with the holding pin onto the metal track.
- Fix a piece of fishing line to the trolley, and suspend the hanger and a all three slotted weights from it.
- Adjust the screw of the holding magnet so that the trolley is just kept from rolling.
- Shift the trolley together with the holding magnet so that the interrupter flag on the trolley still just interrupts the light barrier (origin).

## Carrying out the experiment

■ Load settings

- Determine the mass m of the trolley (including the hanger and the slotted weights).
- Position the light barrier at the distance s = 30 cm from the zero.
- Take all three slotted weights from the hanger and put them on the plug-in holder of the trolley.
- Determine the accelerating force F and enter it in the table.
- Start the measurement by pressing the pushbutton of the holding magnet adapter.
- Read the travel time $\Gamma t_1$ in the display window and accept it with ⏱ for calculating the acceleration.
- One after another take a slotted weight from the plug-in holder, put it on the hanger, and repeat the measurement.
- Before recording a new measurement series, select **Measurement → Append new Measurement Series**
- Next increase the mass of the trolley by 0.05 kg and 0.10 kg, respectively, and repeat the measurements.

## Evaluation

- How can the acceleration of the trolley be calculated from the path s and the travel time $\Gamma t_1$?

  ______________________________

- Enter the force F acting on the trolley in each case in the table. Draw a straight line through the origin and the measuring points in the a(F) diagram.
- What relation between a and F can be derived from the graphical representation?

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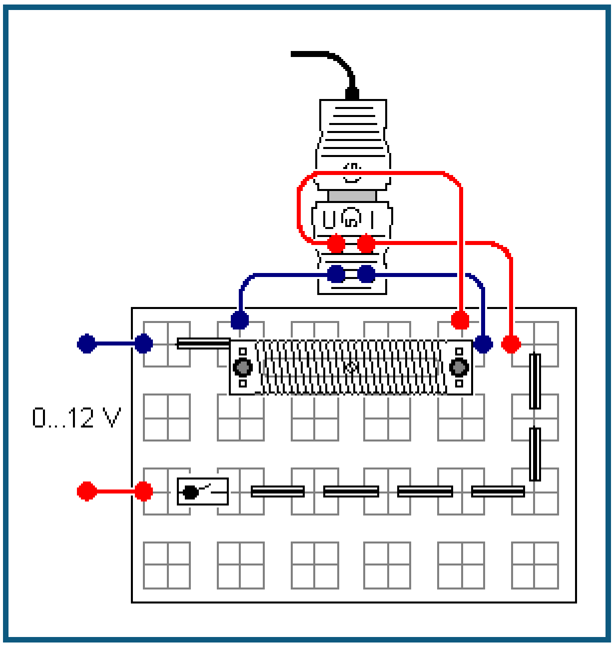
- On which physical quantity does the acceleration a of the trolley depend if the force acting on the trolley is constant?

  ____________________________________________________________________________________

## Ohm's law



### Task

Determine the relation between the voltage *U* applied to a conductor and the current *I* flowing through the conductor.

### Equipment list

| | | |
|---|---|---|
| 1 | Pocket-CASSY | 524 006 |
| 1 | CASSY Lab 2 | 524 220 |
| 1 | UIP sensor S | 524 0621 |
| 1 | Plug-in board A4 | 576 74 |
| 1 | Set of 10 bridging plugs | 501 48 |
| 1 | Wrapping plate for wires | 567 18 |
| 1 | Toggle switch, single pole STE 2/19 | 579 13 |
| 1 | Chrome-nickel wire,<br>0.25 mm, approx. 200 cm long | from 550 46 |
| 1 | Resistor 100 Ω STE 2/19 | 577 32 |
| 3 | Connecting leads, red, 25 cm | 500 411 |
| 3 | Connecting leads, blue, 25 cm | 500 412 |
| 1 | Voltage source, 0...12 V, adjustable | e.g. 521 230 |
| 1 | PC with Windows XP/Vista/7 | |

### Experiment setup (see drawing)

- Wind the chrome-nickel wire on the wrapping plate for wires, and establish electric contact with the plugs via the screws.
- Set up the circuit as shown in the diagram. In the beginning, the switch is open.
- For measuring the voltage and the current, connect the connecting leads to the UIP sensor as shown in the drawing.

### Carrying out the experiment

■ Load settings

- Close the circuit with the switch. Store the first measured value at $U = 0$ V by clicking the ⏱ button.
- Adjust various voltages (3 V, 6 V, 9 V, and 12 V) at the power supply, each time storing the measured values.

*Remark: Allow the current to flow for a short time only during each measurement to avoid warming of the wire because this would lead to an increase in resistance so that the measuring result would be distorted.*

- Replace the wrapping plate for wires in the circuit with the STE resistor 100 Ω and two bridging plugs.
- Select **Measurement → Append new Measurement Series**.
- Repeat the experiment with the STE resistor 100 Ω.

**Evaluation**

- We have the following relation: The greater the voltage *U*, the
- How does the current *I* flowing through a wire change if the voltage *U* is doubled?
- Perform a fit to a Best-fit straight line in the diagram for both measurement series. How are the measured values distributed?
- What is your conclusion regarding the relation between the voltage *U* and the current *I* in the two experiments?
- The electric resistance *R* is defined as the quotient of *U* and *I*:

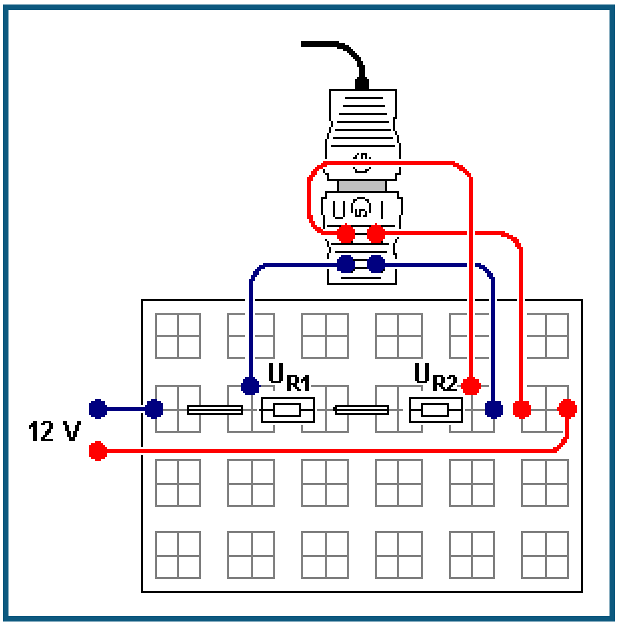
  $$R = \frac{U}{I}$$

  The unit of the electric resistance is Ω (Ohm):

  $$[R] = \Omega = \frac{\text{V}}{\text{A}}$$

  What can you say about the two resistors used in the experiment?
- What is the magnitude of the chrome-nickel wire and of the STE resistor used in the experiment?

## Series connection of resistors



### Task

Measure the voltages $U_0$, $U_{R1}$, $U_{R2}$ and the current $I_0$ at two series-connected resistors $R_1$ and $R_2$, and establish the relation between $R_1$, $R_2$ and the total resistance $R_0$.

### Equipment list

| | | |
|---|---|---|
| 1 | Pocket-CASSY | 524 006 |
| 1 | CASSY Lab 2 | 524 220 |
| 1 | UIP sensor S | 524 0621 |
| 1 | Plug-in board A4 | 576 74 |
| 1 | Set of 10 bridging plugs | 501 48 |
| 1 | Resistor 220 Ω STE 2/19 | 577 36 |
| 1 | Resistor 330 Ω STE 2/19 | 577 38 |
| 1 | Resistor 470 Ω STE 2/19 | 577 40 |
| 1 | Resistor 1 kΩ STE 2/19 | 577 44 |
| 3 | Connecting leads, red, 25 cm | 500 411 |
| 3 | Connecting leads, blue, 25 cm | 500 412 |
| 1 | Voltage source, 0...12 V, adjustable | e.g. 521 230 |
| 1 | PC with Windows XP/Vista/7 | |

### Experiment setup (see drawing)

- Set up the circuit for a combination of resistors, e.g. 220 Ω/330 Ω, as shown in the drawing.
- For measuring the voltage $U_0$ and the current $I_0$, connect the connecting leads to the UIP sensor S as shown in the drawing.

### Carrying out the experiment

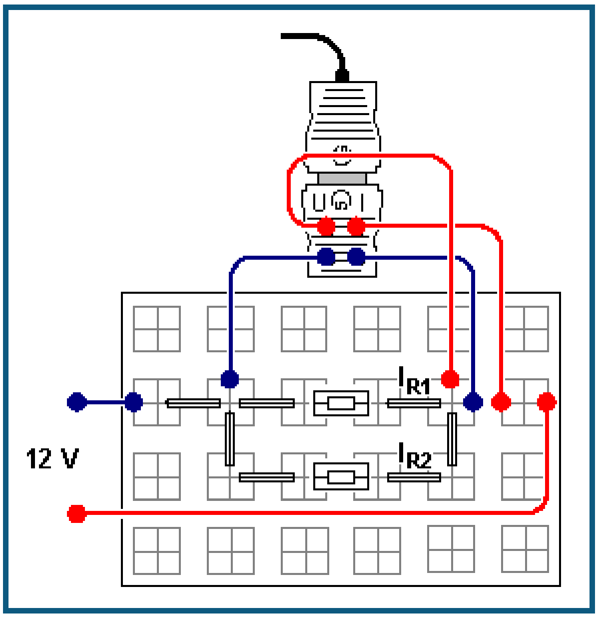
■ Load settings
- Set a voltage of approx. 12 V at the power supply.
- Measure the voltage $U_0$ and the current $I_0$. Using the mouse, transfer the measured values from the display instruments $U$ and $I$ into the prepared table (drag & drop).
- Connect the connecting leads for the voltage measurement of $U_{R1}$ (see drawing), and measure the voltage $U_{R1}$. Using the mouse, transfer the measured value from the display instrument $U$ into the prepared table, and enter the value of the resistance $R_1$ manually.
- Connect the connecting leads for the voltage measurement of $U_{R2}$ (see drawing), and measure the voltage $U_{R2}$. Using the mouse, transfer the measured value from the display instrument $U$ into the prepared table, and enter the value of the resistance $R_2$ manually.
- Repeat the experiment with other combinations of resistors.

## Evaluation

For evaluating the experiment, the prepared table **Evaluation** is provided, from which the relations between the voltages $U_0$, $U_{R1}$, $U_{R2}$ and the resistances $R_0$, $R_1$, $R_2$ become obvious.

- The current which flows through the series-connected resistors $R_1$ and $R_2$ is
- What is the relation between the voltages $U_{R1}$ and $U_{R2}$ and the total voltage $U_0$?
- What is the relation between the ratio of the resistances $R_1$ and $R_2$ and the ratio of the voltages $U_{R1}$ and $U_{R2}$?
- What is the relation between the total resistance $R_0 = U_0/I_0$ and the resistances $R_1$ and $R_2$?

## Parallel connection of resistors



### Task

Measure the voltage $U_0$ and the currents $I_0$, $I_{R1}$, $I_{R2}$ at two parallel connected resistors $R_1$ and $R_2$, and establish the relation between $R_1$ und $R_2$ and the total resistance $R_0$.

### Equipment list

| | | |
|---|---|---|
| 1 | Pocket-CASSY | 524 006 |
| 1 | CASSY Lab 2 | 524 220 |
| 1 | UIP sensor S | 524 0621 |
| 1 | Plug-in board A4 | 576 74 |
| 1 | Set of 10 bridging plugs | 501 48 |
| 1 | Resistor 220 Ω STE 2/19 | 577 36 |
| 1 | Resistor 330 Ω STE 2/19 | 577 38 |
| 1 | Resistor 470 Ω STE 2/19 | 577 40 |
| 1 | Resistor 1 kΩ STE 2/19 | 577 44 |
| 3 | Connecting leads, red, 25 cm | 500 411 |
| 3 | Connecting leads, blue, 25 cm | 500 412 |
| 1 | Voltage source, 0...12 V, adjustable | e.g. 521 230 |
| 1 | PC with Windows XP/Vista/7 | |

### Experiment setup (see drawing)

- Set up the circuit for a combination of resistors, e.g. 220 Ω/330 Ω, as shown in the drawing.
- For measuring the voltage $U_0$ and the current $I_0$, connect the connecting leads to the UIP sensor S as shown in the drawing.

### Carrying out the experiment

☐ Load settings

- Set a voltage of approx. 12 V at the power supply.
- Measure the voltage $U_0$ and the current $I_0$. Using the mouse, transfer the measured values from the display instruments *U* and *I* into the prepared table (drag & drop).
- Connect the connecting leads for the current measurement of $I_{R1}$ (see drawing, plug the bridging plugs appropriately), and measure the current $I_{R1}$. Using the mouse, transfer the measured value from the display instrument *I* into the prepared table, and enter the value of the resistance $R_1$ manually.
- Connect the connecting leads for the current measurement of $I_{R2}$ (see drawing, plug the bridging plugs appropriately), and measure the current $I_{R2}$. Using the mouse, transfer the measured value from the display instrument *I* into the prepared table, and enter the value of the resistance $R_2$ manually.
- Repeat the experiment with other combinations of resistors.

## Evaluation

For evaluating the experiment, the prepared table **Evaluation** is provided, from which the relations between the currents $I0$, $I_{R1}$, $I_{R2}$ and the resistances $R_0$, $R_1$, $R_2$ become obvious.

- The voltages $U_{R1}$ and $U_{R2}$ at the resistors $R_1$ and $R_2$ are equal to

  ______________________________

- What is the relation between the currents $I_{R1}$ and $I_{R2}$ and the total current $I_0$?

  ____________________________________________________________________________________

  ____________________________________________________________________________________

- What is the relation between the ratio of the resistances $R_1$ and $R_2$ and the ratio between the currents $I_{R1}$ and $I_{R2}$?

  ____________________________________________________________________________________

  ____________________________________________________________________________________

- What is the relation between the total resistance $R_0 = U_0/I_0$ and the resistances $R_1$ and $R_2$?

  ____________________________________________________________________________________

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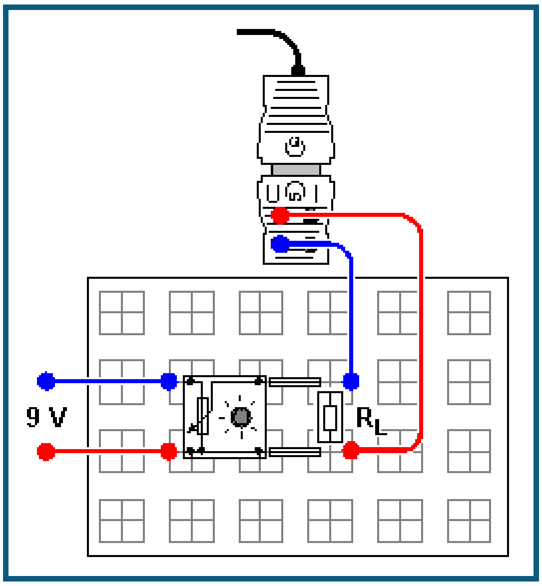
## Adjusting a voltage by means of a potentiometer



### Task

Measure the partial voltage $U_1$ at the potentiometer in the currentless, unloaded state for different potentiometer positions.

Measure the partial voltage $U_1$ at the potentiometer as a function of the potentiometer position for different loads $R_L$, and compare the results with the measurement in the unloaded state ($R_L$ remains constant within a measurement series).

### Equipment list

| | | |
|---|---|---|
| 1 | Pocket-CASSY | 524 006 |
| 1 | CASSY Lab 2 | 524 220 |
| 1 | UIP sensor S | 524 0621 |
| 1 | Plug-in board A4 | 576 74 |
| 1 | Set of 10 bridging plugs | 501 48 |
| 1 | Resistor 47 Ω STE 2/19 | 577 28 |
| 2 | Resistors 100 Ω STE 2/19 | 577 32 |
| 1 | Resistor 150 Ω STE 2/19 | 577 34 |
| 1 | Resistor 470 Ω STE 2/19 | 577 40 |
| 1 | Potentiometer 220 Ω, 3 W, STE 4/50 | 577 90 |
| 2 | Connecting leads, red, 25 cm | 500 411 |
| 2 | Connecting leads, blue, 25 cm | 500 412 |
| 1 | Voltage source, 0...15 V, adjustable | e.g. 521 45 |
| 1 | PC with Windows XP/Vista/7 | |

### Experiment setup (see drawing)

Set up the circuit as shown in the drawing, and connect the UIP sensor for the voltage measurement. At first do not use the load *RL*.

### Carrying out the experiment

■ Load settings

- Apply a total voltage of approx. 9 V.
- The potentiometer being unloaded ($R_L = \infty$), enter the voltage $U_1$ in the prepared table for different potentiometer positions by clicking ⏱, and enter the number corresponding to the switch position in the column $P_N$.
- Before recording a measurement series with another load, each time select **Measurement → Append new Measurement Series**.
- Insert the STE resistor $R_L$ = 470 Ω in the circuit, and record a new measurement series for a loaded potentiometer.
- Repeat the experiment with other loads $R_L$ = 100 Ω, 47 Ω.

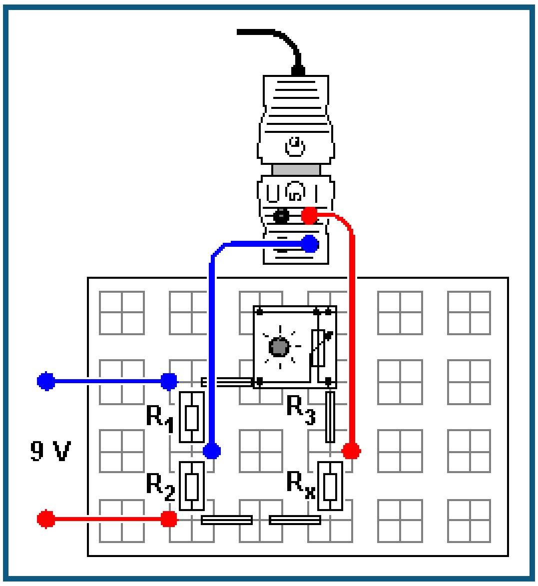
## Evaluation

- What is the relation between the partial voltage $U_1$ and the resistance $R_1$at an unloaded potentiometer?

- What is the effect of loading the potentiometer with a resistance $R_L$?

- Where do you expect the curve of the measurement series to be located if the potentiometer is loaded with a resistance $R_L$ < 47 Ω?

## Principle of Wheatstone's bridge



### Task

In order to measure an "unknown" resistance $R_x$, vary the variable resistance $R_3$ (potentiometer) in the bridge circuit until no current flows between the two arms of the bridge.

### Equipment list

| | | |
|---|---|---|
| 1 | Pocket-CASSY | 524 006 |
| 1 | CASSY Lab 2 | 524 220 |
| 1 | UIP sensor S | 524 0621 |
| 1 | Plug-in board A4 | 576 74 |
| 1 | Set of 10 bridging plugs | 501 48 |
| 1 | Resistor 220 Ω STE 2/19 | 577 36 |
| 2 | Resistors 330 Ω STE 2/19 | 577 38 |
| 1 | Resistor 470 Ω STE 2/19 | 577 40 |
| 1 | Resistor 1 kΩ STE 2/19 | 577 44 |
| 1 | Potentiometer 1 kΩ, 1 W STE 4/50 | 577 92 |
| | or 10-turn potentiometer 1 kΩ, 2 W | 577 93 |
| 2 | Connecting leads, red, 25 cm | 500 411 |
| 2 | Connecting leads, blue, 25 cm | 500 412 |
| 1 | Voltage source, 0...15 V, adjustable | e.g. 521 45 |
| 1 | PC with Windows XP/Vista/7 | |

### Experiment setup (see drawing)

Set up the circuit with the combination of resistors $R_1 = 1k\Omega$ / $R_2 = 470\ \Omega$ as shown in the drawing, and connect the UIP sensor for the current measurement.

### Carrying out the experiment

☐ Load settings

- If necessary, set the display of the current to → **0** ← in Settings I1.
- Apply a voltage of approx. 9 V.
- Adjust the potentiometer for a selected resistance $R_x$ (e.g. 330 Ω) so that no current $I_1$ flows between the arms of the bridge circuit.
- Read the value $R_3$ of the adjusted resistance, and write it in the prepared table. The value of the resistance $R_3$ can be estimated from the position of the rotary knob if the STE potentiometer 1 kΩ is used: the left stop corresponds to approx. 1 kΩ
- Repeat the measurement for other resistances $R_x$.

## Evaluation

- What is the relation between the ratios of the resistances in the two arms of the bridge circuit if no current flows between the two arms ($I_1 = 0$)?
- How is $R_x$ determined if the resistances $R_1$, $R_2$ and $R_3$ are known?
- What is the relation between the voltage drops $U_1$ and $U_3$ or $U_2$ and $U_x$, respectively, at the 4 resistances $R_1$ and $R_3$ or $R_2$ and $R_x$, respectively, if the bridge is balanced ($I_1 = 0$)?
- What is the effect of the applied voltage $U$ on the determination of the resistance $R_x$ if the bridge is balanced ($I_1 = 0$)?

## Remark

The resistance $R_x$ could, of course, also be determined by measuring the voltage drop $U$ while a current $I$ is flowing, i.e. using the relation $R_x=U/I$. However, this presupposes that the internal resistances of the measuring instruments can be neglected, which is usually the case. If the bridge circuit is used, the internal resistance of the ammeter does not play a role at all because no current flows. Therefore the bridge circuit provides an opportunity of an accurate measurement of the fourth resistance if the other three resistances are known precisely.

## Longitudinal expansion of solid bodies

### Task

Heating up metal tubes and determining the change in their length.

### Equipment list

| | | |
|---|---|---|
| 1 | Pocket-CASSY | 524 006 |
| 1 | CASSY Lab 2 | 524 220 |
| 1 | Rotary motion sensor S | 524 082 |
| from BMC 1: | | |
| 2 | Stand bases MF | 301 21 |
| 2 | Stand rods, 50 cm | 301 27 |
| 1 | Double bosshead | 301 09 |
| 1 | Universal clamp, 0...80 mm | 666 555 |
| 1 | Universal bosshead | 666 615 |
| 1 | Tape measure | 311 78 |
| from BMC 2: | | |
| 1 | Stopper with hole | 667 2545 |
| 1 | Connector, straight | 665 226 |
| 1 | Silicone hose, 1 m | 667 194 |
| 1 | Round tin | from 686 53ET5 |
| from CAL 1: | | |
| 1 | Erlenmeyer flask, 50 ml | 664 248 |
| 1 | Al tube, d = 8 mm, l = 44 cm | 381 332 |
| 1 | Fe tube, d = 8 mm, l = 44 cm | 381 333 |
| 1 | Stirring thermometer | 382 21 |
| additionally required: | | |
| 1 | Heat source, e.g. butane gas burner | 666 714 |
| 1 | Double bosshead | 301 09 |
| 1 | Stand ring with stem | 302 68 |
| 1 | Wire gauze | 666 685 |
| | Water | |
| 1 | PC with Windows XP/Vista/7 | |

## Experiment setup (see drawing)

- Push a length of silicone hose (approx. 60 cm) across the transverse hole in the iron tube so that no hot water can escape during the experiment.
- Clamp the iron tube. Adjust the measuring length by shifting the feet of the stand: to do this set the distance from the clamping point (screw in the double sleeve) in the direction of the point of support on the shaft (axle) of the rotary motion sensor initially to l = 40 cm.
- The clamped iron tube must be at right angles and firmly attached to the shaft (axis) of the rotary motion sensor in order for the measuring result not to be falsified by slipping.
- Fill approx. 20 ml water into the Erlenmeyer flask. Firmly insert the stopper with the hose connector and the silicone hose.

## Warning

Hot steam! During the experiment hot steam escapes from the short hose end. All metal parts and hoses will continue to be hot even after the boiling has discontinued.

## Carrying out the experiment

■ Load settings
- Enter the length of the clamped iron tube (distance between the clamping point and the shaft) in the table.
- Measure the room temperature $T_R$.
- Set the origin in the window Settings α1 (right mouse button on button $\alpha_1$) by clicking → **0** ←. Thereafter do not change anything in the setup.
- Switch on the heat source and bring the water to the boil.
- Continue boiling the water until the display for the length change Γl remains constant and enter the measured value ⏱ in the table.
- Allow the iron tube to cool down.

Note: If the setup has been done correctly, the display of the length change Γl will return to 0 mm, i.e. no slippage occurred.

- Repeat the experiment with the aluminum tube.

## Additional task

- Repeat the experiment using different lengths l (e.g. 35 cm, 30 cm, 25 cm, 20 cm,...). Always allow the tube to cool down to room temperature.
- For distinguishing between the two tubes, select **Measurement** → **Append New Measurement Series**.

## Evaluation

- What happens when the metal tubes are heated?
- Which metal expands more and which less?
- $\Gamma l = \alpha \cdot l \cdot \Gamma T$ or $\alpha = \Gamma l / l / \Gamma T$ applies here. What is the value for the coefficient of linear expansion for aluminum and for iron?
- What does the coefficient of linear expansion α indicate:

- The table below indicates the coefficient of linear expansion α of various materials:

| Material | Coefficient of linear expansion α / $10^{-6}$/K |
|---|---|
| Polystyrene | 60 ... 80 |
| Aluminum | 23.8 |
| Copper | 16.8 |
| Stainless steel | 16 |
| Iron | 12.1 |
| Chromium alloy steel | 10.0 |
| Concrete | 6 ... 14 |
| Optical glass | 9.5 |
| Duran glass | 3.2 |

- Why is iron (steel) used for reinforcing concrete and no other material?

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- Why do railway tracks have expansion joints?

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**Additional task**

- Fit a straight line (gradient A) to the measured values in the diagram. What can be said about the relationship?

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- Calculate the coefficient of linear expansion from the gradient of the fitted straight line:

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## Temperature change on account of thermal radiation

### Task

To investigate the heat absorption and heat emission of dark and shiny surfaces.

### Equipment list

| | | |
|---|---|---|
| 1 | Pocket-CASSY | 524 006 |
| 1 | CASSY Lab 2 | 524 220 |
| 1 | NiCr-Ni adapter S | 524 0673 |
| 1 | NiCr-Ni temperature sensor 1.5 mm | 529 676 |
| from BMC 1: | | |
| 2 | Stand bases MF | 301 21 |
| 1 | Stand rod, 25 cm | 301 26 |
| 2 | Stand rods, 50 cm | 301 27 |
| 1 | Double bosshead | 301 09 |
| 1 | Universal clamp, 0...80 mm | 666 555 |
| 1 | Universal bosshead | 666 615 |
| 1 | Tape measure | from 311 78ET5 |
| from CAL 1: | | |
| 1 | Pair of radiation sensors | 384 531 |
| additionally required: | | |
| 1 | Heat source, e.g. butane gas burner | 666 714 |
| 1 | PC with Windows XP/Vista/7 | |

### Experiment setup (see drawing)

- First of all clamp the radiation sensor with the black surface at the same level as the flame in the universal clamp.
- Insert the temperature sensor through the hole in the stopper into the radiation sensor. In order to seal the joint, push the cover disk of the temperature sensor in front of the opening so as to avoid convective heat loss.
- Carefully clamp the temperature sensor into the double bosshead.

## Carrying out the experiment

■ Load settings

- Clamp the radiation sensor with the black surface.
- Switch on the radiation source so that a yellow flame is located at a distance of approx. 2 cm.

Warning! Ensure that direct contact of the flame with the plastic housing is avoided.

- Start the measurement with ⏱.
- Observe the temperature change with time and discontinue the measurement after approx. 5 minutes.

## Remarks

In order for the second experiment to be carried out under identical conditions
Do not extinguish the radiation source. This ensures that the flame glows at the same intensity.
Allow the temperature sensor to cool down to room temperature before commencing the second experiment.
Adjust the distance between the radiation sensor and the flame to an equal value.

- Repeat the experiment using the radiation sensor with the metallic surface.
- Observe the temperature change with time and discontinue the measurement after approx. 5 minutes.
- Remove the flame and immediately re-start the measurement.
- Observe the temperature change with time during the cooling process and discontinue the measurement after approx. 5 minutes.
- Again clamp the radiation sensor with the black surface.
- Place the radiation source in front of the radiation sensor in order to heat the radiation sensor with the metallically reflective surface again.
- Observe the temperature:
  Remove the flame when the temperature is slightly above the starting temperature for the cooling process of the radiation sensor with the metal surface.
  Re-start the measurement when the starting temperature for the cooling process of the radiation sensor with the metal surface has been reached.
- Observe the temperature change with time during the cooling process and discontinue the measurement after approx. 5 minutes.

## Evaluation

- What happens to the radiation sensors when they are close to a flame?
- How does the energy (heat) reach the radiation sensors?
- Which radiation sensor heats up faster?
- Which radiation sensor cools down faster?
- What can be concluded from the observation above?
- Examples of applications:

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### Additional evaluation task

- Connect the measured values e.g. using Diagram → Fit Function → Free Fit with the exponential function of the form A*exp(-x/B)+C (two rising and two falling curves).
  A gives the difference between the starting temperature and the end temperature, i.e. it is negative for rising and positive for falling exponential functions.
  B is the time constant, i.e. it gives the time when the temperature difference has fallen or risen to 1/e.
  C gives the end temperature which is reached after a sufficiently long time.
  Enter estimated values as starting values of the free fit.
- How do the time constants (parameter B) behave in the case of the black and the metallically shiny surfaces?

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- How do the time constants behave for the heating (absorption) and the cooling (emission) process?

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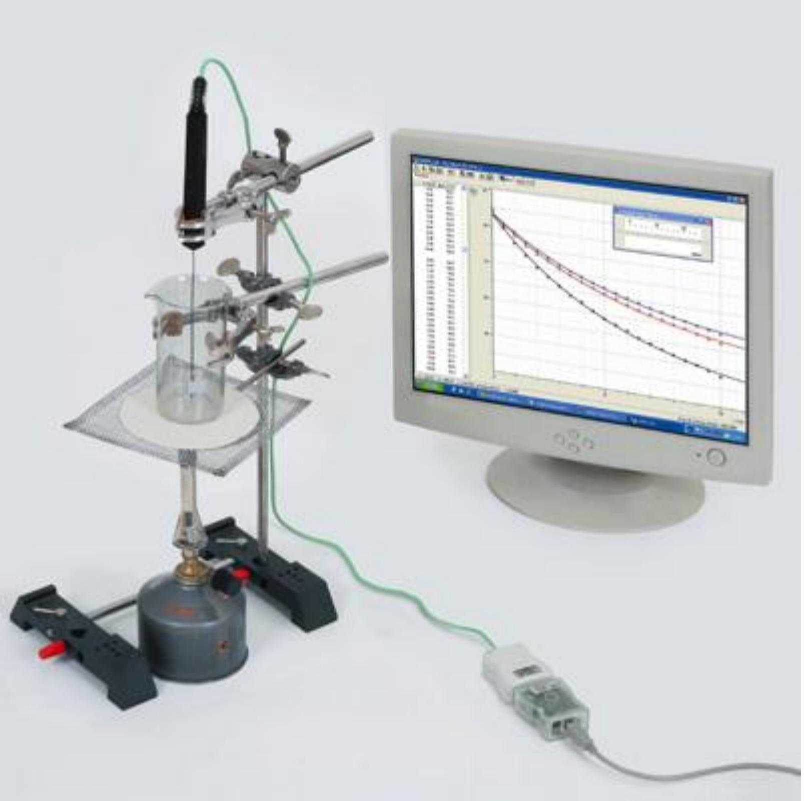
## Cooling down of water



### Task

To investigate the cooling behavior of hot water.

### Equipment list

| | | |
|---|---|---|
| 1 | Pocket-CASSY | 524 006 |
| 1 | CASSY Lab 2 | 524 220 |
| 1 | NiCr-Ni adapter S | 524 0673 |
| 1 | NiCr-Ni temperature sensor 1.5 mm | 529 676 |
| from BMC 1: | | |
| 2 | Stand bases MF | 301 21 |
| 1 | Stand rod, 25 cm | 301 26 |
| 1 | Stand rod, 50 cm | 301 27 |
| 1 | Double bosshead | 301 09 |
| 1 | Universal clamp, 0...80 mm | 666 555 |
| from BMC 2: | | |
| 1 | Beaker, 250 ml | 664 130 |
| additionally required: | | |
| 2 | Double bossheads, e.g. | 301 09 |
| 1 | Universal clamp, 0...80 mm | 666 555 |
| 1 | Heat source, e.g. butane gas burner | 666 714 |
| 1 | Stand ring with stem | 302 68 |
| 1 | Wire gauze | 666 685 |
| | Water | |
| | Cardboard, approx. 10 cm x 10 cm or diameter 10 cm | |
| 1 | PC with Windows XP/Vista/7 | |

### Experiment setup (see drawing)

- Pour approx. 50 ml water into the beaker.

- Clamp the temperature sensor into the universal clamp so that the measuring point is in the water but does not make contact with the bottom of the glass.
- Place the heat source under the beaker.

## Carrying out the experiment

■ Load settings
- Switch on the heat source and wait until the water is boiling.
- Switch off the heat source and start the measurement with ⏱.
- Discontinue the measurement after approx. 10 minutes.
- Make a small hole in the center of the cardboard and stick the measuring point of the temperature sensor through it.
- Switch on the heat source and wait until the water is boiling.
- Switch off the heat source.
- Rapidly clamp the temperature sensor into the universal clamp so that the measuring point is in the water but does not make contact with the bottom of the glass. Gently press the cardboard down onto the beaker.
- Start the measurement with ⏱. Attempt to start at the same temperature as in the first experiment.
- Discontinue the measurement after approx. 10 minutes.

## Additional experiment

- Repeat the experiment with insulation, e.g. paper wrapped around the beaker.

## Evaluation

- How does hot water cool? (Describe the curves.)

  ______________________________________________________________

- What is the effect of the cover?

  ______________________________________________________________

- Reason:

  ______________________________________________________________

  ______________________________________________________________

  ______________________________________________________________

  ______________________________________________________________

Note: Other vessels, in particular e.g. a Dewar vessel, can be investigated.

# Temperature change when heat energy is supplied

## Task

To investigate the temperature change of water with time when heat energy is uniformly supplied.

## Equipment list

| | | |
|---|---|---|
| 1 | Pocket-CASSY | 524 006 |
| 1 | CASSY Lab 2 | 524 220 |
| 1 | NiCr-Ni adapter S | 524 0673 |
| 1 | NiCr-Ni temperature sensor 1.5 mm | 529 676 |
| from BMC 1: | | |
| 2 | Stand bases MF | 301 21 |
| 1 | Stand rod, 25 cm | 301 26 |
| 1 | Stand rod, 50 cm | 301 27 |
| 1 | Double bosshead | 301 09 |
| 1 | Universal clamp, 0...80 mm | 666 555 |
| from CAL 1: | | |
| 1 | Erlenmeyer flask, 50 ml | 664 248 |
| additionally required: | | |
| 1 | Heat source, e.g. butane gas burner | 666 714 |
| 1 | Stand ring with stem | 302 68 |
| 1 | Universal bosshead | 666 615 |
| 1 | Wire gauze | 666 685 |
| | Water | |
| | Ice | |
| 1 | PC with Windows XP/Vista/7 | |

## Experiment setup (see drawing)

Remark:

Care has to be taken that
- the cable of the temperature sensor does not make contact with the flame or hot parts
- the setup is protected from drafts

- Fill the Erlenmeyer flask with ice and top up with water to the 50 ml mark.
- Immerse the temperature sensor with its measuring point into the ice water.
- If necessary, set the starting temperature to $\vartheta = 0°$ C in Settings ϑ11 by selecting **Correct Offset**.

## Carrying out the experiment

■ Load settings

- Start the measurement at a constant temperature ($\vartheta_{11} = 0$ °C) with ⏱.
- Switch on the heat source and place it under the Erlenmeyer flask.
- During the entire measurement carefully stir using the temperature sensor. Care has to be taken that the measuring point does not make contact with the bottom of the Erlenmeyer flask.
- After the measurement extinguish the heat source.

Warning – risk of burning! Hot parts.

## Evaluation

- Description of the temperature change when heat energy is supplied:
- How is the supplied heat energy used in the various sections?
  Ice water ($\vartheta = 0$ °C):

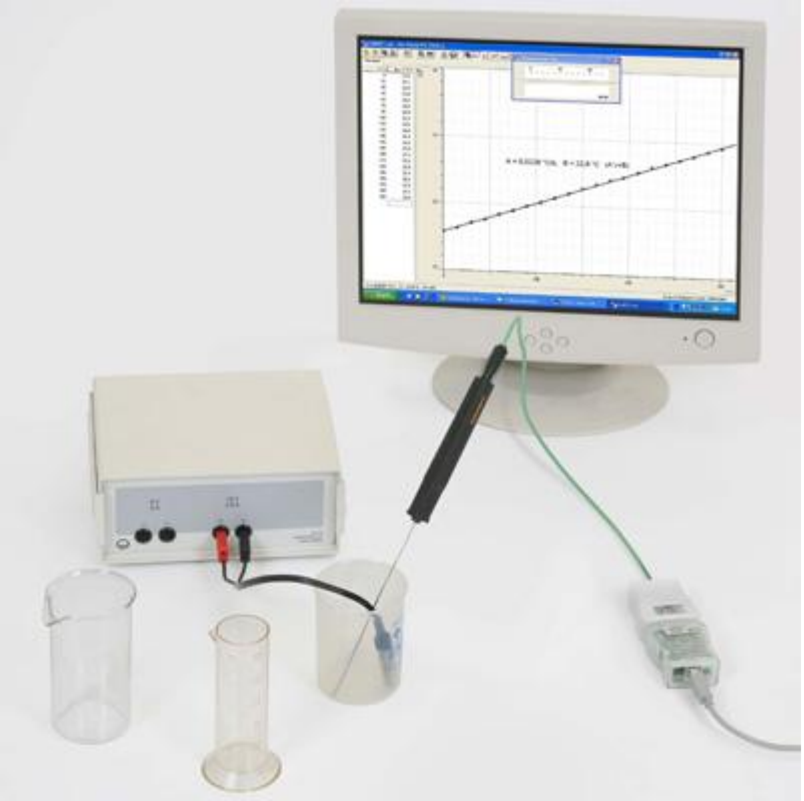
  Water:

  Water ($\vartheta = 100$ °C):

## Additional task

- Estimation of the heat output P (supply of heat energy per time) from the gradient of the straight line:

## Specific heat capacity of water



### Task

To investigate the dependency of the temperature change of water on the energy supplied.

### Equipment list

| | | |
|---|---|---|
| 1 | [Pocket-CASSY]() | 524 006 |
| 1 | [CASSY Lab 2]() | 524 220 |
| 1 | [NiCr-Ni adapter S]() | 524 0673 |
| 1 | NiCr-Ni temperature sensor 1.5 mm | 529 676 |
| from BMC 2: | | |
| 1 | Plastic beaker | 664 123 |
| 1 | Beaker | 664 130 |
| 1 | Measuring cylinder | 590 08 |
| from CAL 1: | | |
| 1 | Immersion heater | 590 48 |
| additionally required: | | |
| 1 | Voltage source, 12 V,<br>e.g. Transformer | 562 73 |
| | Water | |
| 1 | PC with Windows XP/Vista/7 | |

### Experiment setup (see drawing)

- Prepare a beaker with 250 ml water.
- Pour 100 ml water into the plastic beaker by means of the measuring cylinder.

### Carrying out the experiment

■ Load settings
- Place the immersion heater into the plastic beaker in such a way that it is fully immersed into the water.
- Connect the immersion heater to the voltage source and continuously stir for approx. 1 minute using the temperature sensor.

Note: The warming up of the immersion heater (heat capacity) itself should not affect the measured result.

- Start the measurement with ⏱ and continue measuring for approx. 5 minutes.
- During the entire measurement, stir using the temperature sensor.

### Evaluation

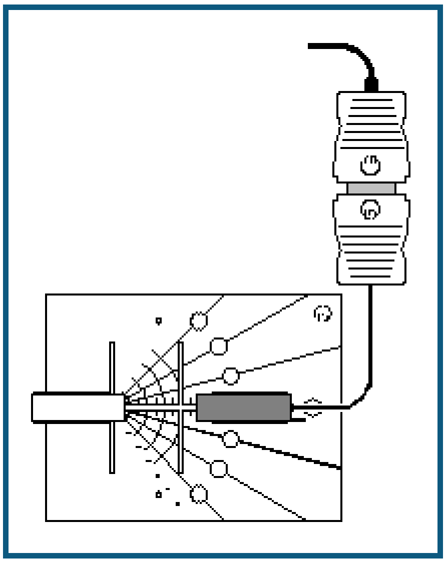
- Where does the energy for heating the water come from?

- Calculation of the specific heat capacity $c_{H2O}$ by means of the equation $c_{H2O} = P \cdot \Gamma t / (m \cdot \Gamma\vartheta)$ using
  P: electrical power ($P = U \cdot I = U^2 / R$ with applied voltage U and the resistance R)
  $\Gamma t$ : time (for $P \cdot \Gamma t = E$ energy supplied)
  m: mass of the water
  $\Gamma\vartheta$: temperature change
  $\Gamma\vartheta / \Gamma t$: gradient of the straight line in the recorded diagram

- How much energy is required for bringing 1 liter of water at 20 °C room temperature to the boil?

- How long will one theoretically need to do this when using a hotplate with a power of P = 1.5 kW? (Estimation, as the heat capacity of the pot and the plate are not taken into consideration. Furthermore, heat loss occurs.)

## The effect of the distance between the radiation source and the end-window counter on the pulse rate



### Task

Increase the distance *d* between the radiation source and the end-window counter step by step, each time measuring the pulse rate *R*.

### Equipment list

| | | |
|---|---|---|
| 1 | Pocket-CASSY | 524 006 |
| 1 | CASSY Lab 2 | 524 220 |
| 1 | GM counter tube S | 524 0331 |
| 1 | RAD experiment board | 686 651 |
| 1 | Holders for counter tube and preparation | 686 653 |
| 1 | Ra226 preparation 30.3 kBq | 559 430 |
| 1 | PC with Windows XP/Vista/7 | |

### Experiment setup (see drawing)

- When handling the radioactive preparation, observe the safety notes (see Instruction sheet 559 430), i.e. in particular, take the preparation out of the protective container only as long as is required for carrying out the experiment, do not allow the aperture for the emission of the radiation to get close to your eyes, and do not touch it.
- Mount the counter tube and the Ra226 preparation on the RAD experiment board so that they are placed opposite each other at a distance of 2 cm.
- Remove the protective cap from the counter tube.

*Remark: Under no circumstances touch the end-window with your finger or with the preparation as it is very thin and therefore easily destroyed.*

### Carrying out the experiment

■ Load settings

- Enter the distance 2 in the column d/cm of the table. Start measurement with ⏱. As soon as the measurement has been finished, the pulse rate *R* is entered in the table automatically.
- Repeat the experiment with the distance between the counter and the preparation being increased step by step. Each time increase the distance by 1 cm up to 10 cm.
- Put the Ra226 preparation back into the protective container.
- Select **Measurement → Append new Measurement Series**.
- Repeat the experiment without preparation to obtain the zero rate from the background radiation.
- After carrying out the experiment, put the protective cap carefully onto the counter tube without keeping the cap closed for the pressure compensation.

## Evaluation

- What is the difference between $N_1$ and the pulse rate $R$?

- How does the pulse rate $R$ change with respect to the distance $d$ between the preparation and the counter tube?

- What kind of curve is described by the measured values? Suggestion:

- Confirm the suggestion by fitting to a corresponding curve with Fit Function.
- What is your conclusion regarding the relation between the pulse rate $R$ and the distance $d$?

- What protective measure derives from this relation for handling radioactive materials?

- What is the magnitude of the zero rate $R_0$?

- At what distance does the preparation used in this experiment lead to an additional irradiation which is of the order of magnitude of the background radiation? To determine this distance, activate Zoom in order that the value can be read.

## Experiment examples physics

These experiment examples support you in using CASSY Lab. Where applicable, the corresponding experiment number from the General Catalogue of Physics Experiments is also given. The measurement data or settings for the examples can be loaded directly into CASSY Lab. Simply click the symbols □ in the descriptions. New examples are labeled with a red •.

### Mechanics

- Uniform motions between two light barriers
- Accelerated motions between holding magnet and light barrier
- P1.3.2.3a Motions with spoked wheel (Newton definition)
- P1.3.3.4-6 Motions on the linear air track (Newton's equation of motion)
- P1.3.4.1-2ab Conservation of momentum and energy (collision)
- Conservation of linear momentum by measuring the motion of the centre of mass (collision)
- Confirming the relation action=reaction by measuring accelerations (collision)
- P1.3.5.3 Free fall with g-ladder
- Free fall with g-ladder (with modeling)
- P1.4.1.2 Rotational motions (Newton's equation of motion)
- P1.4.2.1-2 Conservation of angular momentum and energy (torsion collision)
- Centrifugal force (rotable centrifugal force arm)
- P1.4.3.3 Centrifugal force (centrifugal force apparatus)
- P1.4.4.3 Precession of a gyroscope
- P1.4.4.4 Gyroscope nutation
- Oscillations of a rod pendulum
- Oscillations of a rod pendulum (with added mass)
- Oscillations of a rod pendulum (with modeling)
- Dependency of the period of the oscillation on the amplitude
- Determination of the acceleration due to gravity on earth by means of a reversible pendulum
- Pendulum with changeable acceleration due to gravity (variable g-pendulum)
- P1.5.2.1 Harmonic oscillations of a spring pendulum
- P1.5.2.2 Dependence of the period of oscillation of a spring pendulum on the oscillating mass
- Oscillations of a spring pendulum (with modeling)
- Oscillations of a spring pendulum with solid friction (with modeling)
- Oscillations of a spring pendulum with lubricant friction (with modeling)
- Oscillations of a spring pendulum with laminar liquid friction (with modeling)
- Oscillations of a spring pendulum with turbulent liquid friction/air friction (with modeling)
- P1.5.4.4 Coupled pendulums with two tachogenerators
- Coupled pendulums with two rotary motion sensors
- Three-body problem (with modeling)
- P1.7.1.3 Acoustic beats
- P1.7.2.1 String vibrations
- P1.7.3.3 Velocity of sound in air
- Determining the velocity of sound in air with 2 microphones
- P1.7.3.4 Velocity of sound in gases
- P1.7.3.5 Velocity of sound in solid bodies
- P1.7.7.1 Fourier analysis of simulated signals
- P1.7.7.2 Fourier analysis of signals of a function generator
- P1.7.7.4 Sound analysis
- Sonic synthesis

### Heat

- P2.3.3.2 Conversion of mechanical energy into thermal energy
- P2.3.4.3 Conversion of electrical energy into thermal energy
- P2.6.2.4 pV diagram of a hot-air engine

### Electricity

- P3.1.2.3 Coulomb's law
- P3.3.3.3 Force in the magnetic field of an air coil
- P3.3.3.2 Force in the magnetic field of an electromagnet
- P3.3.3.4 Force between two current-carrying conductors (ampere definition)
- P3.4.1.1 Impulse of voltage (Faraday's law of induction)
- P3.4.3.1-2 Induction in a variable magnetic field

| | |
|---|---|
| P3.4.5.3 | Voltage and current curves of a transformer as a function of time |
| P3.4.5.4 | Power transfer of a transformer |
| | Power of arbitrary loads operated with mains AC voltage |
| | Charging and discharging of a capacitor |
| | Charging and discharging of a capacitor (with modeling) |
| | Charging and discharging of a small capacitor (cable capacitances) |
| | Damped oscillator circuit |
| | Damped oscillator (with modeling) |
| P1.7.7.3 | Coupled oscillators |
| | Forced oscillations (resonance) |
| | Forced oscillations (resonance, with modeling) |
| | RLC filter (low pass, high pass, band pass) |
| | Low-pass filter (with modeling) |
| | High-pass filter (with modeling) |

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| | Characteristic of a diode |
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| P6.4.2.1 | Poisson distribution |
| P6.4.3.2 | Half-life of radon |
| P6.5.4.1 | α spectroscopy of radioactive samples (Am-241) |
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| P6.5.4.4 | Determining the age of a Ra-226 sample |
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| P6.5.5.6 | Coincidence and γ-γ angular correlation in positron decay |
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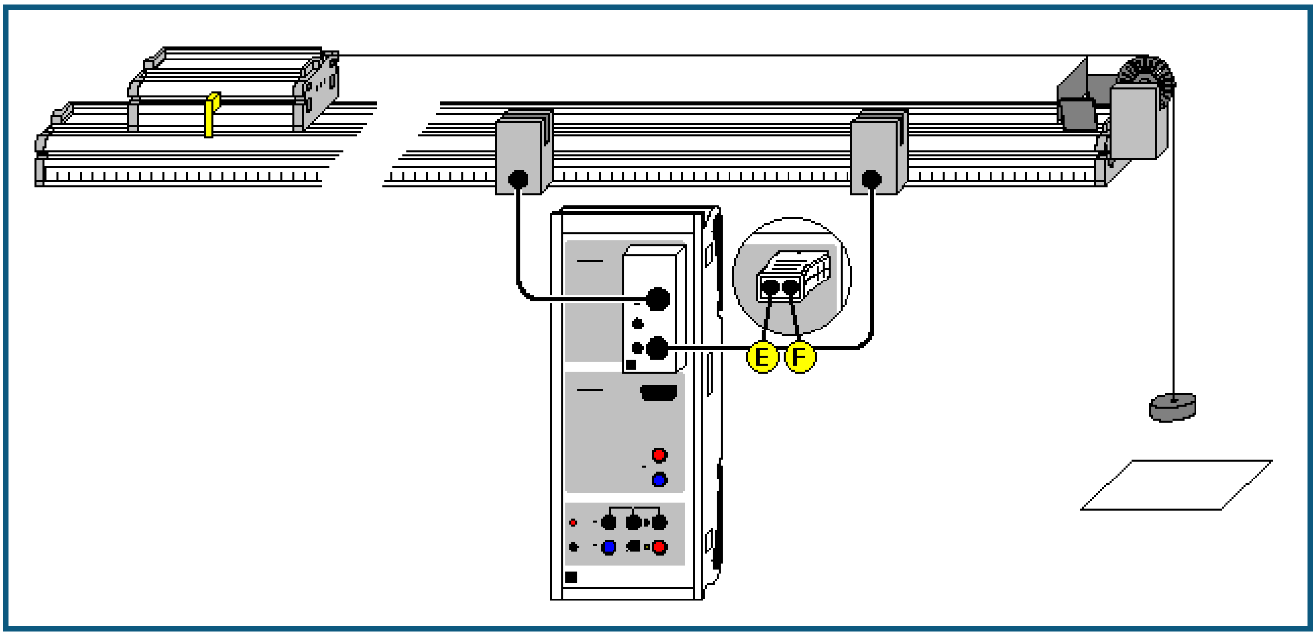
## Solid State Physics

| | |
|---|---|
| P7.2.2.1-2 | Electrical conduction in solid bodies |
| P7.3.2.1 | Hysteresis of a transformer core |
| P7.5.1.1 | Non-destructive analysis of the chemical composition (x-ray fluorescence) |
| P7.5.1.2 | Determination of the chemical composition of a brass sample (x-ray fluorescence) |

## Uniform motions between two light barriers



can also be carried out with Pocket-CASSY

### Experiment description

This experiment measures the times t that a trolley requires to travel different distances (paths) s between two light barriers with a constant velocity v. The path s is read directly from a scale on the track and the s(t) diagram is generated.

Additionally, the software calculates the average velocities $v_m$ = s/t and shows these in a $v_m$(t) diagram.

### Equipment list

| | | |
|---|---|---|
| 1 | Sensor-CASSY | 524 010 or 524 013 |
| 1 | CASSY Lab 2 | 524 220 |
| 1 | Timer box or Timer S | 524 034 or 524 074 |
| 1 | Track | 337 130 |
| 1 | Trolley | 337 110 |
| 1 | Slotted mass hanger | 315 410 |
| 4 | Slotted weights | 315 418 |
| 2 | Combination light barriers | 337 462 |
| 1 | Holder for combination light barrier | 337 463 |
| 1 | Combination spoked wheel | 337 464 |
| 1 | Fishing line | from 309 48ET2 |
| 2 | Multi-core cables, 6-pole, 1.5 m | 501 16 |
| 1 | PC with Windows XP/Vista/7 | |

### Experiment setup (see drawing)

Set up the two light barriers on the track so that the interrupter flag of the trolley breaks both beams. Connect the light barriers to inputs E and F of the timer box at input A of Sensor-CASSY. The direction of motion must always be from the light barrier at E to the one at F.

To achieve a constant velocity between the two light barriers, compensate the friction by inclining the track slightly.

Before each measurement the trolley must be accelerated to a constant, reproducible velocity. To this end, it is accelerated from a fixed position by a drive weight which is trapped at the end of a defined acceleration path (e.g. comes to rest on a supporting surface). The trolley continues to roll with a constant velocity.

### Carrying out the experiment

Load settings

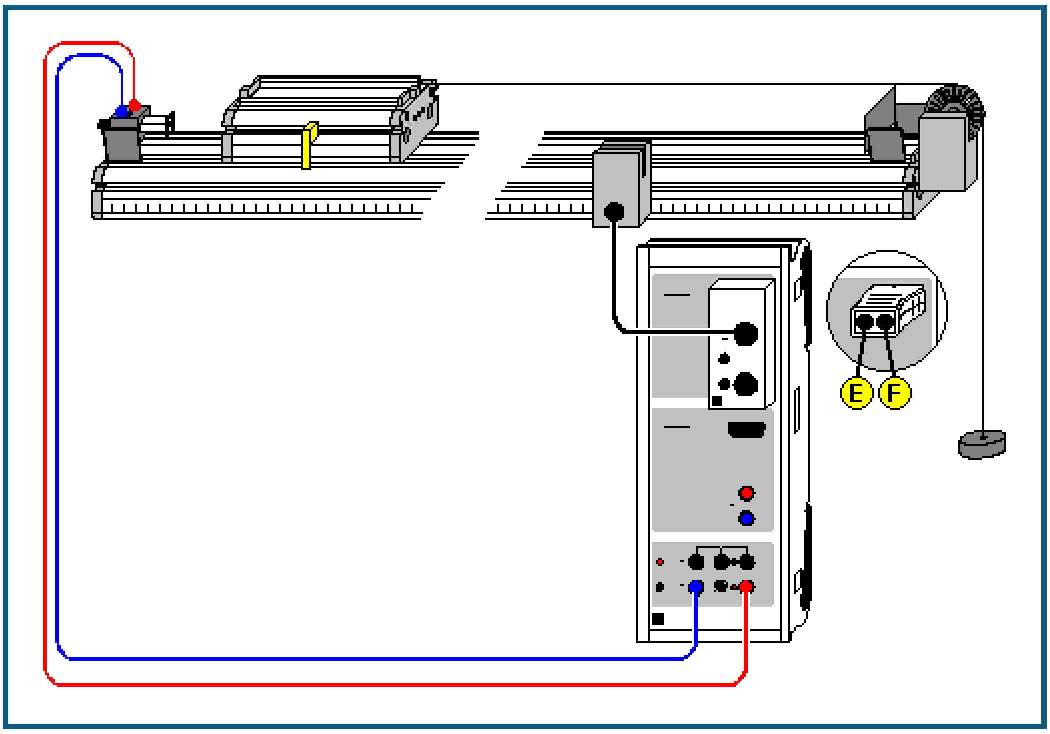
- Accelerate the trolley to a constant speed as described above and allow it to pass through both light barriers.

- Save your measured value with ⏱.
- Read off path s between the two light barriers and enter this in the table (activate keyboard input in the correct table cell using the mouse).
- Repeat the measurement for other paths s; again, accelerate the trolley to the same velocity, let it pass both light barriers and save the measured value with ⏱.

### Evaluation

The s(t) diagram of a uniform motion is a straight line. The slope of the straight line corresponds to the velocity v and can be determined e.g. by fitting a straight line. If you click on the display **Average Velocity**, you can also read off the respective quotients $v_m = s/t$ directly.

## Accelerated motions between holding magnet and light barrier



### Experiment description

This experiment measures the times t that a uniformly accelerated trolley requires to travel different distances (paths) s between a holding magnet and a light barrier. The path s is read directly from a scale on the track and the s(t) diagram is generated.

Additionally, the software calculates the average velocities $v_m$ = s/t and shows these in a $v_m$(t) diagram.

The obscuration times Γt of the light barrier, which are caused by a flag having the width Γs, are also determined. This permits determination of the instantaneous velocities v = Γs/Γt at the site of the light barrier within close approximation and their display in a v(t) diagram. The difference between the average velocity and instantaneous velocity becomes easily recognizable.

### Equipment list

| | | |
|---|---|---|
| 1 | Sensor-CASSY | 524 010 or 524 013 |
| 1 | CASSY Lab 2 | 524 220 |
| 1 | Timer box or Timer S | 524 034 or 524 074 |
| 1 | Track | 337 130 |
| 1 | Trolley | 337 110 |
| 1 | Slotted mass hanger | 315 410 |
| 4 | Slotted weights | 315 418 |
| 1 | Holding magnet | 683 41 |
| 1 | Combination light barrier | 337 462 |
| 1 | Holder for combination light barrier | 337 463 |
| 1 | Combination spoked wheel | 337 464 |
| 1 | Fishing line | from 309 48ET2 |
| 1 | Multi-core cable, 6-pole | 501 16 |
| 1 | Pair of cables, 100 cm, red and blue | 501 46 |
| 1 | PC with Windows XP/Vista/7 | |

### Experiment setup (see drawing)

Set up the light barrier on the track so that the interrupter flag of the trolley breaks the beam. Connect the light barrier to input E of the timer box at input A of Sensor-CASSY. The holding magnet receives its voltage supply from voltage output S of Sensor-CASSY. Sensor-CASSY de-energizes this output simultaneously with the start of time measurement.

To achieve good measuring results, compensate the friction by inclining the track slightly.

Accelerate the trolley over the spoked wheel using a constant mass. Adjust the holding-magnet voltage so that it just holds the trolley.

## Carrying out the experiment

■ Load settings
- You may need to adjust the maximum measuring time in the Measuring Parameters dialog (current setting: 2 s).
- Hold the trolley in place with the holding magnet.
- Start the measurement with ⏱ (trolley starts to move).
- Read off path s between the holding magnet and the light barrier and enter this in the table (activate keyboard input in the correct table cell using the mouse).
- Repeat the measurement for other paths s; fix the trolley in place using the holding magnet and start the measurement with ⏱.

## Evaluation

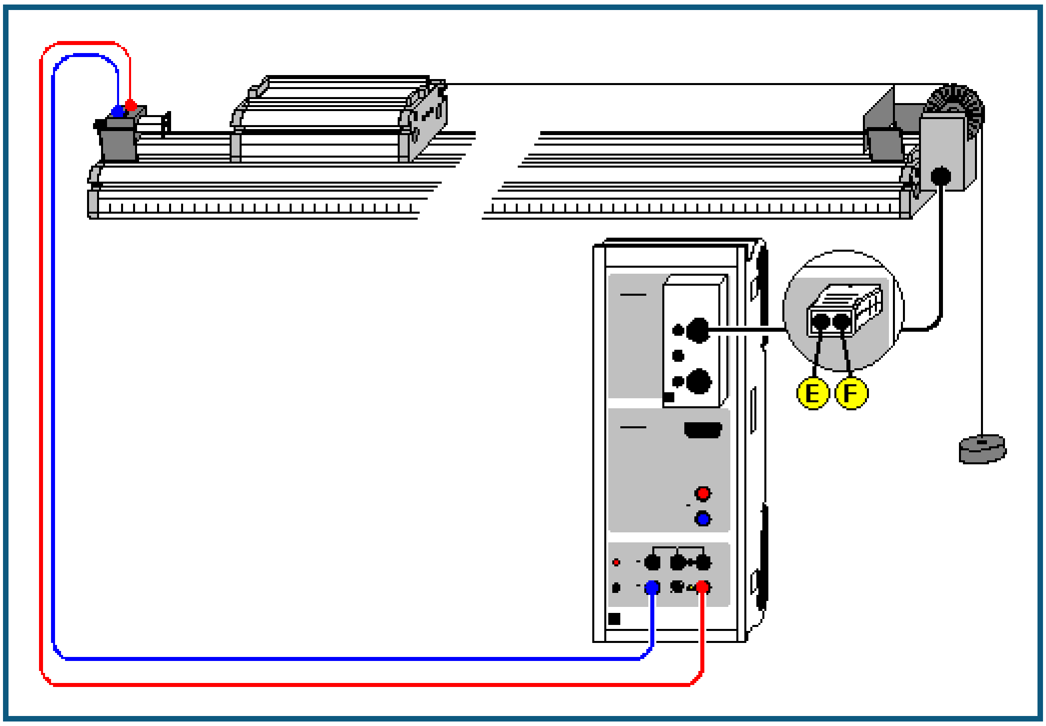
The s(t) diagram of a uniformly accelerated motion is a parabola. You can confirm this e.g. by fitting a parabola.

Click on the display **Average Velocity** to see the rise in the average velocities $v_m$ = s/t. However, for an accelerated motion these do **not** correspond with the instantaneous velocities at the same times t.

The instantaneous velocities v can be determined to within a close approximation from the obscuration times Γt of the light barrier interrupted by the flag with the width Γs. Both the curves of the obscuration times and the instantaneous velocities over time can be read directly from the corresponding displays, simply by clicking on the appropriate tab.

It is apparent that the v(t) diagram of a uniformly accelerated motion is a straight line. The slope of the straight line corresponds to the acceleration a and can be determined e.g. by fitting a straight line.

## Motions with spoked wheel (Newton definition)



### Experiment description

This experiment investigates motion sequences that are transmitted to a spoked wheel by means of a thin cord. The spoked wheel serves as an easy-running deflection pulley, and at the same time enables path measurement. The signals generated by the spoked wheel in the light barrier are recorded and converted into a path-time diagram. As this diagram is generated in real time while the experiment is running, the relationship between the motion and the diagram is extremely clear.

The same experiment sequence can also be used to demonstrate the effect of acceleration of a mass m = 1 kg with a force F = 1 N. The resulting acceleration a is then determined to be $a = 1\ m/s^2$ (newton definition) as theory predicts.

### Equipment list

| | | |
|---|---|---|
| 1 | Sensor-CASSY | 524 010 or 524 013 |
| 1 | CASSY Lab 2 | 524 220 |
| 1 | Timer box or Timer S | 524 034 or 524 074 |
| 1 | Track | 337 130 |
| 1 | Trolley | 337 110 |
| 1 | Newton weights | 337 115 |
| 1 | Holding magnet | 683 41 |
| 1 | Combination light barrier | 337 462 |
| 1 | Combination spoked wheel | 337 464 |
| 1 | Fishing line | from 309 48ET2 |
| 1 | Multi-core cable, 6-pole | 501 16 |
| 1 | Pair of cables, 100 cm, red and blue | 501 46 |
| 1 | PC with Windows XP/Vista/7 | |

### Experiment setup (see drawing)

The combination spoked wheel serves simultaneously as the deflection pulley and the signal generator. Here, the combination light barrier, which is connected to input E of the timer box at input A of Sensor-CASSY, holds the spoked wheel. Each spoke interrupts the light barrier, so that a signal is sent to Sensor-CASSY for every centimeter. The holding magnet receives its voltage supply from voltage output S of Sensor-CASSY. Sensor-CASSY de-energizes this output simultaneously with the start of time measurement.

To obtain an accelerating force of F = 1 N, you need to use a driving mass of 102 g. The trolley (including the equivalent roller mass) must be augmented to a total mass of 898 g so that the total accelerated mass m = 1 kg. This is possible using the additional weights for Newton definition.

To achieve good measuring results, compensate the friction by inclining the track slightly.

Adjust the holding-magnet voltage so that it just holds the trolley.

### Carrying out the experiment

☐ Load settings

- You may want to modify the automatic measuring stop parameter in Settings sA1 (current setting 70 edges for 0.7 m).
- You may need to adjust the maximum measuring time in the Measuring Parameters dialog (current setting: 2 s).
- Hold the trolley in place with the holding magnet.
- Define the path zero point (→ **0** ← in Settings sA1)
- Start the measurement with ⏱ (trolley starts to move).
- The measurement stops automatically after the predefined number of edges.
- If desired, repeat the measurement for other forces F; fix the trolley in place using the holding magnet, define the path zero point and start the measurement with ⏱.

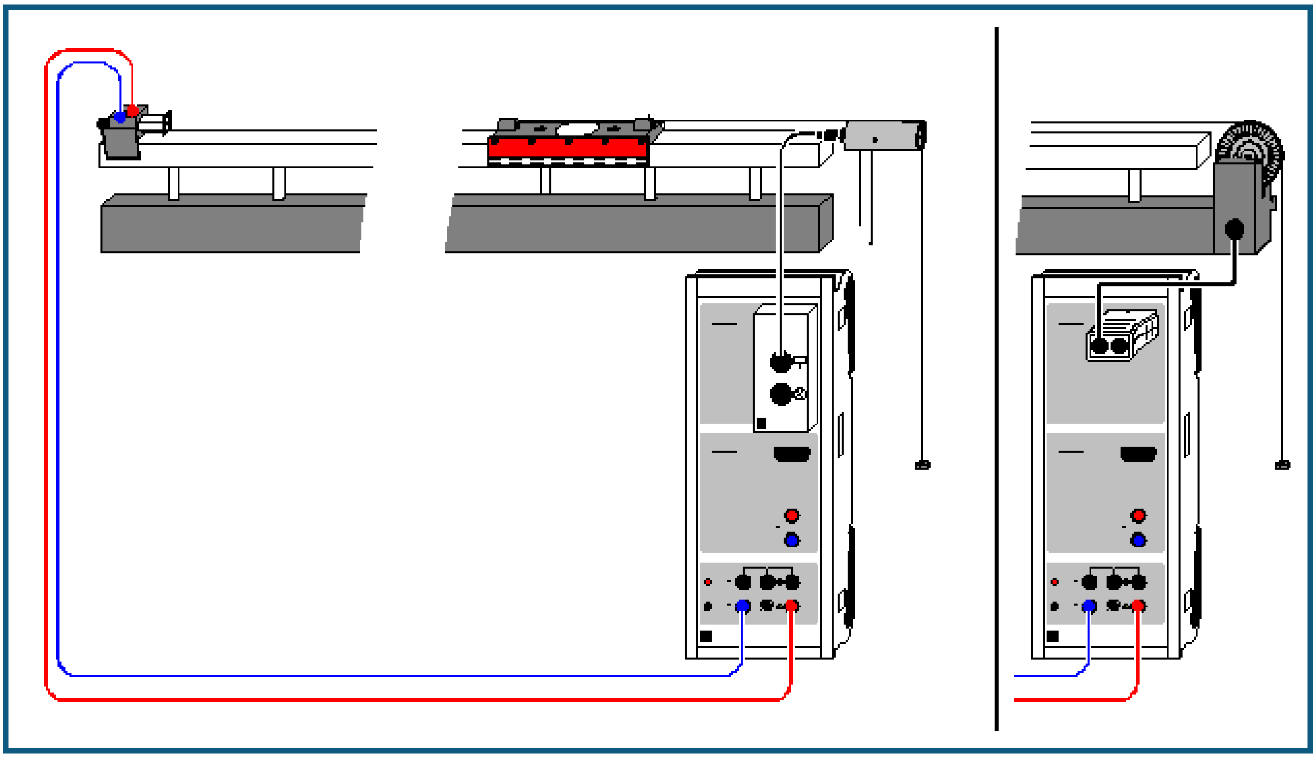
### Evaluation

The s(t) diagram of a uniformly accelerated motion is a parabola. You can confirm this e.g. by fitting a parabola.

Clicking on the **Velocity** display shows the calculated velocities v(t). It is apparent that the v(t) diagram of a uniformly accelerated motion is a straight line. The slope of the straight line is the constant acceleration a and can be determined e.g. by fitting a straight line.

In this example the accelerating force used is F = 1 N and the accelerating mass m = 1 kg (Newton definition). In this case the v(t) diagram gives us of velocity v of 1 m/s after t = 1 s. Also, the straight line in the f(t) diagram has the slope a = 1 m/$s^2$.

## Motions on the linear air track (Newton's equation of motion)



### Experiment description

A trolley with a constant mass m is accelerated with different forces F. When the accelerations a determined in the experiment are plotted as a function of the accelerating forces F, F is found to be proportional to a (with m as the proportionality factor), thus confirming Newton's equation of motion $F=m\cdot a$.

Alternatively, the accelerating force can also be kept constant and the mass m can be varied. The result here is m proportional to 1/a (with F as the proportionality factor).

### Equipment list

| | | |
|---|---|---|
| 1 | Sensor-CASSY | 524 010 or 524 013 |
| 1 | CASSY Lab 2 | 524 220 |
| 1 | BMW box | 524 032 |
| 1 | Motion sensing element | 337 631 |
| | or | |
| 1 | Timer S | 524 074 |
| 1 | Combination light barrier | 337 462 |
| 1 | Combination spoked wheel | 337 464 |
| 1 | Linear air track | 337 501 |
| 1 | Air supply | 337 53 |
| 1 | Power controller | 667 823 |
| 1 | Multi-core cable, 6-pole | 501 16 |
| 1 | Pair of cables, 100 cm, red and blue | 501 46 |
| 1 | PC with Windows XP/Vista/7 | |

### Experiment setup (see drawing)

First put the linear air track into operation; adjust the holding-magnet voltage so that it just holds the trolley. The trolley is accelerated by means of weights suspended from the transmission cord. The transmission cord passes around the motion sensing element, which is connected to the top socket of the BMW box on Sensor-CASSY.

The small weights are also accelerated, and thus are considered part of the accelerated mass m. If the mass is to be kept constant, then the weights not suspended from the cord must be placed on the trolley.

## Carrying out the experiment

■ Load settings

- Enter the maximum travel path $s_{A1}$ as the stop condition in the Measuring Parameters (**Window → Show Measuring Parameters**); current setting: **sA1 > 0.8** for 0.8 m
- You may want to modify the time interval (currently 200 ms) in the Measuring Parameters window; a longer interval means fewer measured values and less scattering in a(t).
- You may need to invert the sign of path measurement (**s** ↔ **-s** in Settings sA1).
- Hold the trolley in place with the holding magnet.
- Define the path zero point (→ **0** ← in Settings sA1)
- Start the measurement with ⏱. You can delete a faulty measurement series from the table with Measurement → Delete Current Measurement Series.
- Repeat the measurement with different parameters (different accelerating force or accelerated mass). Be sure to redefine the path zero point.

## Evaluation

In addition to the s(t) diagrams, the software also calculates the v(t) and a(t) diagrams. You can see these simply by clicking on the tabs of the other displays. Suitable evaluation functions include parabola and line fits and calculation of mean value.

To confirm Newton's equation of motion, you need to fill out a further table, which has already been prepared on the Newton display tab. After determining an acceleration value as the mean of an a(t) diagram or the slope of a v(t) diagram, you can use the mouse to drag this value from the status line and drop it into the table (drag & drop). Enter the parameter force F or mass m directly via the keyboard. The desired diagram is generated as you enter the values. You can easily convert or rescale the axes by clicking on them (e.g. a → 1/a).

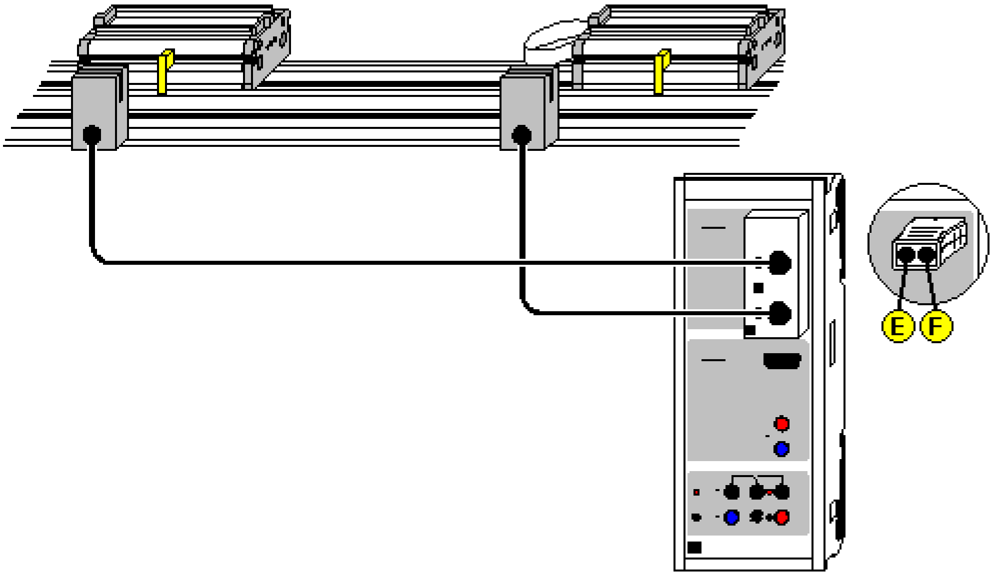
As a further evaluation, you can e.g. compare the kinetic energy with the work performed using formulas. The kinetic energy is

E = **0.5*m*v^2** (type in the numerical value for m)

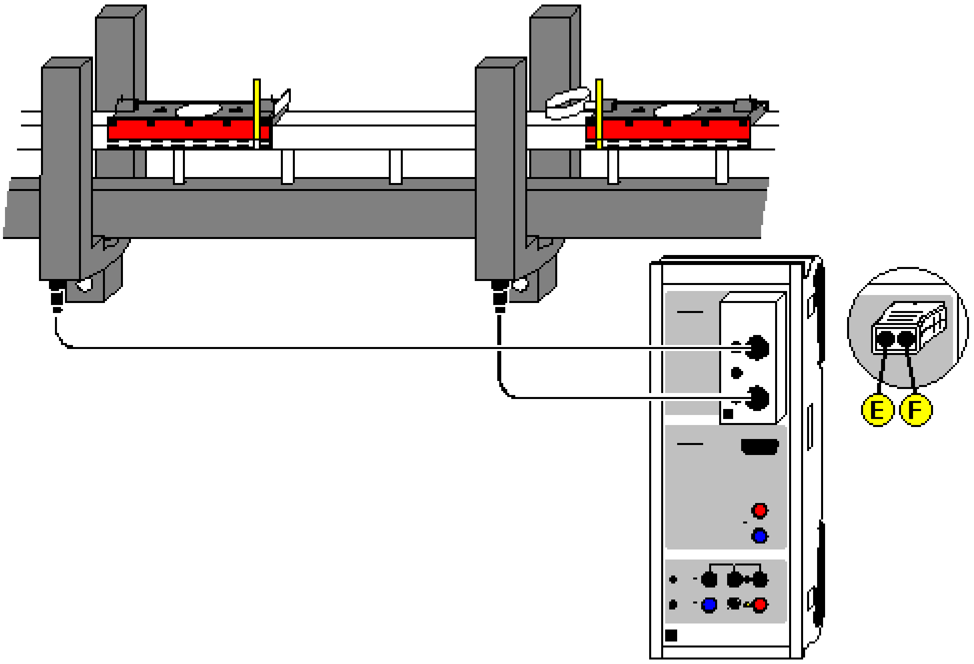
and the work performed is

W = **F*sA1** (type in the numerical value for F).

## Conservation of momentum and energy (collision)



Alternatively (with linear air track):



can also be carried out with Pocket-CASSY

### Experiment description

On a track, the velocities v of two trolleys before and after their collisions can be measured from the obscuration times of two light barriers. By this means, it is possible to verify the law of conservation of momentum for elastic and inelastic collision, as well as that of conservation of energy for elastic collision.

## Equipment list

| | | |
|---|---|---|
| 1 | Sensor-CASSY | 524 010 or 524 013 |
| 1 | CASSY Lab 2 | 524 220 |
| 1 | Timer box or Timer S | 524 034 or 524 074 |
| 1 | Track | 337 130 |
| 2 | Trolleys | 337 110 |
| 1 | Pair of additional weights | 337 114 |
| 1 | Impact spring for trolley | 337 112 |
| 2 | Combination light barriers | 337 462 |
| 2 | Multi-core cables, 6-pole, 1.5 m | 501 16 |
| 1 | PC with Windows XP/Vista/7 | |

## Alternatively (with linear air track)

| | | |
|---|---|---|
| 1 | Sensor-CASSY | 524 010 or 524 013 |
| 1 | CASSY Lab 2 | 524 220 |
| 1 | Timer box or Timer S | 524 034 or 524 074 |
| 1 | Linear air track | 337 501 |
| 1 | Track support | 337 45 |
| 1 | Air supply | 337 53 |
| 1 | Power controller | 667 823 |
| 2 | Forked light barriers | 337 46 |
| 2 | Multi-core cables, 6-pole, 1.5 m | 501 16 |
| 1 | PC with Windows XP/Vista/7 | |

## Experiment setup (see drawing)

First put the track into operation and position the two light barriers (at inputs E and F of the timer box) so that the trolleys collide **between** the light barriers. The flags of the two trolleys must interrupt the light barriers when they pass through.

## Carrying out the experiment

▢ Load settings

- Enter masses m$_1$ and m$_2$ in the table (activate keyboard input in the cells beneath m$_1$ and m$_2$ with the mouse).
- Enter the trolley arrangement before collision in relation to light barriers E and F (Settings v1, v2, v1' or v2'). There are four different arrangements:
  Both trolleys outside of light barriers.
  Left trolley between light barriers, right trolley outside.
  Right trolley between light barriers, left trolley outside.
  Both trolleys inside (explosion).
- Enter the flag width (also in Settings v1, v2, v1' or v2').
- Initiate the collision (if velocities are displayed before the collision, you can clear these with **→ 0 ←**) and watch to make sure that the light barriers do not register any extra pulses (e.g. due to reflection of a trolley at the end of the track).
- Terminate the measurement with **End of Collision** (the measurement is terminated automatically after four measured velocities).
- Transfer the measured values to the table for evaluation with ⏱ or initialize the next measurement with **→ 0 ←**.

## Evaluation

Tables have been pre-defined for momentum before and after collision, total momentum, energy, total energy and energy loss; you can transfer measured values to these tables with ⏱. Click on the table tabs to display these. If you want these quantities to be visible immediately after collision, open the corresponding display instruments.

You can also define additional formulas to compare your results with theory. For elastic collision, we say that

v1' = (2*m2*v2 + (m1-m2)*v1) / (m1+m2)
v2' = (2*m1*v1 + (m2-m1)*v2) / (m1+m2)

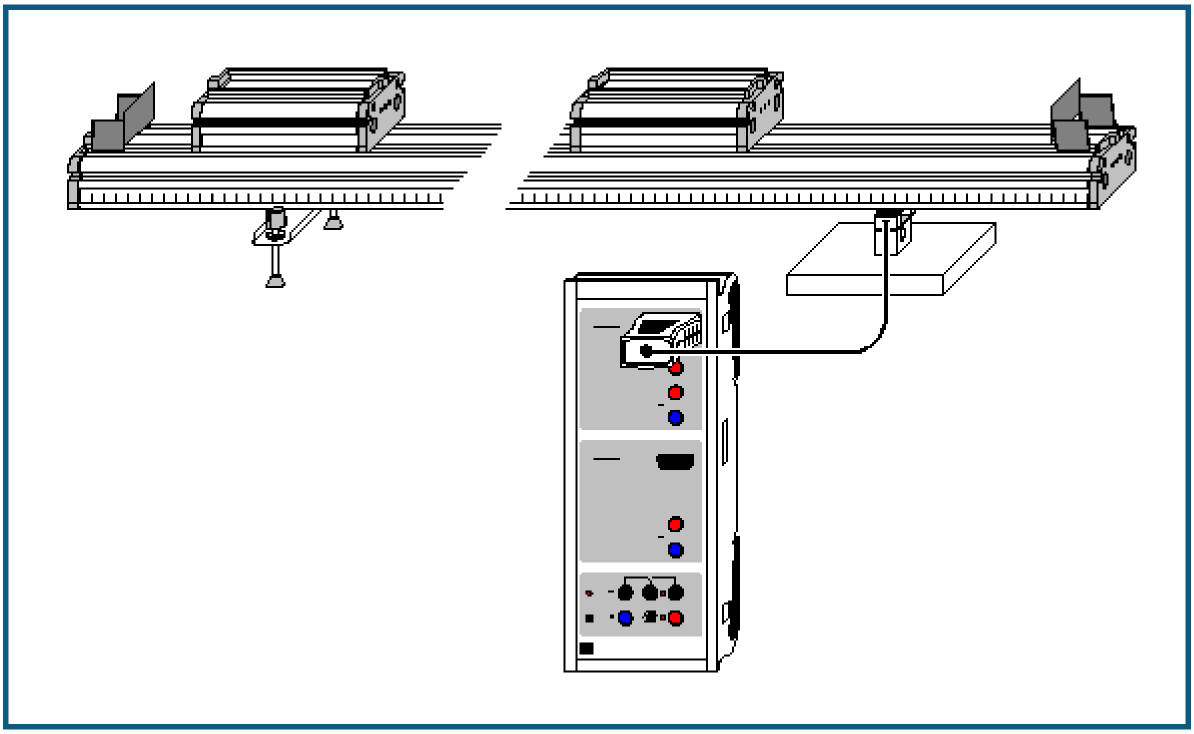
For inelastic collision, the following applies:

v1' = v2' = (m1*v1 + m2*v2) / (m1+m2).

### Table for converting specified units to SI units

| Quantity | SI unit = | Factor | · specified unit |
|---|---|---|---|
| Mass m | kg | 1 | kg |
| Velocity v | m/s | 1 | m/s |
| Momentum p | N·s = kg·m/s | 1000 | mN·s |
| Energy E | J = kg·$m^2/s^2$ | 1000 | mJ |

## Conservation of linear momentum by measuring the motion of the centre of mass (collision)



can also be carried out with Pocket-CASSY

### Experiment description

The motion of the centre of mass is observed during elastic and inelastic collision of two trolleys. As a result, it is shown for both cases that the velocity of the centre of mass is constant during the whole collision process. Conservation of linear momentum during the whole collision process is an immediate consequence of this experiment.

### Principle of measurement

On a track the motion of the centre of mass s of two colliding trolleys with masses $m_1$ and $m_2$ is easily determined by the supporting force F on a force sensor.

For, if the sum of torques M around the left supporting point is considered, this sum has to be 0 - as the track is at rest -, i.e.

$m_1 \cdot g \cdot s_1 + m_2 \cdot g \cdot s_2 + F \cdot d = 0$,

where d is the distance between the two supporting points. The centre of mass s is given by

$s = (m_1 \cdot s_1 + m_2 \cdot s_2) / (m_1+m_2)$.

From this

$s \cdot g/(m_1+m_2) + F \cdot d = 0$

or

$s = -F \cdot d/(m_1+m_2)/g$ is obtained.

Thus measurement of the supporting force F is sufficient, to determine the motion of the centre of mass during a collision. If s(t) is a straight line, this means that the centre of mass moves at a constant velocity v, i.e.

$v = (m_1 \cdot v_1 + m_2 \cdot v_2) / (m_1+m_2) = p / (m_1+m_2) = \text{constant}$.

It follows that the total linear momentum p is conserved.

### Equipment list

| | | |
|---|---|---|
| 1 | Sensor-CASSY | 524 010 or 524 013 |
| 1 | CASSY Lab 2 | 524 220 |
| 1 | Force sensor S, ±50 N | 524 042 |
| 1 | Track | 337 130 |
| 2 | Trolleys | 337 110 |
| 1 | Pair of additional weights | 337 114 |
| 1 | Impact spring | 337 112 |
| 1 | PC with Windows XP/Vista/7 | |

### Experiment setup (see drawing)

The force sensor S is laid under the track instead of the right support so that the track is still aligned horizontally or, if desired, so that compensation of friction is ensured. As the force sensor is somewhat shorter than the support, the force sensor has to be bedded.

### Carrying out the experiment

■ Load settings

- Enter the masses $m_1$ and $m_2$ and the distance d between the two support points into the display instruments (click with the right mouse button and enter them as parameters). The total mass of a trolley is the sum of the mass of the trolley (0.5 kg) and, if present, the spring (0.01 kg) and an additional weight (0.5 kg).
- Set the force to → **0** ← in Settings FA1; thereby the centre of mass s is set to 0 as well.
- Start the measurement with ⏱.
- Make an elastic or inelastic collision; the measurement is stopped automatically after 5 s.

### Evaluation

The display **Standard** shows the F(t) diagram, and the display **Centre of mass** shows the associated s(t) diagram (see Principle of measurement).

Both diagrams exhibit a linear course, also while the collision occurs. From the s(t) diagram the velocity v of the centre of mass and thus the constant total linear momentum $p(t) = (m_1+m_2)\cdot v$ is obtained by a linear fit.

On the other hand, it follows from conservation of linear momentum that

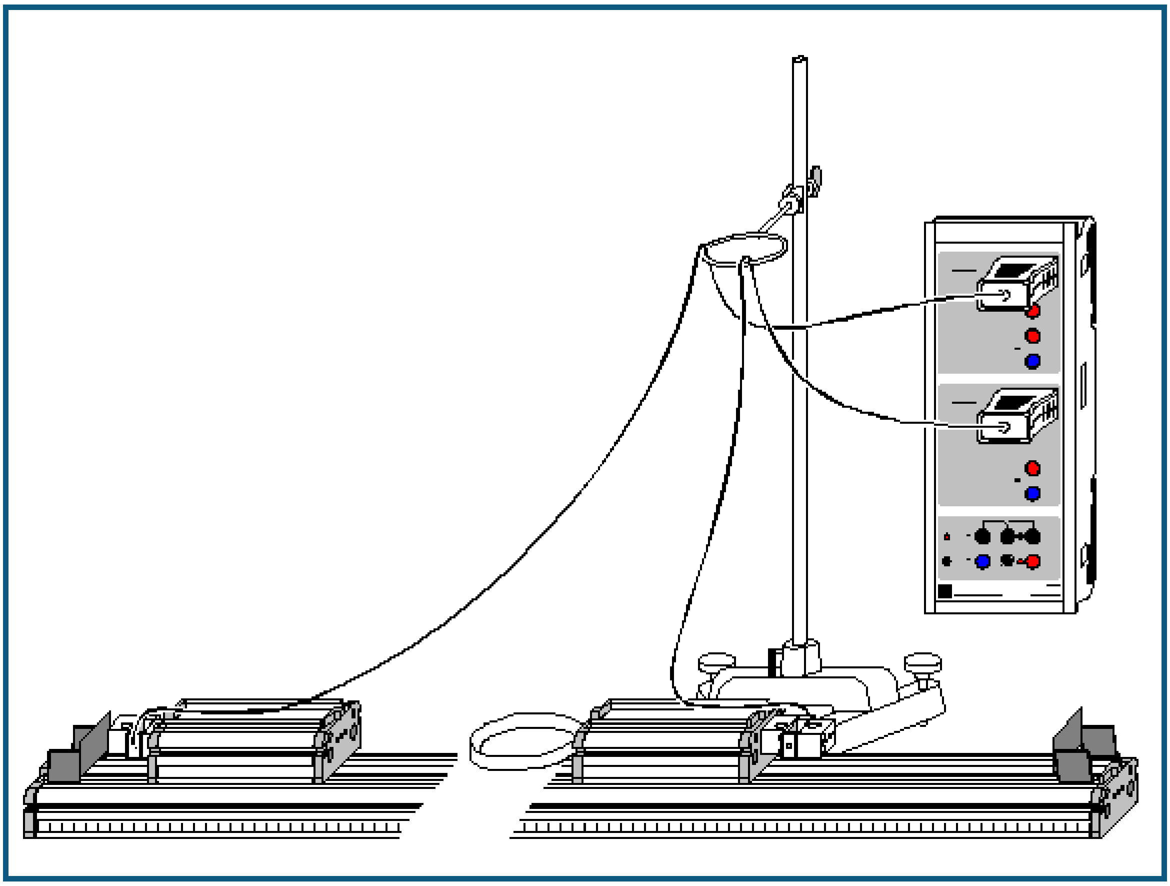
$$0 = d/dt\ (p_1(t) + p_2(t)) = m_1\cdot a_1(t) + m_2\cdot a_2(t) = F_1(t) + F_2(t),$$

i.e.

$$F_1(t) = -F_2(t) \quad \text{("Action = Reaction").}$$

The conclusion relies on the fact that p(t) is a constant, particularly during the collision process. The mere fact that the total linear momentum before and after the collision is the same (e.g. by measurement with light barriers) does not justify the conclusion.

## Confirming the relation action=reaction by measuring accelerations (collision)



can also be carried out with Pocket-CASSY

### Experiment description

During an elastic collision the accelerations $a_1(t)$ and $a_2(t)$ of the two trolleys are measured. If the measured accelerations are multiplied by the masses $m_1$ and $m_2$, the forces $F_1(t)$ and $F_2(t)$ are obtained. The relation $F_1(t) = -F_2(t)$ is confirmed for the time interval during which the collision takes place.

### Principle of measurement

If a force sensor with mass m is attached to a trolley so that that half of the sensor to which the lead is fixed is firmly mounted to the trolley, the other half of mass m/2 hangs in the air and is movable. If the trolley then is accelerated, this mass exerts the force of inertia $F=m\cdot a/2$. This force is measured by the force sensor and automatically converted into the acceleration a.

After the two accelerated masses (trolley + force sensor + spring) have been entered, the software computes the two forces $F_1(t) = m_1\cdot a_1(t)$ and $F_2(t) = m_2\cdot a_2(t)$.

### Equipment list

| | | |
|---|---|---|
| 1 | Sensor-CASSY | 524 010 or 524 013 |
| 1 | CASSY Lab 2 | 524 220 |
| 2 | Force sensors S, ±50 N | 524 042 |
| 4 | Coupling plugs | from 340 89ET5 |
| 1 | Track | 337 130 |
| 2 | Trolleys | 337 110 |
| 1 | Pair of additional weights | 337 114 |
| 1 | Large impact spring | 337 473 |
| 1 | Stand base, V-shape, 20 cm | 300 02 |
| 1 | Stand rod, 1 m | 300 44 |
| 1 | Clamp with ring | 301 10 |
| 1 | PC with Windows XP/Vista/7 | |

## Experiment setup (see drawing)

Attach the two force sensors to the outside of the trolleys with 2 coupling plugs each so that the leads are fixed relative to the trolleys and not to the movable halves of the force sensors. Lock the leads so that they do not move within the force sensors during the collision (e.g. stick them to the trolleys with adhesive tape). In addition, guide the leads so that they do not hinder the trolleys during the collision.

The collision is intercepted by the large impact spring, which is attached to the inside of one of the trolleys. The large impact spring has been proposed deliberately because it leads to a longer collision time so that more measured values can be recorded. However, the spring is relatively soft and should not be overloaded in the collision process.

## Carrying out the experiment

■ Load settings

- Enter the masses $m_1$ and $m_2$ into the display instruments (click with the right mouse button and enter them as parameters). The total mass of a trolley is the sum of the mass of the trolley (0.5 kg), of the force sensor (0.1 kg) and, if present, the mass of the spring (0.01 kg) and an additional mass (0.5 kg).
- Set the acceleration to → **0** ← in Settings aA1 and aB1.
- Start the measurement with ⏱.
- Perform an elastic collision; the measurement is stopped automatically after 5 s.

## Evaluation

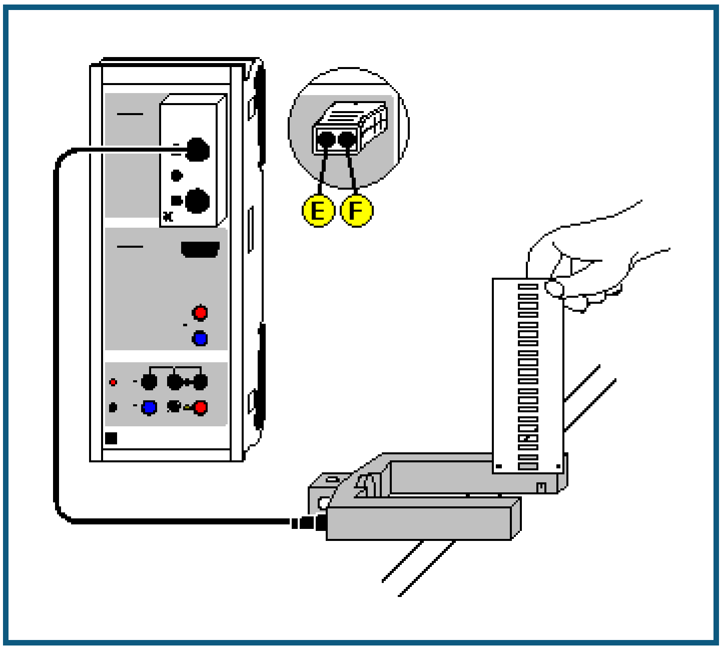
The display **Standard** shows the two a(t) diagrams and the display **Force** the associated F(t) diagrams (see principle of measurement).

In the F(t) diagrams it is easy to see that

$F_1(t) = -F_2(t)$     ("Action = Reaction").

From this conservation of linear momentum can be inferred immediately as the integrals over both curves (momentum transfers) between arbitrary times $t_1$ and $t_2$ always have the same magnitude and opposite signs.

## Free fall with g-ladder



can also be carried out with Pocket-CASSY

### Experiment description

When a ladder falls through a light barrier, the software registers the times of the obscurations of the light barrier caused by the rungs of the ladder. The known rung spacing together with the time information gives us the s(t) diagram of the fall. This is then used to calculate the v(t) and the a(t) diagram. Each of the three diagrams can be used to determine the gravitational acceleration g.

### Equipment list

| | | |
|---|---|---|
| 1 | Sensor-CASSY | 524 010 or 524 013 |
| 1 | CASSY Lab 2 | 524 220 |
| 1 | Timer box or Timer S | 524 034 or 524 074 |
| 1 | g-ladder | 529 034 |
| 1 | Forked light barrier | 337 46 |
| 1 | Multi-core cable, 6-pole | 501 16 |
| 1 | Set of weights, 50 g, optional | 342 61 |
| 1 | PC with Windows XP/Vista/7 | |

### Experiment setup (see drawing)

Suspend or hold the g-ladder above the light barrier so that its rungs interrupt the light beam when falling. The light barrier is connected to Sensor-CASSY via input E of the timer box. The independence of gravitational acceleration from mass can be verified by suspending weights from the ladder. Moreover, the aerodynamic drag of the g-ladder can be increased or decreased by sticking small wings or transparent plastic sheets to it.

### Carrying out the experiment

☐ Load settings

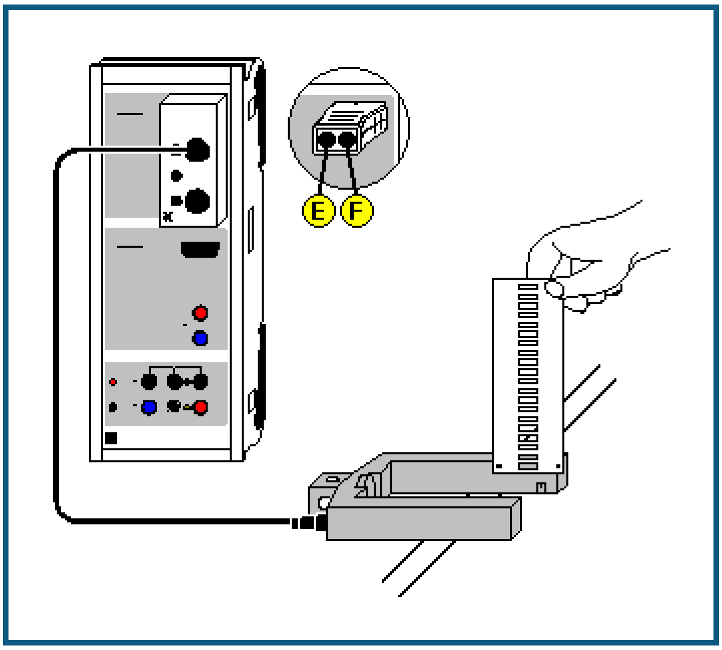
- Start the measurement with ⏱.
- Allow the ladder to fall through the light barrier so that all 21 rungs pass the beam.
- The measurement stops automatically 0.2 seconds after detection of the first rung, or after 21 rungs. You can delete a faulty measurement series from the table with Measurement → Delete Current Measurement Series.
- You can repeat the measurement with different masses or falling heights. Simply restart it with ⏱.

### Evaluation

This example contains prepared display tabs for path s(t), velocity v(t) and acceleration a(t) which can be accessed by clicking on them. The gravitational acceleration g can be determined in the s(t) diagram by fitting a parabola, in the v(t) diagram by fitting a straight line and in the a(t) diagram by finding the mean value. You can enlarge display of the numerical values of the evaluation shown in the status line with ▭.

As the ladder had an initial velocity when the light barrier was interrupted by the first rung, the peak of the s(t) parabola is not visible, and the v(t) straight line does not pass through the origin. However, to better illustrate the matter, you can move e.g. the t and s axes with the mouse so that after fitting a parabola its peak is also visible.

## Free fall with g-ladder (with modeling)



can also be carried out with Pocket-CASSY

### Experiment description

When a ladder falls through a light barrier, the software registers the times of the obscurations of the light barrier caused by the rungs of the ladder. The known rung spacing together with the time information gives us the s(t) diagram of the fall.

As a supplement to the previous experiment, the measured motion is now compared with the motion described by the equation

$s'' = a = g$.

### Equipment list

| | | |
|---|---|---|
| 1 | Sensor-CASSY | 524 010 or 524 013 |
| 1 | CASSY Lab 2 | 524 220 |
| 1 | Timer box or Timer S | 524 034 or 524 074 |
| 1 | g-ladder | 529 034 |
| 1 | Forked light barrier | 337 46 |
| 1 | Multi-core cable, 6-pole | 501 16 |
| 1 | Set of weights, 50 g, optional | 342 61 |
| 1 | PC with Windows XP/Vista/7 | |

### Experiment setup (see drawing)

Suspend or hold the g-ladder above the light barrier so that its rungs interrupt the light beam when falling. The light barrier is connected to Sensor-CASSY via input E of the timer box.

### Carrying out the experiment

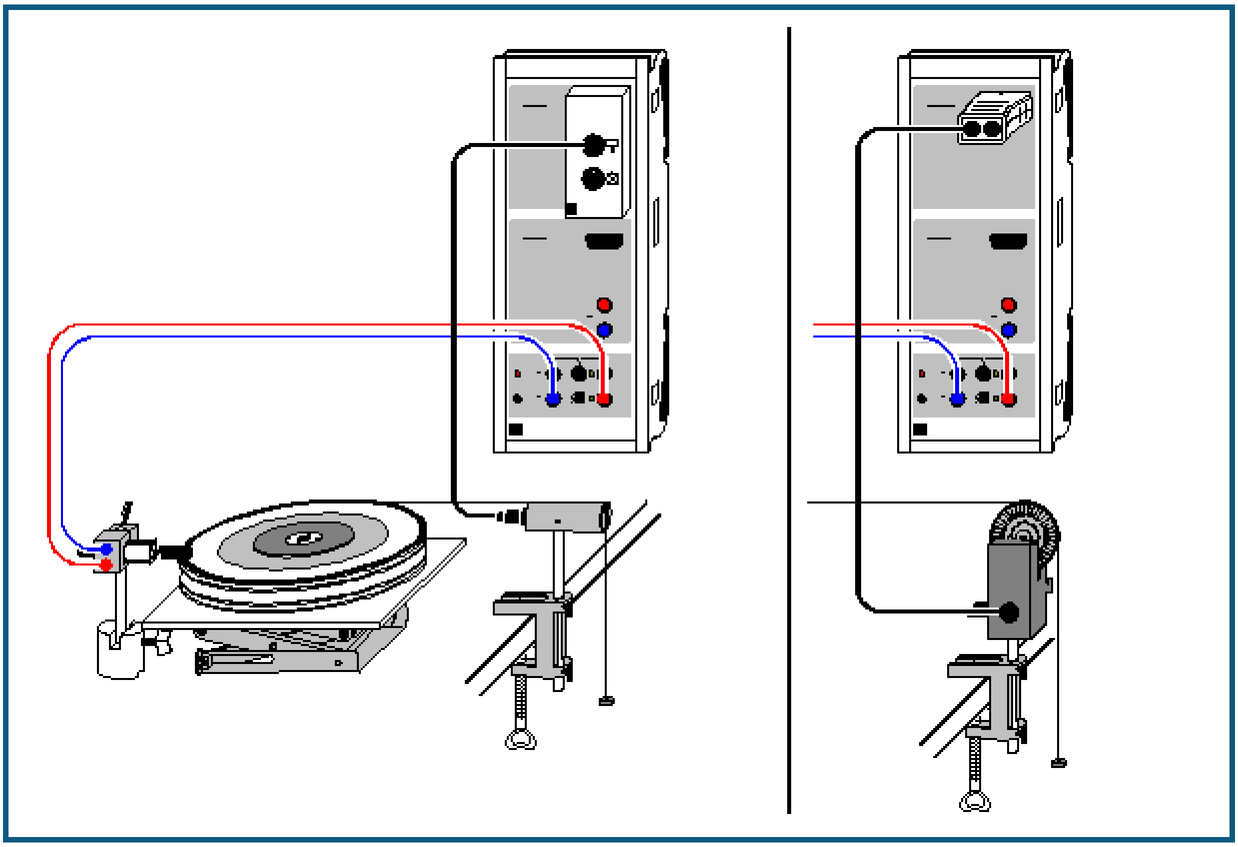
☐ Load settings

- Start the measurement with ⏱.
- Allow the ladder to fall through the light barrier so that all 21 rungs pass the beam.
- The measurement stops automatically 0.2 seconds after detection of the first rung, or after 21 rungs. You can delete a faulty measurement series from the table with Measurement → Delete Current Measurement Series.
- You can repeat the measurement with different masses or falling heights. Simply restart it with ⏱.

### Modeling

In the present example, the two initial conditions $s(t=0)=0$ and $v(t=0)=v_0$ and the acceleration $g=9.81\ m/s^2$ were chosen, whereby g and $v_0$ can be altered by dragging the pointer of the corresponding display instrument (or by clicking to the left or to the right of the pointer) until the model agrees with the measurement.

## Rotational motions (Newton's equation of motion)



### Experiment description

A rotating body with a constant moment of inertia J is accelerated with different torque values. When the angular accelerations α determined are plotted as a function of the accelerating torques M, M is found to be proportional to α (with J as the proportionality factor), thus confirming Newton's equation of motion M=J· α.

Alternatively, you can keep the accelerating torque M constant and vary the moment of inertia J. The result here is J proportional to 1/α (with M as the proportionality factor).

### Equipment list

| | | |
|---|---|---|
| 1 | Sensor-CASSY | 524 010 or 524 013 |
| 1 | CASSY Lab 2 | 524 220 |
| | | |
| 1 | BMW box | 524 032 |
| 1 | Motion sensing element | 337 631 |
| | or | |
| 1 | Timer S | 524 074 |
| 1 | Combination light barrier | 337 462 |
| 1 | Combination spoked wheel | 337 464 |
| | | |
| 1 | Rotation model | 347 23 |
| 1 | Multi-core cable, 6-pole | 501 16 |
| 1 | Holding magnet | 336 21 |
| 1 | Stand rod, 25 cm | 300 41 |
| 1 | Saddle base | 300 11 |
| 1 | Bench clamp, simple | 301 07 |
| 1 | Laboratory stand II | 300 76 |
| 1 | Pair of cables, 100 cm, red and blue | 501 46 |
| 1 | Paper clip | |
| 1 | PC with Windows XP/Vista/7 | |

## Experiment setup (see drawing)

Tie the transmission thread to the flag of the rotation model (r = 10 cm) or to one of the pins of the extra disk (r = 5 cm, 2.5 cm) and run it over the motion sensing element, which is connected to Sensor-CASSY via the top socket of the BMW box. The holding magnet prevents the start of rotation when it is placed close to the paper clip attached to the flag of the rotation model.

The accelerating force is generated e.g. by 3 small suspended weights of 1 g each (F = 0.0294 N). The different torques at a constant moment of inertia are realized using the different pulley radii (M = r·F = 2.94 mNm, 1.47 mNm, 0.73 mNm). Alternatively, you can realize different moments of inertia for a constant torque using extra disks.

## Carrying out the experiment

☐ Load settings

- Modify the maximum rolling angle $\beta_{A1}$ in the stop condition of the Measuring Parameters (**Window → Show Measuring Parameters**); current setting: **&bA1 > 6** for 6 radii, &b stands for β)
- You may want to modify the time interval (currently 500 ms) in the Measuring Parameters window; a longer interval means fewer measured values and less scattering in α(t).
- You may need to invert the sign of angular measurement (**s** ↔ **-s** in Settings βA1).
- Allow the rotating disk to fall from the holding magnet.
- Define the current rolling radius and the path zero point (both in Settings βA1)
- Start the measurement with ⏱. You can delete a faulty measurement series from the table with Measurement → Delete Current Measurement Series.
- Repeat the measurement with different parameters (different accelerating torque or accelerated moment of inertia). Be sure to redefine the rolling radius and path zero point.

## Evaluation

In addition to the β(t) diagrams, the software also calculates the φ(t) and α(t) diagrams. You can see these simply by clicking on the tabs of the other displays. Suitable evaluation functions include parabola and line fits and calculation of mean value.

To confirm Newton's equation of motion, you need to fill out a further table, which has already been prepared on the Newton display tab. After determining an angular acceleration value as the mean of an α(t) diagram or the slope of an φ(t) diagram, you can use the mouse to drag this value from the status line and drop it into the table (drag & drop). As the parameter, enter the parameter angular momentum M or moment of inertia directly via the keyboard. The desired diagram is generated as you enter the values. You can easily convert or rescale the axes by clicking on them with the right mouse button (e.g. α → 1/α).

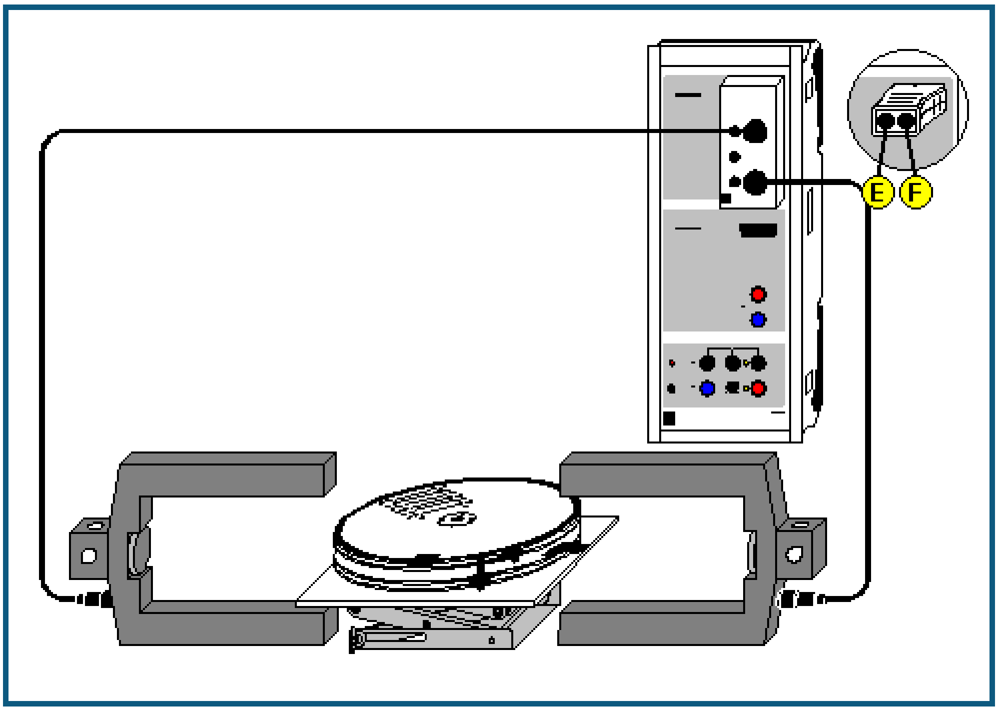
As a further evaluation, you can e.g. compare the rotational energy with the work performed using formulas. The rotational energy is

E = **0.5*J*&w^2** (enter the numerical value for J, &w stands for φ)

and the work performed is

W = **M*&bA1** (enter the numerical value for M, &b stands for β).

## Conservation of angular momentum and energy (torsion collision)



can also be carried out with Pocket-CASSY

### Experiment description

With the rotation model, the angular velocities φ of two bodies before and after their collisions can be measured from the obscuration times of two light barriers. By this means, it is possible to verify the law of conservation of angular momentum for elastic and inelastic torsion collision, as well as that of conservation of energy for elastic torsion collision.

### Equipment list

| | | |
|---|---|---|
| 1 | Sensor-CASSY | 524 010 or 524 013 |
| 1 | CASSY Lab 2 | 524 220 |
| 1 | Timer box or Timer S | 524 034 or 524 074 |
| 1 | Rotation model | 347 23 |
| 2 | Forked light barriers | 337 46 |
| 2 | Multi-core cables, 6-pole, 1.5 m | 501 16 |
| 1 | Laboratory stand II | 300 76 |
| 1 | PC with Windows XP/Vista/7 | |

### Experiment setup (see drawing)

First position the rotation model and the two light barriers (connected to inputs E and F of the timer box) so that the flags of the rotating bodies are **between** the light barriers when torsion collision occurs. The flags of the two bodies must interrupt the light barriers when they pass through.

### Carrying out the experiment

☐ Load settings
- Enter the moments of inertia $J_1$ and $J_2$ in the table (activate keyboard input in the cells beneath $J_1$ and $J_2$ with the mouse).
- Enter the arrangement of the flags before collision in relation to light barriers E and F (Settings φ1, φ2, φ1' or φ2'). There are four different arrangements:
  Both flags outside of light barriers.
  Left flag between the light barriers, right flag outside.
  Left flag outside the light barriers, right flag between them.
  Both flags inside (explosion).
- Enter the flag width and radius (also in Settings φ1, φ2, φ1' or φ2').

- Initiate the collision (if angular velocities are displayed before the collision, you can clear these with **→ 0 ←**) and watch to make sure that the light barriers do not register any extra pulses (e.g. due to reflection of a rotating body).
- Terminate the measurement with **End of Collision** (the measurement is terminated automatically after four measured angular velocities).
- Transfer the measured values to the table for evaluation with ⏱ or initialize the next measurement with **→ 0 ←**.

### Evaluation

Tables have been pre-defined for angular momentum before and after collision, overall angular momentum, energy, total energy and energy loss; you can transfer measured values to these with ⏱. Click on the table tabs to display these. If you want these quantities to be visible immediately after collision, open the corresponding display instruments.

You can also define additional formulas to compare your results with theory. For elastic torsion collision, we say that

&w1' = (2*J2*&w2 + (J1-J2)*&w1) / (J1+J2)

&w2' = (2*J1*&w1 + (J2-J1)*&w2) / (J1+J2)

For inelastic torsion collision, the following applies:

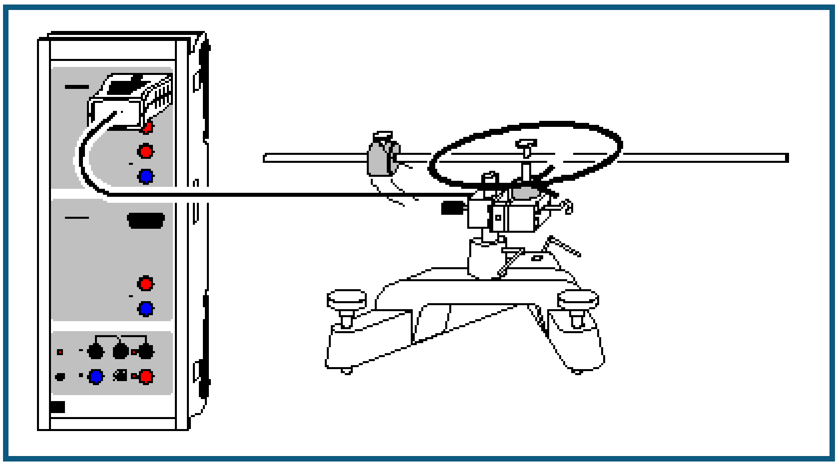
&w1' = &w2' = (J1*&w1 + J2*&w2) / (J1+J2).

In all formulas, the character combination & plus w is used to represent (and generate) the Greek φ.

### Table for converting specified units to SI units

| Quantity | SI unit = | Factor | · specified unit |
|---|---|---|---|
| Moment of inertia J | kg·m$^2$ | 1000 | g·m$^2$ |
| Angular velocity φ | rad/s | 1 | rad/s |
| Angular momentum L | N·s·m = kg·m$^2$/s | 1000 | mJ·s |
| Energy E | J = kg·m$^2$/s$^2$ | 1000 | mJ |

## Centrifugal force (rotable centrifugal force arm)



can also be carried out with Pocket-CASSY

### Experiment description

The centrifugal force F acting on a rotating mass m is described by $F = m\cdot\varphi^2\cdot r$ ($\varphi$: angular velocity, r: distance of the centre of mass from the axis of rotation). This law is confirmed by varying the three parameters m, $\varphi$ and r.

The centrifugal force F can be measured by means of the force sensor S, ±50 N. As the sensor almost exclusively measures forces in one direction, the measurement results in a sinusoidal shape of the force, the minima and maxima corresponding to the radial centrifugal force.

### Equipment list

| | | |
|---|---|---|
| 1 | Sensor-CASSY | 524 010 or 524 013 |
| 1 | CASSY Lab 2 | 524 220 |
| 1 | Force sensor S, ±50 N | 524 042 |
| 1 | Rotable centrifugal force arm | 347 211 |
| 1 | Stand base, V-shape, 28 cm | 300 01 |
| 1 | Stand rod, 10 cm | 300 40 |
| 1 | PC with Windows XP/Vista/7 | |

### Experiment setup (see drawing)

Use the stand rod to mount the force sensor horizontally as close as possible to the stand base. Tighten all screws firmly! Then align the stand base horizontally with the leveling screws so that the rotable centrifugal force arm swings as little as possible and rotates at a constant velocity even if the angular frequency is low.

### Carrying out the experiment

☐ Load settings

- Screw the weights at a certain distance (r is determined between the axis of rotation and the centre of the weight) onto the rotable arm.
- Set the force sensor to → **0** ← in Settings Force FA1.
- Make the rotable arm rotate by tapping it with your finger near the axis of rotation. When the force has reached about 5 N, start data recording with ⏱. Repeat the measurement every 5 to 10 s until the measured force has reached about 1 N. A set of sine curves is obtained with decreasing amplitudes and increasing periods. In the example the trigger is set so that all curves start in the coordinate origin.

### Evaluation

Determine the period T and the minimum and maximum force $F_{min}$ and $F_{max}$ of the first period for each sine curve by clicking with the mouse and reading the table values. Transfer these values into the display **Input** (mouse click). If there are inaccuracies in the setup or the zero adjustment of the force sensor, these are compensated by taking into account $F_{min}$ and $F_{max}$.

In the display **Centrifugal Force**, the result of this evaluation is plotted automatically. The centrifugal force $F = (F_{max}-F_{min})/2$ shown in the diagram and the angular velocity $\varphi=2\pi/T$ are calculated from the input values. The proportionality $F \propto \varphi^2$ is clearly seen.

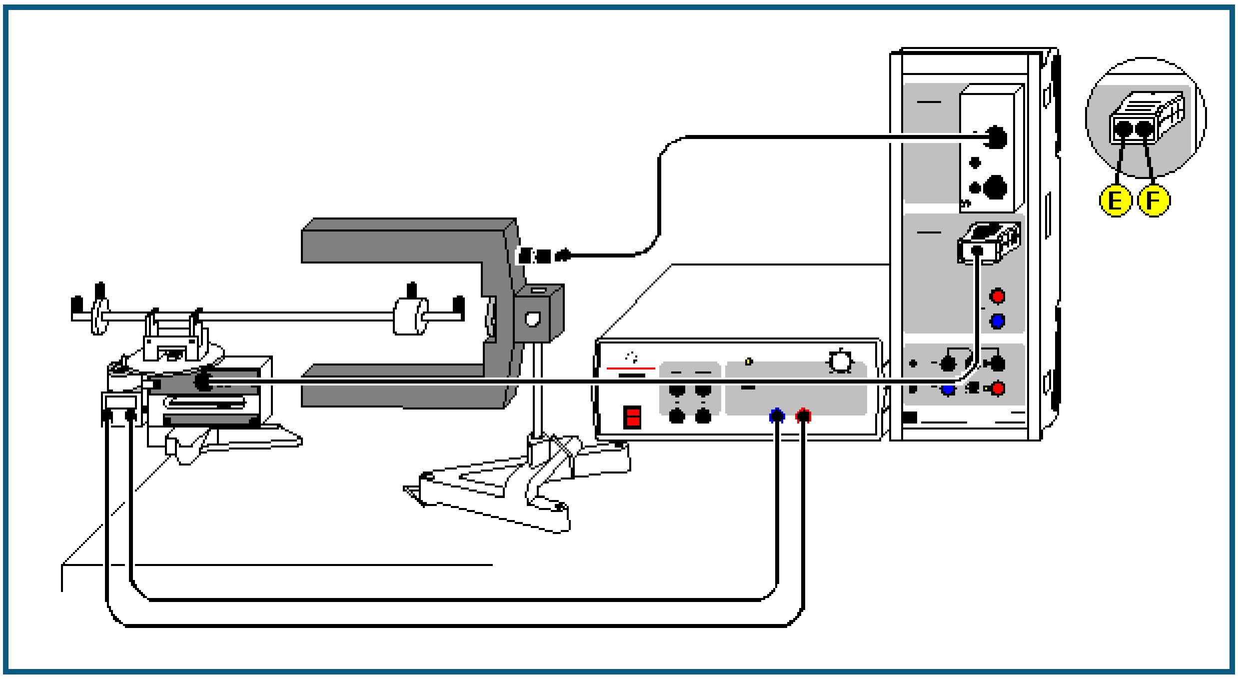
For confirming the proportionalities $F \propto m$ and $F \propto r$, the measurements have to be repeated with other weights and radii and then evaluated all together. It is recommendable to evaluate each measurement individually and to store it in a separate file because several measurements are confusing for an evaluation in a graphic representation. Afterwards several evaluated measurements can be loaded into a common display.

### Hint

As the experiment has to be repeated with other masses m and radii r for a complete evaluation, manual evaluation is very tedious. However, the period T and the two forces $F_{min}$ and $F_{max}$ can also be determined automatically. For this the display instruments T', $F'_{min}$, and $F'_{max}$ in the upper line have to be opened. Immediately after an individual measurement, the values calculated there can be shifted into the display **Input** with the mouse (drag & drop). As long as the rotable arm is still rotating and the measured force is greater than 1 N, this procedure is repeated for decreasing angular velocities φ in short intervals.

Alternatively, this evaluation can be made for each of the measurement series subsequently by selecting the measurement series via # Measurement → Select Measurement Series.

## Centrifugal force (centrifugal force apparatus)



can also be carried out with Pocket-CASSY

### Experiment description

The centrifugal force apparatus enables experimental investigation of the centrifugal force F as a function of the rotating mass m, the distance r of the mass from the centre of rotation and the angular velocity φ, thus making it possible to confirm the relation $F = m\cdot\varphi^2\cdot r$ for the centrifugal force.

In the centrifugal force apparatus, the force F acting on a rotating mass m is transmitted via a lever with ball-and-socket joint and a push pin in the axis of rotation to a leaf spring, whose deflection is measured electrically by means of a bridge-connected strain gauge. In the measuring range relevant for the experiment, the deformation of the leaf spring is elastic and thus proportional to the force F.

### Equipment list

| | | |
|---|---|---|
| 1 | Sensor-CASSY | 524 010 or 524 013 |
| 1 | CASSY Lab 2 | 524 220 |
| 1 | Timer box or Timer S | 524 034 or 524 074 |
| 1 | Centrifugal force apparatus S | 524 068 |
| 1 | Power supply | 521 49 |
| 1 | Forked light barrier | 337 46 |
| 1 | Multi-core cable, 6-pole | 501 16 |
| 1 | Bench clamp | 301 06 |
| 1 | Stand base, V-shape, 20 cm | 300 02 |
| 1 | Stand rod, 10 cm | 300 40 |
| 1 | Pair of cables, 50 cm, red and blue | 501 45 |
| 1 | PC with Windows XP/Vista/7 | |

If there are centrifugal force apparatus (347 21) available, they can be upgraded by means of the centrifugal force adapter (524 0681). Handling and measuring results of this combination do not differ from those of the centrifugal force apparatus S (524 068). Before the centrifugal force apparatus (347 21) is used with the centrifugal force adapter (524 0681) for the first time, the zero and the gain at the centrifugal force apparatus should once be readjusted according to the instruction sheet of the centrifugal force adapter.

### Experiment setup (see drawing)

Use the bench clamp to fix the centrifugal force apparatus to the table. The light barrier is set up by means of the stand rod and the stand base so that the rotating arm can freely rotate between the legs of the light barrier; the light beam should not be interrupted by the weight. The centrifugal force apparatus is connected to Input B and the light barrier via the 6-pole cable to the timer box at Input A of the Sensor-CASSY. The power supply is connected to the driving motor of the centrifugal force apparatus via two connecting leads. The maximum voltage for driving the motor should be selected so that the force measuring range does not exceed 15 N.

## Carrying out the experiment

■ Load settings

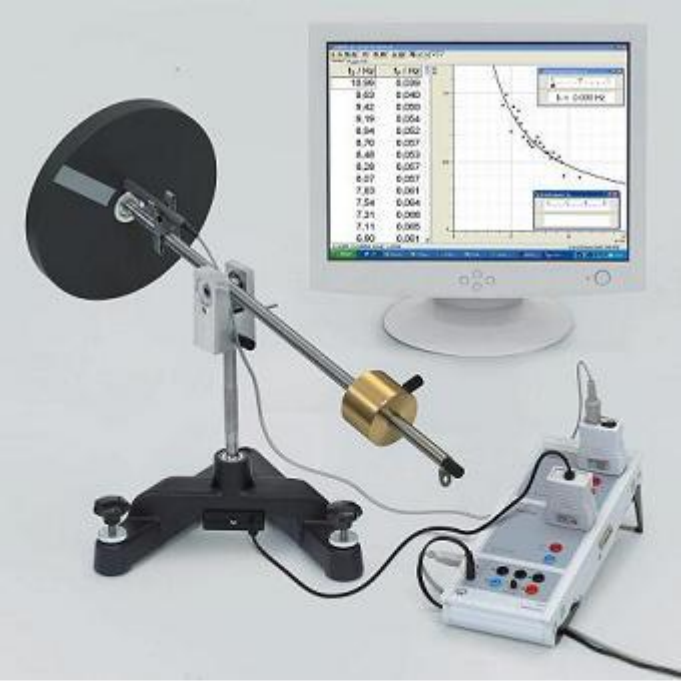
- Set the force display to 0 while the rotating arm is at rest. For this set the centrifugal force apparatus to → **0** ← in Settings Force FB1 (right mouse button).
- Adjust the compensating weight on the short arm of the apparatus so that no force F is measured when the measurement is made without additional weight m but with the safety screw.
- Starting with low angular velocities $\varphi$, store the measured force manually with ⏱ in the table.
- Repeat the measurement with higher angular velocities $\varphi$.
- After finishing a measurement series, repeat the measurements with other masses m (r=constant) or radii r (m = constant). For this select **Measurement → Append New Measurement Series** and restart at low angular velocities.

## Evaluation

Each individual measurement series immediately confirms the proportionality between the force F and $\varphi^2$ by a fit to a straight line. If you want to confirm the two other proportionalities between F and m ($\varphi$,r constant) and between F and r ($\varphi$,m constant), the forces F have to be determined for constant angular velocities $\varphi$. To do this, draw a vertical line at a value of $\varphi^2$ in the diagram and read the coordinates of the intersections with the $F(\varphi^2)$ line (switch the coordinate display on). Enter these coordinates manually into the prepared second display F(m) or F(r) (click the field in the table with the mouse). There the desired proportionality eventually shows up.

$F = m\cdot\varphi^2\cdot r$ is confirmed by determining the proportionality factors.

## Precession of a gyroscope



✓ can also be carried out with Pocket-CASSY

### Principle

In the experiment, the precession frequency $f_P$ of a gyroscope is investigated as a function of the exerted force F, i.e. the torque M = F · d and the rotational frequency $f_D$ of the gyroscope disk.

The following relationship applies:

$$f_P = \frac{1}{4\pi^2} \cdot \frac{M}{J_S} \cdot \frac{1}{f_D}$$

The moment of inertia of the gyroscope disk is given approximately by:

$$J_S = \frac{m}{2} \cdot r^2$$

### Experiment description

The precession frequency (frequency $f_{B1}$) is measured directly using the rotary motion sensor. The rotational frequency is determined by means of the reflection light barrier. To do this, the period $T_D$ of the rotational motion of the gyroscope disk is measured, and from this the rotational frequency $f_D = 1/T_D$ is calculated.

### Equipment list

| | | |
|---|---|---|
| 1 | Sensor-CASSY | 524 010 or 524 013 |
| 1 | CASSY Lab 2 | 524 220 |
| 1 | Rotary motion sensor S | 524 082 |
| 1 | Timer S | 524 074 |
| 1 | Reflection light barrier | 337 468 |
| 1 | Gyroscope | 348 20 |
| 1 | Double spring clip | 590 021 |
| 1 | Set of weights, each 50 g | 342 61 |
| 1 | PC with Windows XP/Vista/7 | |

### Experiment setup (see diagram)

- Attach the reflection light barrier by means of the spring clip approx. 1 cm in front of the gyroscope disk. The supply cable is to be laid in such a way that it does not exert any forces on the gyroscope and so that the gyroscope can rotate freely for at least one turn.

- Fit the rotary motion sensor onto the gyroscope axis from below and fix it with the thumb screw.
- Shift the balancing mass so that the gyroscope is balancing, i.e. it is initially free of forces. Then hang a weight (50 g) on the end of the gyroscope rod on the same side as the balancing mass.
- The gyroscope should be precisely horizontally aligned above the adjustment screws on the foot.

## Carrying out the experiment

☐ Load settings

- Testing of the correct adjustment of the reflection light barrier
  Start the gyroscope disk by hand. The rotational frequency (approx. 1 Hz) should be displayed. If necessary, move the reflection light barrier slightly.
- Test of the correct adjustment of the rotary motion sensor
  Rotate the gyroscope slowly about its vertical axis, the precession frequency (approx. 0.05 Hz) should be displayed after a short time.
- Start the gyroscope disk rotating rapidly by means of a piece of string. The maximum rotational frequency is approx. 10 Hz.
- Allow the gyroscope to precess and - once the gyroscope precesses uniformly - take a measurement by means of ⏱.
  The precession motion must not be overlaid by the nutation movement. The precession of the gyroscope is best obtained by starting up the gyroscope without nutation. Rotate the gyroscope back and start precession repeatedly for decreasing rotational frequencies and make measurements. If necessary, the gyroscope disk may be braked somewhat.
- Repeat the experiment with two suspended weights (100 g).

## Evaluation

In the diagram of the dependency of the precession frequency $f_P$ on the rotational frequency $f_D$ a hyperbola is found, or, in the diagram of $f_P$ plotted against $1/f_D$ a straight line, i.e. $f_P \propto 1/f_D$. The gradient of the straight line is the proportionality factor

$$\frac{m_2 \cdot g \cdot d}{4\pi^2 \cdot J_S},$$

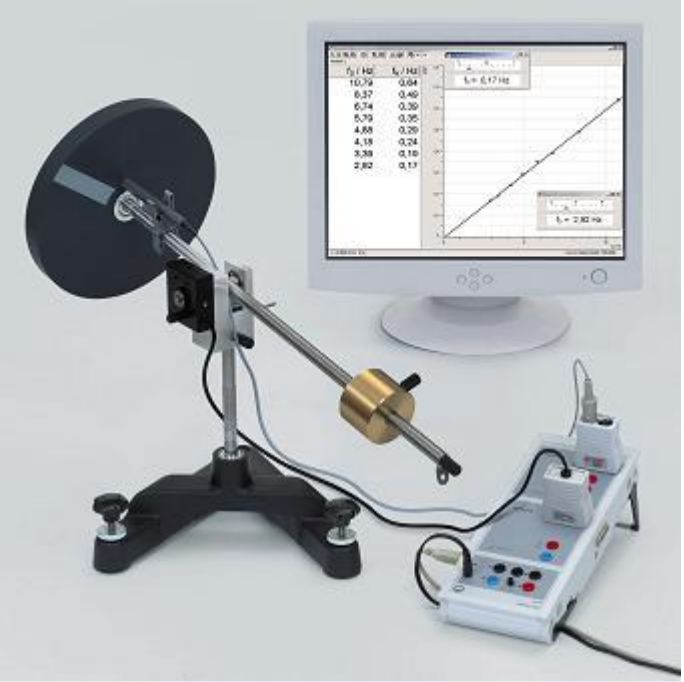
for the example with one weight 0.45, with two weights 0.91.

With the estimated moment of inertia (with the simplifying assumption of an homogeneous and point mass)

$J_S = ½m \cdot r^2 \approx 0.010\ \text{kg} \cdot \text{m}^2$ (with m = 1.54 kg, r = 11.5 cm)

results, with a single weight ($m_2$ = 50 g), in a proportionality factor of 0.43 or with two weights ($m_2$ = 0.1 kg) of 0.86.

## Gyroscope nutation



can also be carried out with Pocket-CASSY

### Principle

In the experiment, the nutation frequency $f_N$ of a free gyroscope as a function of the rotational frequency $f_D$ for the gyroscope disk is being investigated.

The relationship $f_D = J_S/J_K \cdot f_N$ applies

with $J_S = ½m \cdot r^2$: moment of inertia of the gyroscope disk about its rotational axis
and $J_K$: moment of inertia of the gyroscope about the gyroscope axis (point of suspension)

The moment of inertia of the gyroscope $J_K$ is essentially the combination of the moments of inertia of the gyroscope rod $J_1$, the gyroscope disk $J_2$ and the balancing mass $J_3$ about the rotational axis.

For $J_1$, with the help of the parallel axes theorem: $J_1 = m_{St}/12 \cdot l^2 + m_{St} \cdot s^2$, applies,

with l: rod length, $m_{St}$: rod mass, s: distance of the gyroscope axis from the center of gravity (centre) of the rod.

For $J_2$: $J_2 = m_{KS} \cdot a_{KS}^2$ applies,

with $m_{KS}$: mass of the gyroscope disk, $a_{KS}$: distance from the gyroscope axis.

$J_3$ is calculated similarly (with $m_{AM}$: balancing mass).

### Experiment description

The nutation frequency is determined by means of a rotary motion sensor which is fitted to the gyroscope axis. In addition, the time of oscillation $T_N$ of the vertical component of the nutation motion of the gyroscope is measured, and from this the nutation frequency $f_N = 1/T_N$ is calculated. The rotational frequency is determined by means of the reflection light barrier. To do this, the period $T_D$ of the rotational motion of the gyroscope disk is measured, and from this the rotational frequency $f_D = 1/T_D$ is calculated.

### Equipment list

| | | |
|---|---|---|
| 1 | Sensor-CASSY | 524 010 or 524 013 |
| 1 | CASSY Lab 2 | 524 220 |
| 1 | Rotary motion sensor S | 524 082 |
| 1 | Timer S | 524 074 |
| 1 | Reflection light barrier | 337 468 |
| 1 | Gyroscope | 348 20 |

| | | |
|---|---|---|
| 1 | Double spring clip | 590 021 |
| 1 | PC with Windows XP/Vista/7 | |

### Experiment setup (see diagram)

- Attach the reflection light barrier by means of the spring clip approx. 1 cm in front of the gyroscope disk.
- Fit the rotary motion sensor from below onto the gyroscope axis and fix with the thumb screw.
- The supply cable is to be laid in such a way that it does not exert any forces on the gyroscope and so that the gyroscope can rotate freely for at least one turn.
- Shift the balancing mass so that the gyroscope is balancing, i.e. it is free of forces.

### Carrying out the experiment

■ Load settings

- Testing of the correct adjustment of the reflection light barrier
  Start the gyroscope disk by hand. The rotational frequency (approx. 1 Hz) should be displayed). If necessary, move the reflection light barrier slightly.
- Test of the correct adjustment of the rotary motion sensor
  Move the gyroscope uniformly up and down about its axis. The nutation frequency should be displayed (approx. 1 Hz).
- Start the gyroscope disk rotating rapidly by means of a piece of string. The maximum rotational frequency is approx. 10 Hz.
- Start the gyroscope nutation by gently pushing it.
- Record the measured value with ⏱.
- Start up nutation repeatedly for slowly decreasing rotational frequencies and make measurements. If necessary, the gyroscope disk may be braked somewhat.

### Evaluation

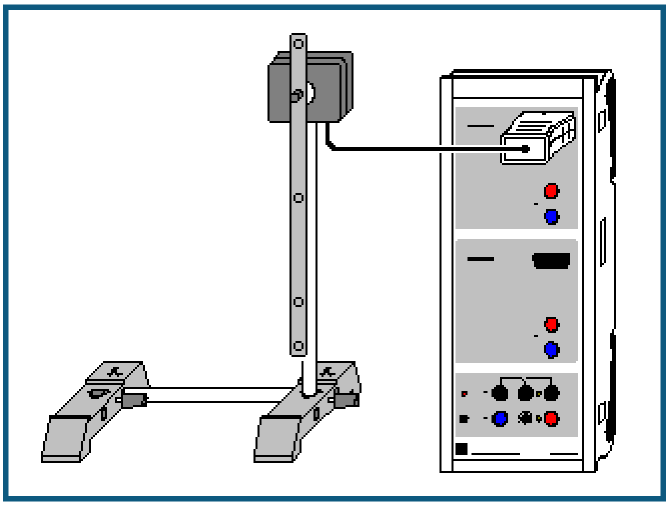
In the diagram of the nutation frequency $f_N$ as a function of the rotational frequency $f_D$ a straight line appears, i.e. $f_N \propto f_D$. The gradient of the straight line is the proportionality factor $J_S/J_K$; in the example $J_S/J_K = 0.0659$.

With the estimated moment of inertia (with the simplifying assumption of an homogeneous and point mass)

$J_S = ½m·r^2 \approx 0.010\ kg·m^2$ (with $m = 1.54$ kg, $r = 11.5$ cm)
$J_1 = m_{St}/12 · l^2 + m_{St} · s^2 \approx 0.056\ kg·m^2$ (with $m_{St} = 0.50$ kg, $l = 57$ cm, $s = 6.6$ cm)
$J_2 = m_{KS} · a_{KS}^2 \approx 0.056\ kg·m^2$ (with $m_{KS} = 1.54$ kg, $a_{KS} = 19$ cm)
$J_3 = m_{AM} · a_{AM}^2 \approx 0.063\ kg·m^2$ (with $m_{AM} = 1$ kg, $a_{AM} = 25$ cm)
$J_K = J_1 + J_2 + J_3 \approx 0{,}136\ kg·m^2$

results in $J_S/J_K \approx 0.074$.

## Oscillations of a rod pendulum



✓ can also be carried out with Pocket-CASSY

### Experiment description

The equation of motion for a physical pendulum with moment of inertia J, mass m and distance s between fulcrum and centre of gravity

$M = J\cdot\alpha'' = -m\cdot g\cdot s\cdot\sin\alpha$

describes for small deflections ($\sin\alpha\approx\alpha$) an harmonic oscillation with period of oscillation

$T = 2\pi\cdot\text{sqrt}(J/mgs)$.

For a better understanding, the reduced pendulum length $l_r = J/ms$ is introduced. Then the period of oscillation is

$T = 2\pi\cdot\text{sqrt}(l_r/g)$.

For mathematical pendulums, the entire pendulum mass is concentrated at a single point. It has therefore the moment of inertia $J = ms^2$ and the reduced pendulum length is $l_r = J/ms = s$, which is equivalent to the distance between the pendulum mass (centre of gravity) and fulcrum.

A physical pendulum with the reduced pendulum length $l_r$ corresponds to a mathematical pendulum of this length.

In this experiment the reduced pendulum length is determined from the measured period of oscillation and compared with the reduced pendulum length.

### Equipment list

| | | |
|---|---|---|
| 1 | Sensor-CASSY | 524 010 or 524 013 |
| 1 | CASSY Lab 2 | 524 220 |
| 1 | Rotary motion sensor S | 524 082 |
| 1 | Physical pendulum | 346 20 |
| 1 | Stand rod, 25 cm, d = 10 mm | 301 26 |
| 2 | Stand bases MF | 301 21 |
| 1 | PC with Windows XP/Vista/7 | |

### Experiment setup (see drawing)

The pendulum is screwed on the axle of the rotary motion sensor.

### Carrying out the experiment

☐ Load settings

- Define the zero point in the equilibrium position of the pendulum (→ **0** ← in Settings αA1)
- Deflect the pendulum by approx. 5° only and release
- Start the measurement with ⏱. The measurement will stop automatically after 10 s
- Repeat the measurement without the mass or with a further mass added

### Evaluation

After several oscillations, the duration of these oscillations can be determined by means of a vertical line and from this the period of oscillation. In the example, the result is $T = 0.840$ s. With $g = 9.81$ m/s$^2$ this results in a reduced pendulum length of $l_r = g \cdot T^2/4\pi^2 = 17.5$ cm.

This corresponds well to the calculated (using an approximation) pendulum length $l_r$ of the rod. The moment of inertia of the rod for rotation through the centre of gravity is $J_S = 1/12 \cdot ml^2$. The axis of rotation of this pendulum is, however, $s = 1/3 \cdot l$ displaced from the centre of gravity. According to Steiner's theorem this gives $J = J_S + ms^2 = 7/36\ ml^2$ and $lr = 7/36 \cdot ml^2 / ms = 7/12 \cdot l = 17.5$ cm (for $l = 30$ cm).

Conversely, from the calculated reduced pendulum length and the measured period of oscillation the earth's acceleration due to gravity can also be calculated $g = l_r \cdot 4\pi^2/T^2$ .

### Experimental determination of the reduced pendulum length

If mass $m_2$ is shifted on the pendulum rod until the period of oscillation T compared to the rod without added mass is unchanged, then the reduced pendulum length $l_r$ will also be unchanged. The position x when the (point) mass is now found increases the moment of inertia of the pendulum by $J_2 = m_2 \cdot x^2$. Because the reduced pendulum length $l_r$ has not been changed, the following applies

$l_r = J/ms = (J + J_2)/(m + m_2)/s'$

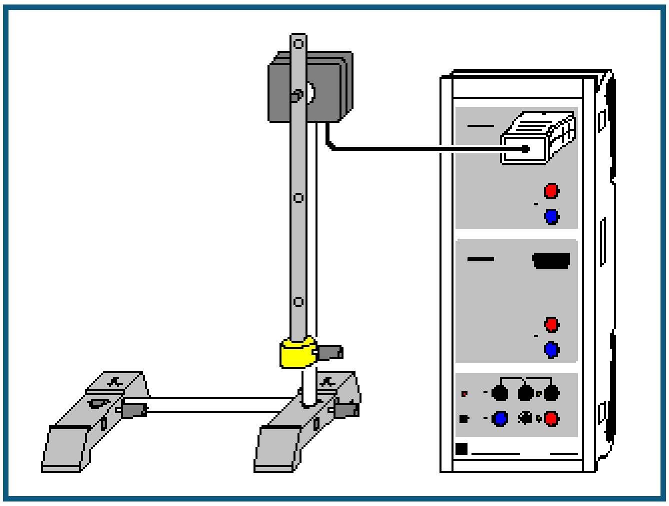
with s' being the distance between the new centre of gravity and the fulcrum, therefore $s' = (m \cdot s + m_2 \cdot x)/(m + m_2)$. From this you get

$J/ms = (J + m_2 \cdot x^2)/(m \cdot s + m_2 \cdot x) = J/ms \cdot (1 + m_2 \cdot x^2/J)/(1 + m_2 \cdot x/ms)$ or $m_2 \cdot x^2/J = m_2 \cdot x/ms$, therefore

$x = J/ms = l_r$.

The (point) mass is then exactly located at the reduced pendulum length. But, because in reality it has a finite size, this is only an approximation.

## Oscillations of a rod pendulum (with added mass)



can also be carried out with Pocket-CASSY

### Experiment description

The oscillations of a physical rod pendulum are recorded as a function of time t. For the evaluation, the angle α, velocity φ and acceleration a are compared to one another. There is a choice of displaying them as a function of time t or in the form of a phase diagram.

In addition, the reduced pendulum length $l_r$ = J/ms is determined from the measured oscillation period $T = 2\pi\cdot\mathrm{sqrt}(l_r/g)$.

### Equipment list

| | | |
|---|---|---|
| 1 | Sensor-CASSY | 524 010 or 524 013 |
| 1 | CASSY Lab 2 | 524 220 |
| 1 | Rotary motion sensor S | 524 082 |
| 1 | Physical pendulum | 346 20 |
| 1 | Stand rod, 25 cm, d = 10 mm | 301 26 |
| 2 | Stand bases MF | 301 21 |
| 1 | PC with Windows XP/Vista/7 | |

### Experiment setup (see drawing)

The pendulum is screwed on the axle of the rotary motion sensor and the weight is attached to the lower end of the pendulum.

### Carrying out the experiment

Load settings

- Define the zero point in the equilibrium position of the pendulum (→ **0** ← in Settings αA1)
- Deflect the pendulum by approximately 20° and release
- Start the measurement with ⏱. The measurement will stop automatically after 10 s
- Repeat the measurement without the mass or with a further mass added

### Evaluation

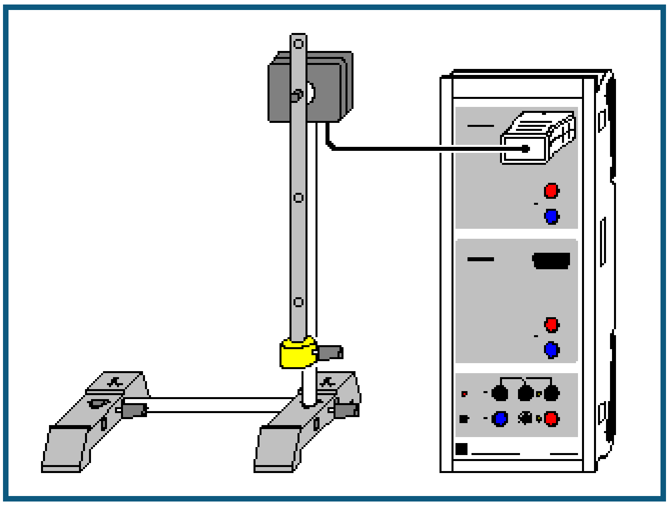
In addition to the angular diagram, an overview diagram with α(t), φ(t) and a(t) and a phase diagram φ(α) have already been prepared. The various diagrams can be selected by clicking on them.

After several oscillations, the duration of these oscillations can be determined by means of a vertical line and from this the period of oscillation. In the example the result is T = 0.96 s. With $g = 9.81\ \mathrm{m/s^2}$, this results in the reduced pendulum length $l_r = g\cdot T^2/4\pi^2 = 22.9$ cm. This is a somewhat less than the distance between the weight and the fulcrum (25 cm).

**Remark**

The recorded curve forms depend greatly on the selected time interval. The time interval can only be a compromise between rapid measuring sequence, clearly marked α(t) minima and maxima (short time interval) and low errors in the φ(t) and a(t) diagram (longer time interval).

## Oscillations of a rod pendulum (with modeling)



can also be carried out with Pocket-CASSY

### Experiment description

A rod pendulum is excited and the free oscillation is recorded. In addition to an investigation of the oscillations of a rod pendulum purely based on measurements, the measured oscillation is compared to the oscillation α(t) which results from the equation of motion

$M = J\cdot\alpha'' = -m\cdot g\cdot s\cdot\sin\alpha$

with moment of inertia J, mass m and the distance s between the fulcrum and the centre of gravity. The required modeling equation is

$\alpha'' = a = -m\cdot g\cdot s\cdot\sin\alpha \,/\, J = g/l_r\cdot\ \sin\alpha$

with the reduced pendulum length $l_r = J/ms$.

For small angles α, sin α is usually approximated by α and then the equation can be solved analytically. In this example, this approximation is not required, because the solution is found numerically.

### Equipment list

| | | |
|---|---|---|
| 1 | Sensor-CASSY | 524 010 or 524 013 |
| 1 | CASSY Lab 2 | 524 220 |
| 1 | Rotary motion sensor S | 524 082 |
| 1 | Physical pendulum | 346 20 |
| 1 | Stand rod, 25 cm, d = 10 mm | 301 26 |
| 2 | Stand bases MF | 301 21 |
| 1 | PC with Windows XP/Vista/7 | |

### Experiment setup (see drawing)

The pendulum is screwed on the axle of the rotary motion sensor and the weight is attached to the lower end of the pendulum.

### Carrying out the experiment

☐ Load settings
- Define the zero point in the equilibrium position of the pendulum (→ **0** ← in Settings αA1)
- Deflect the pendulum by approximately 20° (this corresponds to an angle of approximately 0.35 rad) and release
- Start the measurement with ⏱. The measurement will stop 10 s later.

### Modeling

In the present example, the two starting conditions are selected α(t=0)=0 and φ(t=0)=$\varphi_0$ because the oscillation was triggered at the origin. The starting speed $\varphi_0$ and reduced pendulum length $l_r$ can be modified by pulling the pointer of the corresponding display instrument (or by clicking on the left-hand button or after clicking on the right-hand button) until Model corresponds to the measurement.

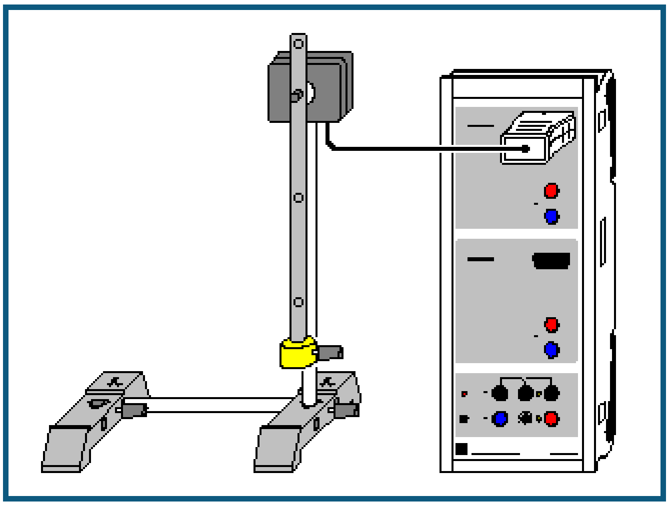
For confirmation of the model, the weight can be moved to a different position and the experiment be repeated. The new measured oscillation will again correspond to the mathematical model.

### Influence of the approximation sinα ≈ α

It is very impressive to observe the influence of the otherwise commonly used approximation for small deflections (sin α≈α). For this the model equation can be reduced from –9.81/lr*rsin &a to –9.81/lr*&a. The change to the period through the influence of the approximation is already clearly apparent for a deflection of 20°.

In the following Example this influence is investigated in more detail.

## Dependency of the period of the oscillation on the amplitude



can also be carried out with Pocket-CASSY

### Experiment description

The period T depending on the amplitude of the oscillation is recorded. For this the pendulum is activated once at the beginning and the amplitude and period are continuously recorded. Because of the low degree of friction, the amplitude reduces slowly. This in turn results in a small reduction in the oscillation period.

The equation of motion for a physical pendulum with moment of inertia J, mass m and distance s between fulcrum and centre of gravity

$M = J\cdot\alpha'' = -m\cdot g\cdot s\cdot \sin\alpha$

describes for small deflections ($\sin\alpha\approx\alpha$) an harmonic oscillation with the period

$T = 2\pi\cdot \mathrm{sqrt}(l_r/g)$,

with the reduced pendulum length being $l_r = J/ms$. Without this approximation, in general the following applies

$T = 2\pi\cdot \mathrm{sqrt}(l_r/g)\cdot(1 + (1/2)^2\cdot(\sin(\alpha/2)^2 + (3/4)^2\cdot(\sin(\alpha/2)^4 + (5/6)^2\cdot(\sin(\alpha/2)^6 + \dots))))$.

### Equipment list

| | | |
|---|---|---|
| 1 | Sensor-CASSY | 524 010 or 524 013 |
| 1 | CASSY Lab 2 | 524 220 |
| 1 | Rotary motion sensor S | 524 082 |
| 1 | Physical pendulum | 346 20 |
| 1 | Stand rod, 25 cm, d = 10 mm | 301 26 |
| 2 | Stand bases MF | 301 21 |
| 1 | PC with Windows XP/Vista/7 | |

### Experiment setup (see drawing)

The pendulum is screwed on the axle of the rotary motion sensor and the weight is attached to the lower end of the pendulum.

### Carrying out the experiment

Load settings

- Deflect the pendulum by approximately 30° and release
- Once the displayed value for the oscillation period $T_{A1}$ has settled to a constant value, start the measurement by pressing ⏱
- If after a while no measuring points appear, click on the y-axis with the right mouse button and select **Find Minimum and Maximum.**
- Stop the measurement by clicking ⏱ as soon as the amplitude falls below 5°. Below this the determined oscillation period will become unreliable.

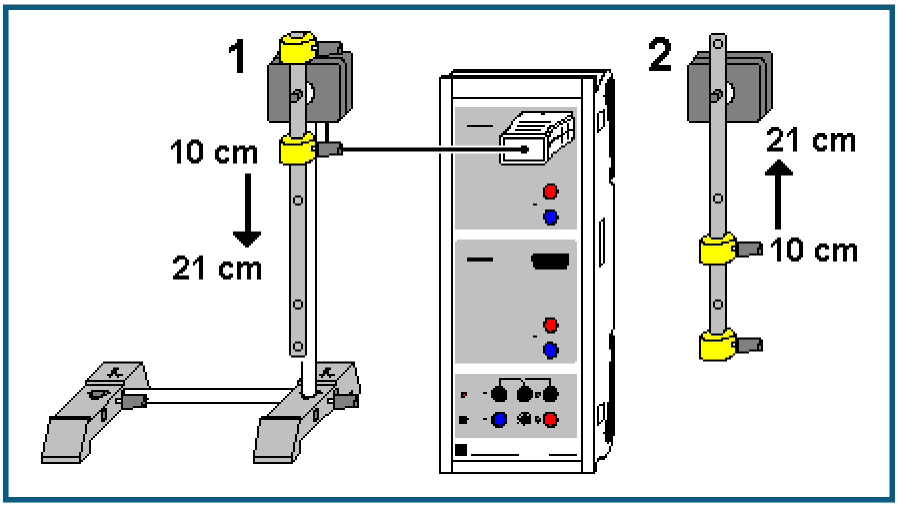
## Evaluation

During the measurement, the amplitude decreases slowly. This causes a minor reduction in oscillation period. The theoretical connection between amplitude and period is

$T = T_0 \cdot (1 + (1/2)^2 \cdot (\sin(\alpha/2)^2 + (3/4)^2 \cdot (\sin(\alpha/2)^4 + (5/6)^2 \cdot (\sin(\alpha/2)^6 + ...))))$

and can be easily confirmed by carrying out a free fit.

## Determination of the acceleration due to gravity on earth by means of a reversible pendulum



can also be carried out with Pocket-CASSY

### Experiment description

For a physical pendulum with small deflections, the oscillation period is given by

$T = 2\pi\cdot\mathrm{sqrt}(l_r/g)$

with the reduced pendulum length $l_r = J/ms$. If the reduced pendulum length $l_r$ and the oscillation period T are known, this can be used for calculating the acceleration due to gravity $g = l_r\cdot 4\pi^2/T^2$.

Often the reduced pendulum length cannot be determined with the desired precision if the precise determination of the moment of inertia or of the centre of gravity are difficult. With the reversible pendulum, the mass distribution is modified in such a way that the oscillation period is identical for both rotational axes. From this it can be concluded that the reduced pendulum length $l_r$ corresponds to the distance between the two axes and therefore is known to a high degree of precision.

According to Steiner's theorem, $J = J_S + ms^2$ with $J_S$ being the moment of inertia of the pendulum with respect to the axis through the centre of gravity and s being the distance between the centre of gravity and rotational axes. The reduced pendulum length is therefore

$l_r = J/ms = J_S/ms + s.$

The second rotational axis is now located on the other side of the centre of gravity and, with the same oscillation period and the same reduced pendulum length, is at a distance x from the centre of gravity. In this case

$l_r = J_S/mx + x.$

If the equation is rearranged to give the value for x, $x = l_r - s$. The distance between the two rotational axes s+x therefore precisely corresponds to the reduced pendulum length $l_r$.

Because the oscillation period T can be determined precisely, the reversible pendulum is very suitable for the determination of the value of the earth's acceleration g.

### Equipment list

| | | |
|---|---|---|
| 1 | Sensor-CASSY | 524 010 or 524 013 |
| 1 | CASSY Lab 2 | 524 220 |
| 1 | Rotary motion sensor S | 524 082 |
| 1 | Physical pendulum | 346 20 |
| 1 | Stand rod, 25 cm, d = 10 mm | 301 26 |
| 2 | Stand bases MF | 301 21 |
| 1 | PC with Windows XP/Vista/7 | |

### Experiment setup (see drawing)

The pendulum is screwed on the axle of the rotary motion sensor and the mass is attached to the pendulum as shown in (1).

The rod of the pendulum is marked starting from the top in 1 cm steps using a pencil. A range from 10 cm to approximately 21 cm is adequate for this.

### Carrying out the experiment

☐ Load settings

- Attach the variable pendulum mass at the position x = 10 cm and deflect by approximately 10°.
- Once the value displayed for the oscillation period $T_{A1}$ has settled to a constant value and the amplitude $\alpha_{A1}$ has fallen to approximately 5°, record the measuring value by pressing ⏱ and enter the position in column x (click at the cell in the table with the mouse)
- Push the pendulum mass 1 cm down and measure again. Repeat until x = 21 cm is reached.
- Move the mass back to x = 10 cm and change the suspension point of the pendulum as shown in (2); reverse the pendulum
- Select **Measurement → Append new Measurement Series**.
- Again deflect the pendulum by approximately 10° and wait until the value displayed for the oscillation period $T_{A1}$ has settled to a constant and the amplitude $\alpha_{A1}$ has fallen to approximately 5°, record the measuring value by pressing ⏱ and enter the position in column x (click on the cell in the table with the mouse)
- Push the pendulum mass 1 cm **upwards** and measure again. Repeat until x = 21 cm is reached.

### Evaluation

In the graphic display, two intersections of the oscillation period curves can be seen. In both intersection the period of oscillation and therefore the reduced pendulum length are equal. It corresponds to the displacement of the two axes of rotation, that is $l_r = 0.20$ m.

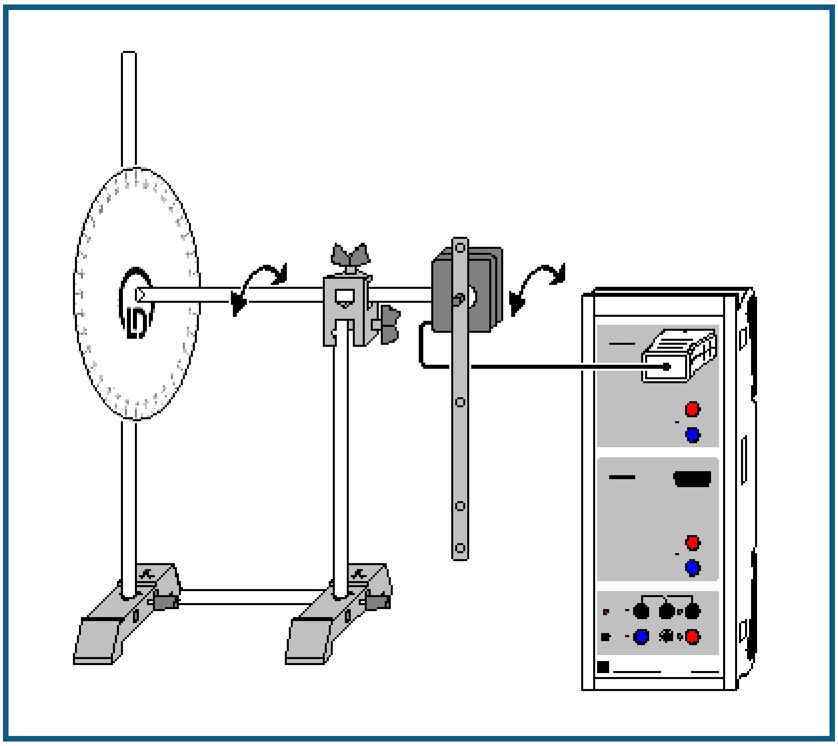
By means of a horizontal mark the corresponding period can be determined. In this example it is T = 0.898 s. This results in an earth's acceleration due to gravity of $g = l_r \cdot 4\pi^2/T^2 = 7.896\ \mathrm{m}/T^2 = 9.79\ \mathrm{m/s}^2$.

Alternatively, the earth's acceleration due to gravity can be found with somewhat higher resolution in diagram **g.**

### Comments about the measuring error

In addition to the manufacturing error in the rod, which will appear as an error in the reduced pendulum length $l_r$ (approximately $\Gamma l_r = \pm 0.1$ mm, that is $\Gamma g = \pm 0.005\ \mathrm{m/s}^2$), an error in the oscillation period T is to be considered. Besides the simple measuring fault (in this case approximately $\Gamma T = \pm 0.001 \cdot T$, corresponding to $\Gamma g = \pm 0.02\ \mathrm{m/s}^2$) there is also a systematic fault. As already demonstrated in the experiment Dependency of the period of the oscillation on the amplitude, the oscillation period shows a weak dependency on the amplitude. For the 5° amplitude this systematic error is $\Gamma T = +0.0005 \cdot T$, corresponding to $\Gamma g = -0.01\ \mathrm{m/s}^2$. With even smaller amplitudes the determination of the oscillation period by means of the rotary motion sensor will become unreliable. For greater amplitudes, this systematic fault will soon exceed the normal measuring fault (for 10° amplitude it is $\Gamma T = +0.002 \cdot T$, corresponding to $\Gamma g = -0.04\ \mathrm{m/s}^2$)

## Pendulum with changeable acceleration due to gravity (variable g-pendulum)



✓ can also be carried out with Pocket-CASSY

### Experiment description

With a variable g-pendulum (pendulum after Mach) only the component g·cos $\vartheta$ of the earth's gravitational acceleration affects the pendulum. Depending on the inclination $\vartheta$, different oscillation periods result

$T = 2\pi \cdot \mathrm{sqrt}(l_r/g/\cos \vartheta)$

with the reduced pendulum length $l_r$ = J/ms.

In the experiment, the oscillation period is investigated depending on the angle of inclination. Alternatively, the acceleration due to gravity of a number of simulated celestial bodies can be determined. The reduced pendulum length $l_r$ = 17.5 cm was calculated in the experiment Oscillations of a rod pendulum and confirmed experimentally. The effective part of the acceleration due to gravity is therefore $a = g\cdot\cos \vartheta = l_r\cdot 4\pi^2/T^2 = 6.91\ \mathrm{m}/T^2$.

On the printable angle scale the settings for

| Celestial body | $\vartheta$ | g·cos $\vartheta$ |
|---|---|---|
| Earth (reference location) | 0° | 9.81 $\mathrm{m/s^2}$ |
| Venus | 25.3° | 8.87 $\mathrm{m/s^2}$ |
| Mars | 67.8° | 3.71 $\mathrm{m/s^2}$ |
| Mercury | 67.8° | 3.70 $\mathrm{m/s^2}$ |
| Moon | 80.5° | 1.62 $\mathrm{m/s^2}$ |
| Pluto | 86.6° | 0.58 $\mathrm{m/s^2}$ |

are already entered.

### Equipment list

| | | |
|---|---|---|
| 1 | Sensor-CASSY | 524 010 or 524 013 |
| 1 | CASSY Lab 2 | 524 220 |
| 1 | Rotary motion sensor S | 524 082 |
| 1 | Physical pendulum | 346 20 |
| 1 | Angle scale with the entered celestial bodies | print out |
| 1 | Leybold multiclamp | 301 01 |
| 2 | Stand rods, 25 cm, d = 10 mm | 301 26 |

| | | |
|---|---|---|
| 1 | Stand rod, 50 cm, d = 10 mm | 301 27 |
| 2 | Stand bases MF | 301 21 |
| 1 | PC with Windows XP/Vista/7 | |

### Experiment setup (see drawing)

The pendulum is screwed on the axle of the rotary motion sensor. The scale is pushed onto the stand rod of the rotary motion sensor. To do this cut the scale as indicated by means of a sharp knife.

### Carrying out the experiment

■ Load settings

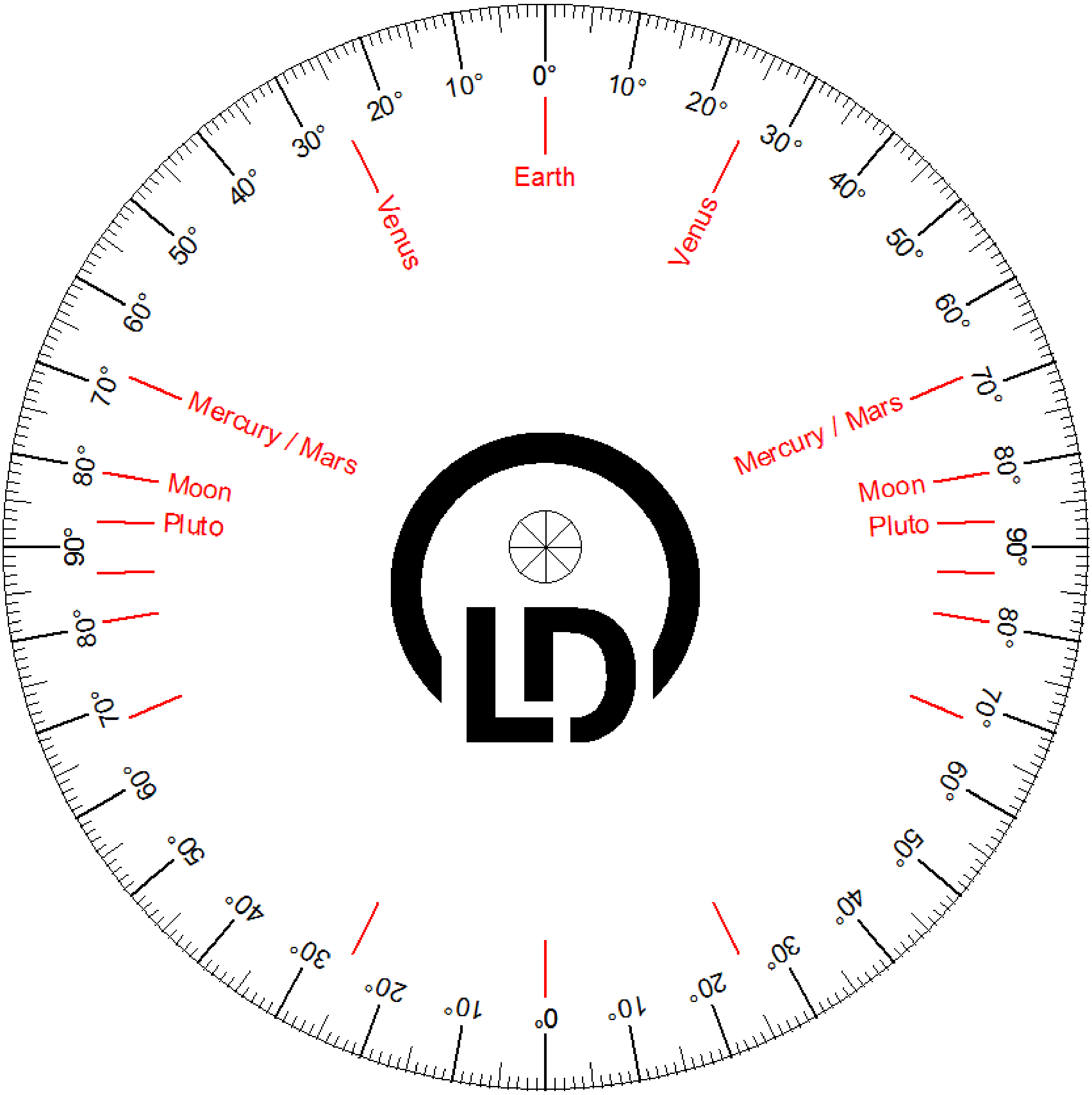
- Set up pendulum vertically ($\vartheta = 0°$), align the experiment setup and deflect the pendulum by approximately 10°
- Once the displayed value for the oscillation period $T_{A1}$ has settled to a constant value, start the measurement by pressing ⏱ and enter the angle in column $\vartheta$ (click with the mouse onto the table cell)
- Increase the angle repeatedly by 10° and repeat measurement until $\vartheta = 80°$ is reached.

### Evaluation

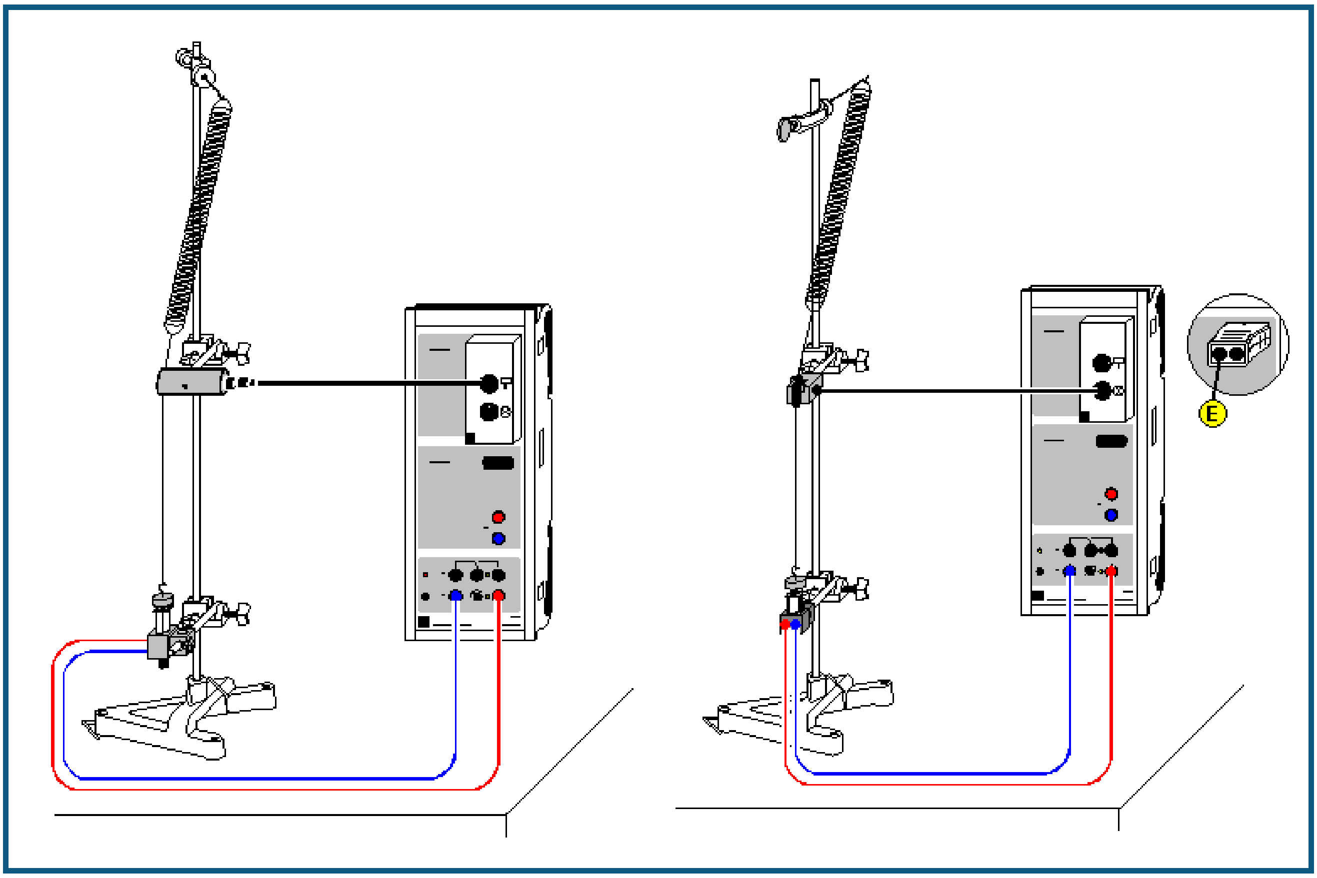
During the measurement, the effective part of the acceleration due to gravity $a = l_r \cdot 4\pi^2/T^2$ with $l_r = 17.5$ cm is entered into the diagram.

With a free fit the relationship $a = g \cdot \cos \vartheta$ can easily be confirmed.

Alternatively, a range of celestial bodies can be simulated and their acceleration due to gravity determined. To do this align the pendulum with the red markers on the angle scale.


0°
10°
20°
30°
40°
50°
60°
70°
80°
90°
Earth
Venus
Venus
Mercury / Mars
Mercury / Mars
Moon
Moon
Pluto
Pluto

## Harmonic oscillations of a spring pendulum



### Experiment description

This experiment records the harmonic oscillations of a spring pendulum as a function of the time t. The evaluation compares the path s, velocity v and acceleration a. These can be displayed either as a function of the time t or as a phase diagram.

### Equipment list

| | | |
|---|---|---|
| 1 | Sensor-CASSY | 524 010 or 524 013 |
| 1 | CASSY Lab 2 | 524 220 |
| | | |
| 1 | BMW box | 524 032 |
| 1 | Motion sensing element | 337 631 |
| | or | |
| 1 | Timer S | 524 074 |
| 1 | Combination light barrier | 337 462 |
| 1 | Combination spoked wheel | 337 464 |
| | | |
| 1 | Multi-core cable, 6-pole | 501 16 |
| 1 | Helical spring, 3 N/m | 352 10 |
| 1 | Set of weights, 50 g | 342 61 |
| 1 | Holding magnet | 336 21 |
| 1 | Stand base, V-shape, 28 cm | 300 01 |
| 1 | Stand rod, 25 cm | 300 41 |
| 1 | Stand rod, 150 cm | 300 46 |
| 2 | Leybold multiclamps | 301 01 |
| 1 | Clamp with hook | 301 08 |
| 1 | Fishing line, 10 m | from 309 48ET2 |
| 1 | Pair of cables, 100 cm, red and blue | 501 46 |
| 1 | PC with Windows XP/Vista/7 | |

## Experiment setup (see drawing)

Lay the string of the spring pendulum over the deflection pulley of the motion sensing element so that the oscillation of the pendulum is transmitted to the sensor without slip; connect the sensor to the top socket of the BMW box. The holding magnet enables a defined measurement start by holding the pendulum weight in the bottom reversing point of the oscillation before the start of measurement recording.

This experiment can be expanded to investigate air friction (e.g. with a piece of cardboard on the weight) or the effect of a change in the pendulum mass.

## Carrying out the experiment

☐ Load settings

- If necessary, change the time interval in the Measuring Parameters (**Window → Show Measuring Parameters**). A shorter interval enables more measured values and smoother s(t) and v(s) diagram, while a longer interval generates fewer measured values and less scattering in a(t).
- You may need to invert the sign of path measurement (**s** ↔ **-s** in Settings sA1).
- Define the zero point in the equilibrium position of the pendulum (→ **0** ← in Settings sA1)
- Deflect the pendulum approx. 10 cm and hold it there with the holding magnet.
- Start the measurement with ⏱ and stop it with ⏱ when the experiment is finished.
- Always check that the path zero point is at the equilibrium position before repeating the experiment.

## Evaluation

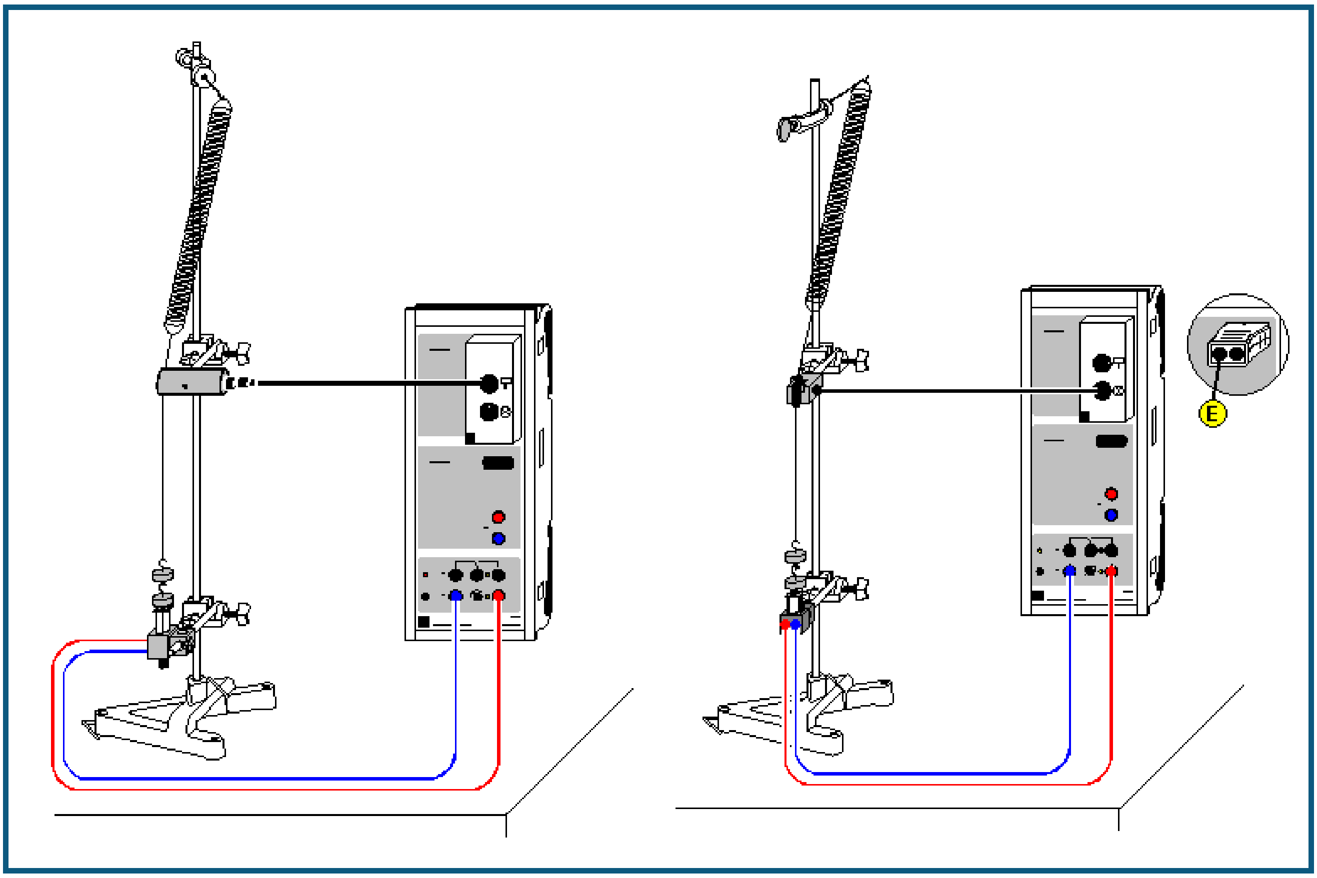
In addition to the path display, this example also contains an overview display with s(t), v(t) and a(t) and a phase diagram v(s). The various diagrams can be selected by clicking on them.

The phase relations and the damping are easy to see.

## Remark

The recorded curve forms depend greatly on the selected time interval. The time interval is necessarily a compromise between a rich sequence of measured values, clearly apparent s(t) minima (shorter interval) and low inaccuracy in the v(t) and a(t) diagram (longer interval).

## Dependence of the period of oscillation of a spring pendulum on the oscillating mass



### Experiment description

The harmonic oscillations of a spring pendulum as a function of the time t are recorded for various suspended masses. From the path-time diagram s(t), the period of oscillation T2 is determined. A plot of $T^2$ as a function of the suspended mass m confirms the relation $T^2 = (2\pi)^2 \cdot m/D$ (D = spring constant).

### Equipment list

| | | |
|---|---|---|
| 1 | Sensor-CASSY | 524 010 or 524 013 |
| 1 | CASSY Lab 2 | 524 220 |

| | | |
|---|---|---|
| 1 | BMW box | 524 032 |
| 1 | Motion sensing element | 337 631 |
| | or | |
| 1 | Timer S | 524 074 |
| 1 | Combination light barrier | 337 462 |
| 1 | Combination spoked wheel | 337 464 |

| | | |
|---|---|---|
| 1 | Multi-core cable, 6-pole | 501 16 |
| 1 | Helical spring, 3 N/m | 352 10 |
| 1 | Set of 12 weights, each 50 g | 342 61 |
| 1 | Holding magnet | 336 21 |
| 1 | Stand base, V-shape, 28 cm | 300 01 |
| 1 | Stand rod, 25 cm | 300 41 |
| 1 | Stand rod, 150 cm | 300 46 |
| 2 | Leybold multiclamps | 301 01 |
| 1 | Clamp with hook | 301 08 |
| 1 | Fishing line, 10 m | from 309 48ET2 |
| 1 | Pair of cables, 100 cm, red and blue | 501 46 |
| 1 | PC with Windows XP/Vista/7 | |

### Experiment setup (see drawing)

- Clamp the stand rod in the stand base, and fasten the clamp with hook to the upper end of the stand rod.
- Suspend the spring from the hook, and elongate it via a piece of fishing line of approx. 45 cm length by means of the desired number of weights.
- Fasten a multiclamp with the motion sensing element close to the middle of the piece of fishing line.
- Lay the piece of fishing line over the deflection pulley of the motion sensing element so that the oscillations of the pendulum are transmitted to the motion sensing element without slip. In order to keep damping of the oscillation low, see to it that the axis of the spring does not deviate too much from the vertical.
- Position the holding magnet at the lower dead point of the oscillation of the spring pendulum.
- Connect the motion sensing element via the upper socket of the BMW box to the input A of the Sensor-CASSY.
- Connect the holding magnet to the output S of the Sensor-CASSY.

### Experiment notes

The holding magnet provides a well-defined start of the oscillation by keeping the weights suspended for a particular measurement in the lower dead point of the oscillation. Depending on the number of suspended weights, the motion sensing element and the holding magnet have to be displaced vertically with respect to the position of the hook. The ideal position of the motion sensing element is close to the middle of the fishing line when the pendulum is in its equilibrium position.

### Carrying out the experiment

■ Load settings
- Suspend the desired number of weights, and adjust the height of the holding magnet and of the motion sensing element.
- Calibrate the zero of the path $s_{A1}$ in the equilibrium position of the pendulum – to do this, click the → **0** ← button in Settings sA1.
- If required, invert the sign of the path measurement (**s** ↔ **–s** button in Settings sA1)
- Elongate the pendulum so that the weights are held by the holding magnet.
- Start the measurement with ⏱.
- When repeating a measurement, check the zero of the path in the equilibrium position of the pendulum before recording data.

### Evaluation

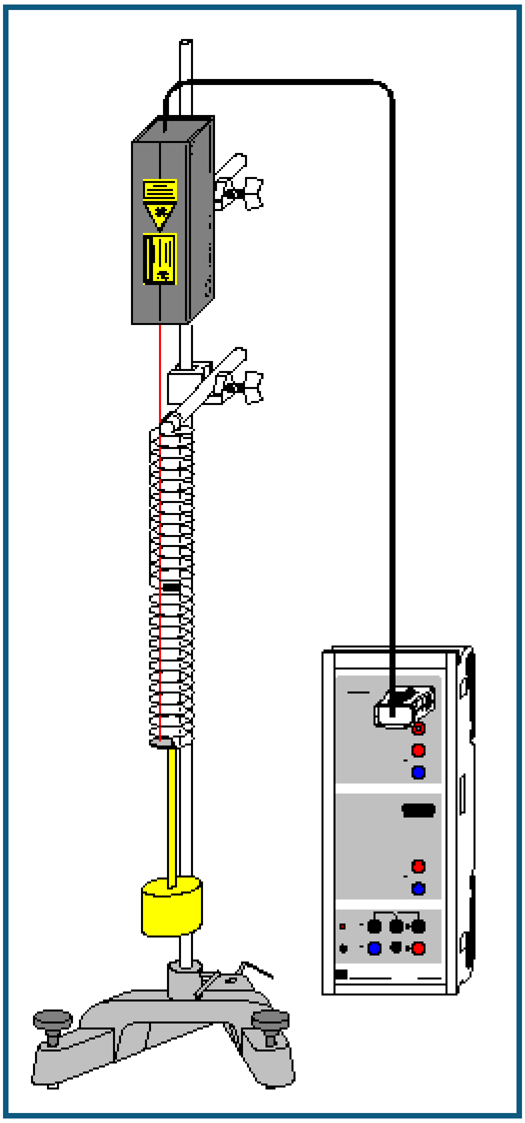
For every path-time diagram, the period of oscillation T is determined by clicking Measure Difference with the right mouse button (or **Alt+D**) and subsequently clicking two corresponding zero passages with the left mouse button. The value of the period of oscillation then displayed in the status line can be transferred into the prepared display **Input** by means of the mouse (drag & drop). In addition, the mass m associated with T has to be entered in the table. By a fit to a straight line in the display **Evaluation**, the proportionality $T^2 \propto m$ is confirmed in a further step.

The spring constant D can be determined from the slope of the straight line. Note that the straight line does not pass the origin. For a description of this experiment result, the mass of the spring has also to be taken into account.

### Hint

As a complete evaluation requires the experiment to be repeated for various masses m, the period of oscillation T would have to be determined manually in each case. Alternatively, the period of oscillation T can also be determined automatically. For this you only have to open the display instrument T' in the upper line. After the oscillation has been measured, the value display there can be copied directly into the display **Input** (drag & drop).

## Oscillations of a spring pendulum (with modeling)



can also be carried out with Pocket-CASSY

### Safety note

Mind the safety notes in the instruction sheet of the laser motion sensor S.

### Experiment description

A spring pendulum is excited, and the free oscillation is recorded for various masses m.

As a supplement to the investigation of the oscillations of a spring pendulum merely by way of measurement, the measured oscillation is now additionally compared with the oscillation s(t) which is obtained from the equation

$s'' = a = -D/m \cdot s$

The gravitational force $-m \cdot g$ is not taken into account (see Remark concerning the gravitational force). The constants D and m correspond to the spring constant and the oscillating mass. As a certain portion of the spring oscillates too, the oscillating mass is greater than the mass of the pendulum bob by approximately 20 g (=1/3 of the mass of the spring).

### Equipment list

| | | |
|---|---|---|
| 1 | Sensor-CASSY | 524 010 or 524 013 |
| 1 | CASSY Lab 2 | 524 220 |
| 1 | Laser motion sensor S | 524 073 |

| | | |
|---|---|---|
| 1 | Stand rod with thread | 688 808 |
| 1 | Pair of helical springs | 352 15 |
| 1 | Slotted mass hanger | 315 450 |
| 1 | Slotted weight 100 g | 315 456 |
| 1 | Slotted weight 200 g | 315 458 |
| 1 | Slotted weight 500 g | 315 460 |
| 1 | Stand rod, 1 m | 300 44 |
| 1 | Stand rod, 25 cm | 300 41 |
| 2 | Leybold multiclamps | 301 01 |
| 1 | Stand base, V-shape, 28 cm | 300 01 |
| 1 | PC with Windows XP/Vista/7 | |

### Alternative

Instead of the laser motion sensor S, the force sensor S, ±50 N (524 042) can also be used for the path measurement. From the measured force $F_{A1}$ and the spring constant D, the deflection $s_{A1}=F_{A1}/D$ can be calculated using a formula.

### Experiment setup (see drawing)

Set up the spring pendulum with the large spring (∅=3.5 cm). For the path measurement, attach a piece of retroreflecting foil to the lowest turn of the spring so that the laser spot of the motion sensor hits the foil during the entire oscillation (if necessary, attach the foil outside the spring).

Due to the reversal of its helical sense in the middle, this particular spring makes possible a free stable up and down oscillation because no torsional oscillation is excited.

### Carrying out the experiment

■ Load settings

- If modeling is not yet desired, switch to the **Standard** display during the measurement.
- Define the pendulum's equilibrium position as the zero point of the path (→ **0** ← in Settings sA1; before doing so, you may allow the laser motion sensor S to warm up for some minutes).
- Deflect the pendulum bob downwards.
- Start the measurement with ⏱.
- Release the pendulum bob. The measurement starts automatically when the equilibrium position at s=0 is passed for the first time.
- After carrying out the evaluation, repeat the experiment for various masses (slotted weights), and compare the results with the prediction of the model.

### Modeling

In the present example, the two initial conditions $s(t=0)=0$ and $v(t=0)=v_0$ were chosen because the triggering took place in the zero point of the path. The initial velocity $v_0$, the spring constant D and the mass m can be altered by dragging the pointer of the corresponding display instrument (or by clicking to the left or to the right of the pointer) until the model agrees with the measurement.

In order to confirm the model, you can increase the mass m and repeat the experiment with this increased mass. The new measured oscillation will again agree with the mathematical model (you may have to adjust the initial velocity).

### Solution of the differential equation

The differential equation can also be solved analytically, and, with the initial conditions $s(t=0)=0$ and $v(t=0)=v_0$, we obtain

$s(t) = v_0/\varphi_0 \cdot \sin(\varphi_0 \cdot t)$

with $\varphi_0=\mathrm{sqr}(D/m)$.

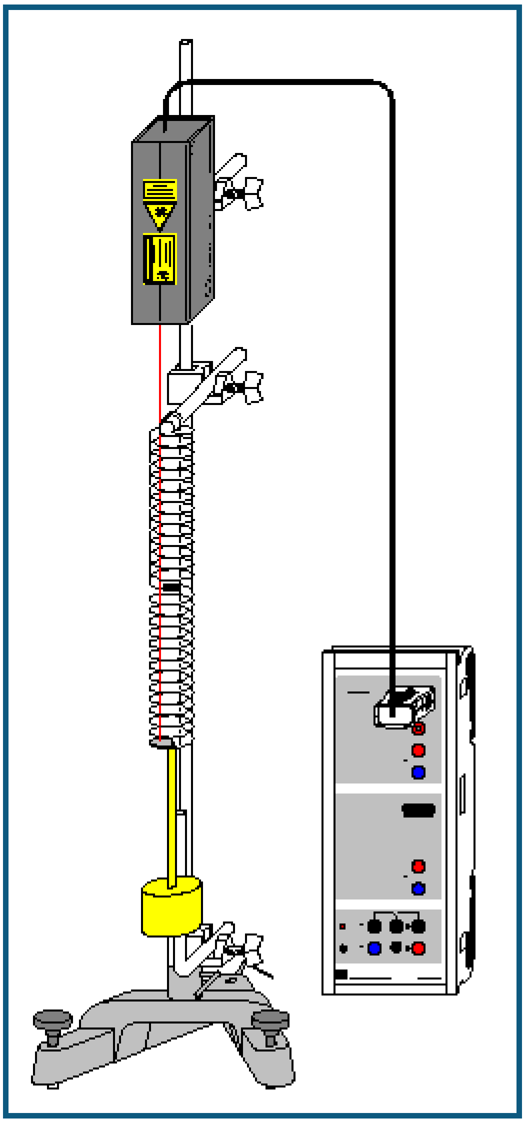
### Remark concerning the gravitational force

In the model equation used above, the action of the gravitational force m·g on the pendulum mass m was not taken into account. Strictly speaking, the model equation should read

$s'' = a = -D/m \cdot s - g = -D/m \cdot (s + m \cdot g/D) = -D/m \cdot (s - s_0)$

with $s_0=-m \cdot g/D$. This shift of the zero point of the pendulum is exactly displayed in the display **Modeling with g**, which can be selected with the mouse. As only the zero point is shifted, the gravitational force is usually omitted in the model equation. This is also done in the following examples, where solid friction, lubricant friction, laminar liquid friction and turbulent liquid friction/air friction will be investigated.

## Oscillations of a spring pendulum with solid friction (with modeling)



✓ can also be carried out with Pocket-CASSY

### Safety note

Mind the safety notes in the instruction sheet of the laser motion sensor S.

### Experiment description

As a supplement to the experiment Oscillations of a spring pendulum, the oscillating body is subjected to an additional frictional force F through sliding friction on a metal rod (Coulomb friction). The magnitude of this frictional force is constant and its direction is always opposite to that of the motion. Thus it can be written in the form $F=-F_0 \cdot \mathrm{sgn}(v)$ with a constant $F_0$. The model equation then reads

$s'' = a = -D/m \cdot s - F_0/m \cdot \mathrm{sgn}(v)$.

The gravitational force $-m \cdot g$ is not taken into account (see Remark concerning the gravitational force). The constants D and m correspond to the spring constant and the oscillating mass. As a certain portion of the spring oscillates too, the oscillating mass is greater than the mass of the pendulum bob by approximately 20 g (=1/3 of the mass of the spring).

### Equipment list

| | | |
|---|---|---|
| 1 | Sensor-CASSY | 524 010 or 524 013 |
| 1 | CASSY Lab 2 | 524 220 |

| | | |
|---|---|---|
| 1 | Laser motion sensor S | 524 073 |
| 1 | Stand rod with thread | 688 808 |
| 1 | Pair of helical springs | 352 15 |
| 1 | Slotted mass hanger | 315 450 |
| 1 | Slotted weight 500 g | 315 460 |
| 1 | Stand rod, 1 m | 300 44 |
| 1 | Stand rod, 25 cm | 300 41 |
| 1 | Stand rod, bent at right angles | 300 51 |
| 3 | Leybold multiclamps | 301 01 |
| 1 | Stand base, V-shape, 28 cm | 300 01 |
| 1 | PC with Windows XP/Vista/7 | |

### Alternative

Instead of the laser motion sensor S, the force sensor S, ±50 N (524 042) can also be used for the path measurement. From the measured force $F_{A1}$ and the spring constant D, the deflection $s_{A1}=F_{A1}/D$ can be calculated using a formula.

### Experiment setup (see drawing)

Set up the spring pendulum with the large spring (∅=3.5 cm). For the path measurement, attach a piece of retroreflecting foil to the lowest turn of the spring so that the laser spot of the motion sensor hits the foil during the entire oscillation (if necessary, attach the foil outside the spring).

Due to the reversal of its helical sense in the middle, this particular spring makes possible a free stable up and down oscillation because no torsional oscillation is excited.

When the pendulum bob is in its equilibrium position, it should be near the middle of the bent stand rod. During the oscillation, the pendulum bob should always slide along the bent stand rod with friction.

### Carrying out the experiment

■ Load settings

- If modeling is not yet desired, switch to the **Standard** display during the measurement.
- Define the pendulum's equilibrium position as the zero point of the path (→ **0** ← in Settings sA1; before doing so, you may allow the laser motion sensor S to warm up for some minutes).
- Deflect the pendulum bob downwards.
- Start the measurement with ⏱.
- Release the pendulum bob. The measurement starts automatically when the equilibrium position at s=0 is passed for the first time.
- After carrying out the evaluation, repeat the experiment for other frictional forces, and compare the results with the prediction of the model. In order to vary the frictional force, clamp the bent stand rod in slightly varied positions.

### Modeling

In the present example, the two initial conditions s(t=0)=0 and $v(t=0)=v_0$ were chosen because the triggering took place in the zero point of the path. The initial velocity $v_0$, the spring constant D, the mass m and the frictional force $F_0$ can be altered by dragging the pointer of the corresponding display instrument (or by clicking to the left or to the right of the pointer) until the model agrees with the measurement.

The dependence of the model's frictional force on the velocity can be seen in the **Frictional force** display.

In order to confirm the model, you can increase the frictional force $F_0$ (shift the bent stand rod correspondingly). If the magnitude of the frictional force $F_0$ in the model is increased correspondingly and, if necessary, the initial velocity $v_0$ is adjusted, the new measured oscillation will again agree with the mathematical model.

### Estimating the frictional force

The order of magnitude of the force of sliding friction can be estimated directly from the experiment setup. In the case of sliding friction, the magnitude of the frictional force is

$$F_0 = \kappa \cdot F_N = \kappa \cdot m \cdot g \cdot \sin\alpha$$

with the coefficient of sliding friction κ and the normal force $F_N=m \cdot g \cdot \sin\alpha$. In this example, the angle α between the vertical and the axis of friction was approximately 2° and κ=0.12 (coefficient of sliding friction for steel on steel), and we obtain $F_0$=20 mN, which is in agreement with the model.

### Envelope

The linear decrease of the amplitude of the oscillation in the case of a frictional force with constant magnitude follows from energy conservation. Between two subsequent reversal points $s_1>0$ and $s_2<0$, the work performed by the friction is $W = F_0 \cdot s_1+(–F_0) \cdot s_2$. Since the kinetic energy at the reversal points is 0, only the energy of the spring $1/2 \cdot D \cdot s_1^2$ and $1/2 \cdot D \cdot s_2^2$ is left (see also Remark concerning the gravitational force).

The energy balance thus is

$1/2 \cdot D \cdot s_1^2 = 1/2 \cdot D \cdot s_2^2 + W$ or

$W = 1/2 \cdot D \cdot (s_1^2–s_2^2) = 1/2 \cdot D \cdot (s_1+s_2)\ (s_1–s_2) = F_0 \cdot (s_1–s_2)$.

From this it follows that the difference of the magnitudes of the amplitudes is $|s_1|–|s_2| = s_1+s_2 = 2F_0/D$. Then it follows that the constant decrease of the amplitude for an entire period is $\Gamma s = 4F_0/D$.

The initial amplitude $s_0$ of the envelope also derives from the constants of the model from

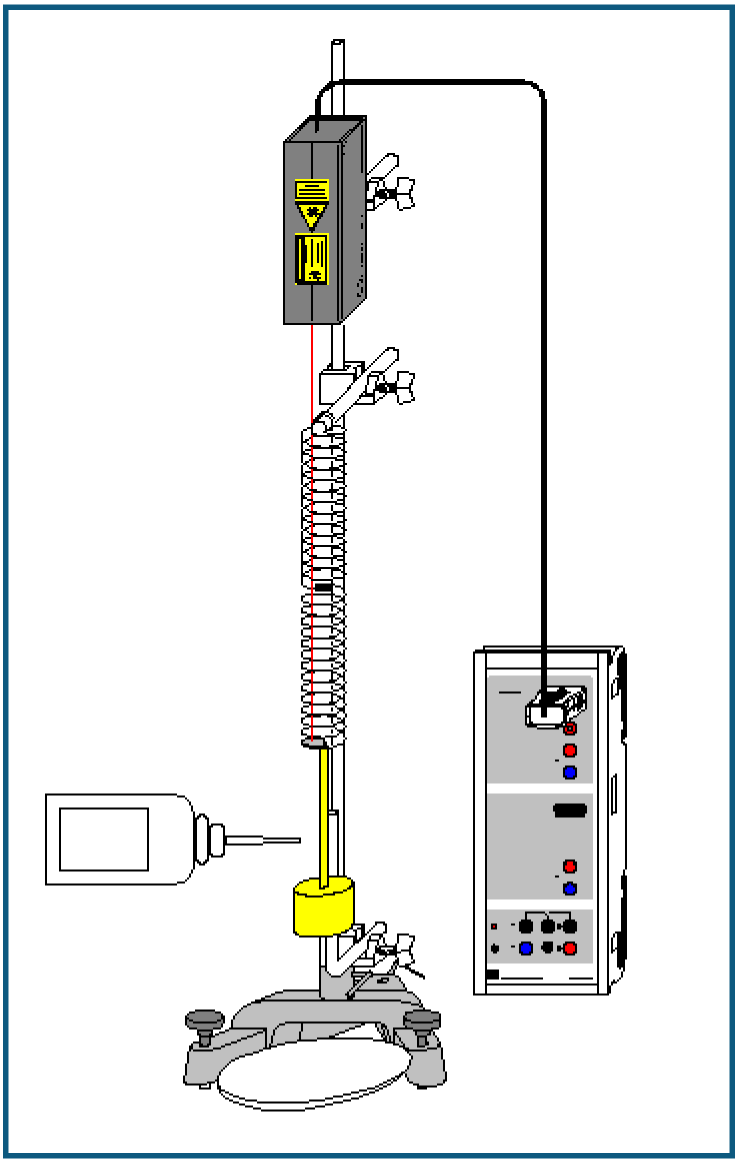
$1/2 \cdot m \cdot v_0^2 = 1/2 \cdot D \cdot s_0^2$.

For small frictional forces, the function describing the envelope can be written in the form

$\pm f(t) = s_0–4F_0/D \cdot t/T = |v_0|/\varphi_0–4F_0/D \cdot t/(2\pi/\varphi_0) = |v_0|/\varphi_0 \cdot (1–2/\pi \cdot F_0/m/|v_0| \cdot t) = s_0 \cdot (1–2/\pi \cdot k \cdot t)$

with $\varphi_0$=sqr(D/m), $s_0=|v_0|/\varphi_0$ and $k=F_0/m/|v_0|$.

## Oscillations of a spring pendulum with lubricant friction (with modeling)



can also be carried out with Pocket-CASSY

### Safety note

Mind the safety notes in the instruction sheet of the laser motion sensor S.

### Experiment description

As a supplement to the experiment Oscillations of a spring pendulum, the oscillating body is subjected to an additional frictional force F through lubricant friction (Reynolds friction). The magnitude of this frictional force is proportional to the square root of the velocity, but its direction is always opposite to that of the motion. Thus it can be written in the form F=–$F_0$·sqr|v/$v_0$|·sgn(v). $F_0$ is the magnitude of the frictional force acting on the system at the initial velocity |$v_0$|. The model equation then reads

s'' = a = –D/m·s – $F_0$/m·sqr|v/$v_0$|·sgn(v).

The gravitational force –m·g is not taken into account (see Remark concerning the gravitational force). The constants D and m correspond to the spring constant and the oscillating mass. As a certain portion of the spring oscillates too, the oscillating mass is greater than the mass of the pendulum bob by approximately 20 g (=1/3 of the mass of the spring).

### Equipment list

| | | |
|---|---|---|
| 1 | Sensor-CASSY | 524 010 or 524 013 |
| 1 | CASSY Lab 2 | 524 220 |
| 1 | Laser motion sensor S | 524 073 |
| 1 | Stand rod with thread | 688 808 |
| 1 | Pair of helical springs | 352 15 |
| 1 | Slotted mass hanger | 315 450 |
| 1 | Slotted weight 500 g | 315 460 |
| 1 | Paraffin, viscous, 100 ml | 674 0800 |
| 1 | Petri dish | 664 183 |
| 1 | Stand rod, 1 m | 300 44 |
| 1 | Stand rod, 25 cm | 300 41 |
| 1 | Stand rod, bent at right angles | 300 51 |
| 3 | Leybold multiclamps | 301 01 |
| 1 | Stand base, V-shape, 28 cm | 300 01 |
| 1 | PC with Windows XP/Vista/7 | |

### Alternative

Instead of the laser motion sensor S, the force sensor S, ±50 N (524 042) can also be used for the path measurement. From the measured force $F_{A1}$ and the spring constant D, the deflection $s_{A1}=F_{A1}/D$ can be calculated using a formula.

### Experiment setup (see drawing)

Set up the spring pendulum with the large spring (∅=3.5 cm). For the path measurement, attach a piece of retroreflecting foil to the lowest turn of the spring so that the laser spot of the motion sensor hits the foil during the entire oscillation (if necessary, attach the foil outside the spring).

Due to the reversal of its helical sense in the middle, this particular spring makes possible a free stable up and down oscillation because no torsional oscillation is excited.

When the pendulum bob is in its equilibrium position, it should be near the middle of the bent stand rod. During the oscillation the viscous paraffin should always form a film between the pendulum bob and the bent stand rod. Other suitable lubricants are liquid soaps or vaseline (675 3100) mixed with oil.

### Carrying out the experiment

■ Load settings

- If modeling is not yet desired, switch to the **Standard** display during the measurement.
- Apply a good deal of viscous paraffin to the bent stand rod in order that there is always a film between the pendulum bob and the stand rod during the measurement.
- Define the pendulum's equilibrium position as the zero point of the path (→ **0** ← in Settings sA1; before doing so, you may allow the laser motion sensor S to warm up for some minutes).
- Deflect the pendulum bob downwards.
- Start the measurement with ⏱.
- Release the pendulum bob. The measurement starts automatically when the equilibrium position at s=0 is passed for the first time.

### Modeling

In the present example, the two initial conditions $s(t=0)=0$ and $v(t=0)=v_0$ were chosen because the triggering took place in the zero point of the path. The initial velocity $v_0$, the spring constant D, the mass m and the friction constant $F_0$ can be altered by dragging the pointer of the corresponding display instrument (or by clicking to the left or to the right of the pointer) until the model agrees with the measurement.

The dependence of the model's frictional force on the velocity can be seen in the **Frictional force** display.

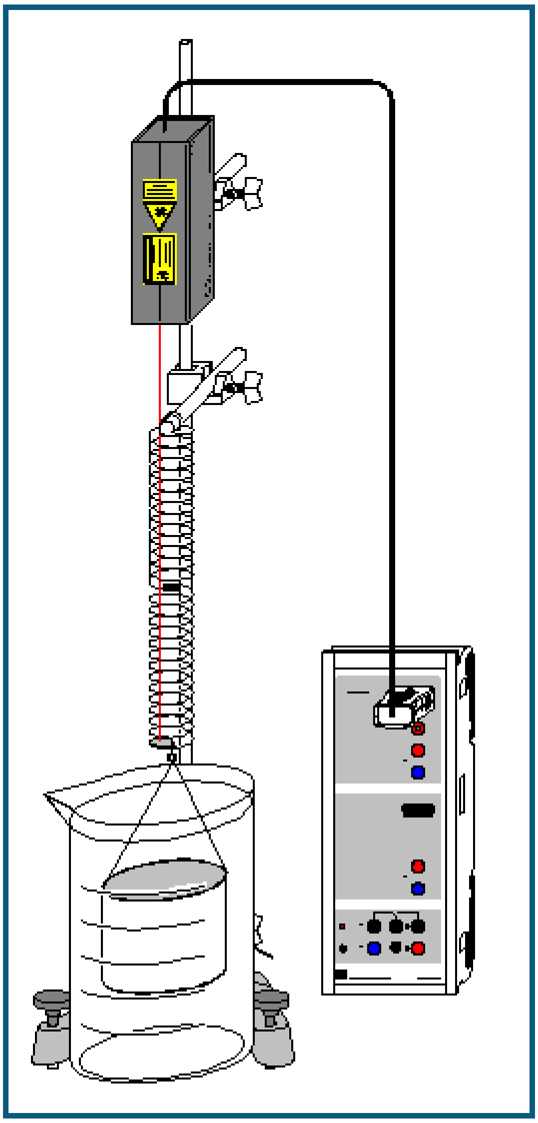
### Envelope

For small frictional forces proportional to the square root of the velocity, the function describing the envelope is given by

$$\pm f(t) = |v_0|/\varphi_0 \cdot (1-0.2782 \cdot F_0/m/|v_0| \cdot t)^2 = s_0 \cdot (1-0.2782 \cdot k \cdot t)^2$$

with $\varphi_0=\mathrm{sqr}(D/m)$, $s_0=|v_0|/\varphi_0$ and $k=F_0/m/|v_0|$.

## Oscillations of a spring pendulum with laminar liquid friction (with modeling)



✓ can also be carried out with Pocket-CASSY

### Safety note

Mind the safety notes in the instruction sheet of the laser motion sensor S.

### Experiment description

As a supplement to the experiment Oscillations of a spring pendulum, the oscillating body is subjected to an additional frictional force F through laminar liquid friction (Stokes friction) in water. The magnitude of this frictional force is proportional to the velocity, but its direction is always opposite to that of the motion. Thus it can be written in the form $F=-F_0 \cdot v/|v_0|$. $F_0$ is the magnitude of the frictional force acting on the system at the initial velocity $|v_0|$. The model equation then reads

$s'' = a = -D/m \cdot s - F_0/m \cdot v/|v_0|$.

The gravitational force $-m \cdot g$ is not taken into account (see Remark concerning the gravitational force). The constants D and m correspond to the spring constant and the oscillating mass. As water is moved and a certain portion of the spring oscillates too, the oscillating mass is greater than the mass of the pendulum bob.

### Equipment list

| | | |
|---|---|---|
| 1 | Sensor-CASSY | 524 010 or 524 013 |
| 1 | CASSY Lab 2 | 524 220 |

| | | |
|---|---|---|
| 1 | Laser motion sensor S | 524 073 |
| 1 | Stand rod with thread | 688 808 |
| 1 | Pair of helical springs | 352 15 |
| 1 | Hollow cylinder for liquid friction | 342 11 |
| 1 | Beaker, 3000 ml | 664 134 |
| 1 | Stand rod, 1 m | 300 44 |
| 1 | Stand rod, 25 cm | 300 41 |
| 2 | Leybold multiclamps | 301 01 |
| 1 | Stand base, V-shape, 28 cm | 300 01 |
| 1 | PC with Windows XP/Vista/7 | |

### Alternative

Instead of the laser motion sensor S, the force sensor S, ±50 N (524 042) can also be used for the path measurement. From the measured force $F_{A1}$ and the spring constant D, the deflection $s_{A1}=F_{A1}/D$ can be calculated using a formula.

### Experiment setup (see drawing)

Set up the spring pendulum with the large spring (∅=3.5 cm). For the path measurement, attach a piece of retroreflecting foil to the lowest turn of the spring so that the laser spot of the motion sensor hits the foil during the entire oscillation (if necessary, attach the foil outside the spring).

Due to the reversal of its helical sense in the middle, this particular spring makes possible a free stable up and down oscillation because no torsional oscillation is excited.

When the hollow cylinder is in its equilibrium position, it should be near the middle of the water-filled beaker. In order to obtain approximately laminar friction, align the hollow cylinder vertically as precisely as possible.

### Carrying out the experiment

■ Load settings
- If modeling is not yet desired, switch to the **Standard** display during the measurement.
- Define the pendulum's equilibrium position as the zero point of the path (→ **0** ← in Settings sA1; before doing so, you may allow the laser motion sensor S to warm up for some minutes).
- Deflect the hollow cylinder downwards.
- Start the measurement with ⏱.
- Release the hollow cylinder. The measurement starts automatically when the equilibrium position at s=0 is passed for the first time.

### Modeling

In the present example, the two initial conditions $s(t=0)=0$ and $v(t=0)=v_0$ were chosen because the triggering took place in the zero point of the path. The initial velocity $v_0$, the spring constant D, the mass m and the friction constant $F_0$ can be altered by dragging the pointer of the corresponding display instrument (or by clicking to the left or to the right of the pointer) until the model agrees with the measurement.

The dependence of the model's frictional force on the velocity can be seen in the **Frictional force** display.

### Solution of the differential equation

In contrast to Coulomb friction, Reynolds friction and Newton friction, the differential equation can be solved analytically in the case of Stokes friction. With the initial conditions $s(t=0)=0$ and $v(t=0)=v_0$,

$$s(t) = v_0/\varphi\ \sin(\varphi\cdot t)\ \exp(-1/2\cdot k\cdot t)$$

is obtained, with $\varphi_0=\mathrm{sqr}(D/m)$, $\varphi=\mathrm{sqr}(\varphi_0^2-k^2/4)$ and $k=F_0/m/|v_0|$.

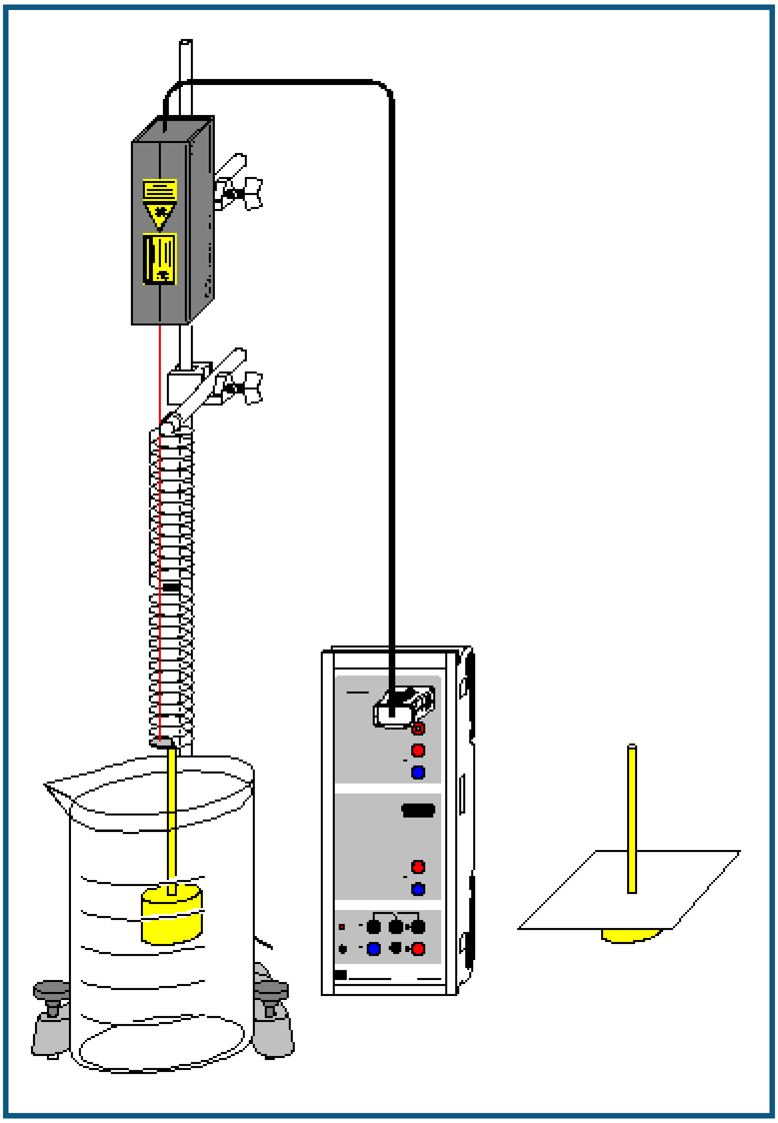
### Envelope

For frictional forces proportional to the velocity, the function describing the envelope therefore has the form

$$\pm f(t) = s_0\cdot\exp(-1/2\cdot k\cdot t)$$

with $s_0=|v_0|/\varphi$.

# Oscillations of a spring pendulum with turbulent liquid friction/air friction (with modeling)



can also be carried out with Pocket-CASSY

## Safety note

Mind the safety notes in the instruction sheet of the laser motion sensor S.

## Experiment description

As a supplement to the experiment Oscillations of a spring pendulum, the oscillating body is subjected to an additional frictional force F through turbulent liquid friction or turbulent air friction (Newton friction). The magnitude of this frictional force is proportional to the square of the velocity, but its direction is always opposite to that of the motion. Thus it can be written in the form $F=-F_0\cdot(v/v_0)^2\cdot\mathrm{sgn}(v)$. $F_0$ is the magnitude of the frictional force acting on the system at the initial velocity $|v_0|$. The model equation then reads

$s'' = a = -D/m\cdot s - F_0/m\cdot(v/v_0)^2\cdot\mathrm{sgn}(v)$.

The gravitational force $-m\cdot g$ is not taken into account (see Remark concerning the gravitational force). The constants D and m correspond to the spring constant and the oscillating mass. As water is moved and a certain portion of the spring oscillates too, the oscillating mass is greater than the mass of the pendulum bob.

From the friction constant $F_0$ the drag coefficient ($c_w$ value) for the cylindrical pendulum bob can be estimated.

### Equipment list

| | | |
|---|---|---|
| 1 | Sensor-CASSY | 524 010 or 524 013 |
| 1 | CASSY Lab 2 | 524 220 |
| 1 | Laser motion sensor S | 524 073 |
| 1 | Stand rod with thread | 688 808 |
| 1 | Pair of helical springs | 352 15 |
| 1 | Slotted mass hanger | 315 450 |
| 1 | Slotted weight 500 g | 315 460 |
| 1 | Beaker, 3000 ml | 664 134 |
| 1 | Stand rod, 1 m | 300 44 |
| 1 | Stand rod, 25 cm | 300 41 |
| 2 | Leybold multiclamps | 301 01 |
| 1 | Stand base, V-shape, 28 cm | 300 01 |
| 1 | PC with Windows XP/Vista/7 | |

### Alternatives

Instead of the laser motion sensor S, the force sensor S, ±50 N (524 042) can also be used for the path measurement. From the measured force $F_{A1}$ and the spring constant D, the deflection $s_{A1}=F_{A1}/D$ can be calculated using a formula.

For investigating air friction, attach a piece of cardboard to the pendulum bob to create air friction.

### Experiment setup (see drawing)

Set up the spring pendulum with the large spring (∅=3.5 cm). For the path measurement, attach a piece of retroreflecting foil to the lowest turn of the spring so that the laser spot of the motion sensor hits the foil during the entire oscillation (if necessary, attach the foil outside the spring).

Due to the reversal of its helical sense in the middle, this particular spring makes possible a free stable up and down oscillation because no torsional oscillation is excited.

When the pendulum bob is in its equilibrium position, it should be near the middle of the water-filled beaker.

### Carrying out the experiment

■ Load settings

- If modeling is not yet desired, switch to the **Standard** display during the measurement.
- Define the pendulum's equilibrium position as the zero point of the path (→ **0** ← in Settings sA1; before doing so, you may allow the laser motion sensor S to warm up for some minutes).
- Deflect the pendulum bob downwards.
- Start the measurement with ⏱.
- Release the pendulum bob. The measurement starts automatically when the equilibrium position at s=0 is passed for the first time.

### Modeling

In the present example, the two initial conditions $s(t=0)=0$ and $v(t=0)=v_0$ were chosen because the triggering took place in the zero point of the path. The initial velocity $v_0$, the spring constant D, the mass m and the friction constant $F_0$ can be altered by dragging the pointer of the corresponding display instrument (or by clicking to the left or to the right of the pointer) until the model agrees with the measurement.

The dependence of the model's frictional force on the velocity can be seen in the **Frictional force** display.

The drag force $F_L$ for the pendulum bob around which the liquid flows is given by

$$F_L = c_w \cdot 1/2 \cdot \rho \cdot v^2 \cdot A = F_0 \cdot (v/v_0)^2$$

with the drag coefficient $c_w$, the dynamic pressure $p=1/2 \cdot \rho \cdot v^2$ and the backwater surface $A=\pi \cdot r^2$. The drag coefficient is the ratio of the measured force and the imagined dynamic force $p \cdot A$. We obtain

$$c_w = 2F_0/v_0^2/(\rho \cdot A).$$

In the present example, we have r = 2.5 cm and $\rho$ = 1 g/cm$^3$, and therefore $\rho \cdot A$ = 1.96 kg/m. The modeling process gives $F_0$ = 0.1828 N and $v_0$ = 0.325 m/s. Thus we find $c_w$ = 1.7.

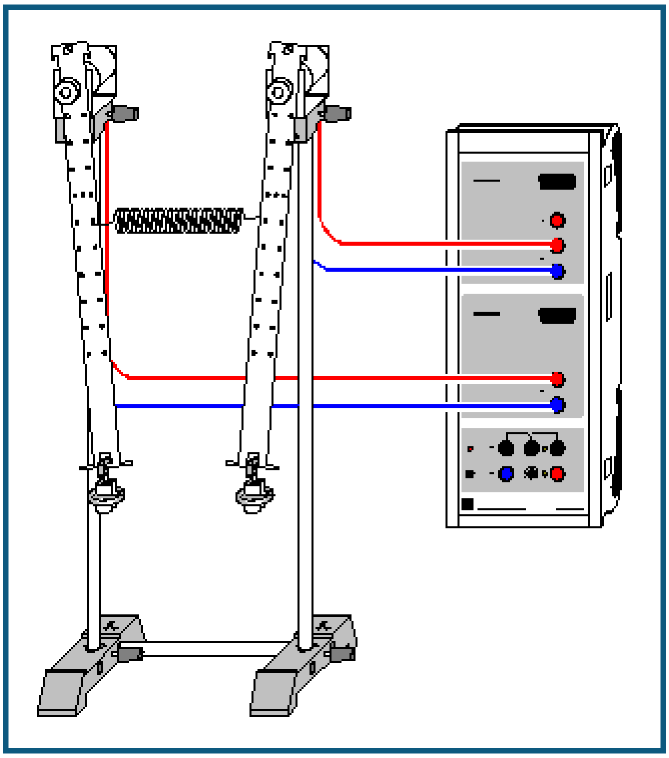
### Envelope

For small frictional forces proportional to the square of the velocity, the function describing the envelope is given by

$\pm f(t) = |v_0| \cdot \mathrm{sqr}(m/D)/(1+4/3\pi \cdot F_0/m/|v_0| \cdot t) = s_0/(1+4/3\pi \cdot k \cdot t)$

with $\varphi_0=\mathrm{sqr}(D/m)$, $s_0=|v_0|/\varphi_0$ and $k=F_0/m/|v_0|$.

## Coupled pendulums with two tachogenerators



can also be carried out with Pocket-CASSY

### Experiment description

Two coupled pendulums swing in phase with a frequency $f_1$ when they are deflected from the rest position by the same distance. When the second pendulum is deflected in the opposite direction, the two pendulums oscillate in opposing phase with the frequency $f_2$. Deflecting only one pendulum generates a coupled oscillation with the frequency

$f_n = ½ (f_1 + f_2)$

in which oscillation energy is transferred back and forth between the two pendulums. The first pendulum comes to rest after a certain time, while the second pendulum simultaneously reaches its greatest amplitude. The time from one standstill of a pendulum to the next is called $T_s$. For the corresponding beat frequency, we can say

$f_s = | f_1 – f_2 |$.

### Equipment list

| | | |
|---|---|---|
| 1 | Sensor-CASSY | 524 010 or 524 013 |
| 1 | CASSY Lab 2 | 524 220 |
| 1 | Pair of bar pendulums, 40 cm | 346 03 |
| 1 | Set of weights | 340 85 |
| 2 | Support clips, for plugging in | from 314 04ET5 |
| 1 | Helical spring, 3 N/m | 352 10 |
| 2 | STE tachogenerators | 579 43 |
| 2 | Clamping blocks MF | 301 25 |
| 1 | Stand rod, 25 cm, d = 10 mm | 301 26 |
| 2 | Stand rods, 50 cm, d = 10 cm | 301 27 |
| 2 | Stand bases MF | 301 21 |
| 2 | Pairs of cables, 100 cm, red and blue | 501 46 |
| 1 | PC with Windows XP/Vista/7 | |

### Experiment setup (see drawing)

The motions of the pendulums are transmitted to the tachogenerators. The voltages of the tachogenerators are measured at Sensor-CASSY inputs A and B. To vary the coupling, the coupling spring can be connected at different heights.

### Carrying out the experiment

- ■ Load settings
- Start the measurement with ⏱ and deflect both pendulums in phase (measurement stops after 30 s).
- Start the measurement with ⏱ and deflect both pendulums in opposing phase (measurement stops after 30 s).
- Start the measurement with ⏱and deflect only the first pendulum (measurement stops after 30 s).

### Evaluation

Click on the **Natural Oscillations** display to view the two natural oscillations:

$U_+ = U_A + U_B$

$U_- = U_A – U_B$

When the pendulums are excited in phase, only $U_+$ oscillates with a frequency $f_1$; only $U_-$ oscillates for opposing phase oscillation and has the frequency $f_2$. Only when the single pendulum alone is deflected does the system oscillate with both natural frequencies, thus generating the typical beat in the **Standard** display.

To determine the beat frequency $f_s$ and the new oscillation frequency $f_n$, you can mark e.g. the diagram with vertical lines or measure the difference directly (to increase the accuracy you should average the values over several periods when determining the oscillation frequency $f_n$).

In this example we obtain $f_1 = 0.875$ Hz, $f_2 = 0.986$ Hz, $f_n = 0.93$ Hz, $f_s = 0.11$ Hz, which closely confirms the theory $f_n = ½ (f_1 + f_2) = 0.93$ Hz and $f_s = | f_1 – f_2 | = 0.11$ Hz.

In the **Frequency Spectrum**, you can compare the frequencies and amplitudes $U_+$, $U_-$ and $U_A$. The easiest way to determine the frequency is to find the peak centers.

### Theory

When we apply suitable approximations (small deflections, negligible weight of coupling spring and pendulum bar, no damping), the motion equations of the pendulum bodies are as follows:

$F_1 = ma_1 = –Dx_1 + C(x_2 – x_1)$
$F_2 = ma_2 = –Dx_2 – C(x_2 – x_1)$

$-Dx_i$ (where $D = mg/l$) represents the restoring force of the individual pendulum, and $C(x_2 – x_1)$ describes the force of the coupling between the two pendulums. These resolve to the superposition

$x(t) = A \cos(\varphi_1 \cdot t) + B \cos(\varphi_2 \cdot t)$

with the fundamental frequencies $\varphi_1$ and $\varphi_2$. The specific initial conditions provide the values for A and B:

In-phase excitation gives us $A = x_0$, $B = 0$ (harmonic oscillation with $\varphi_1$)
Opposing phase excitation gives us $A = 0$, $B = x_0$ (harmonic oscillation with $\varphi_2$)
Deflection of one pendulum gives us $A = B = ½ x_0$.

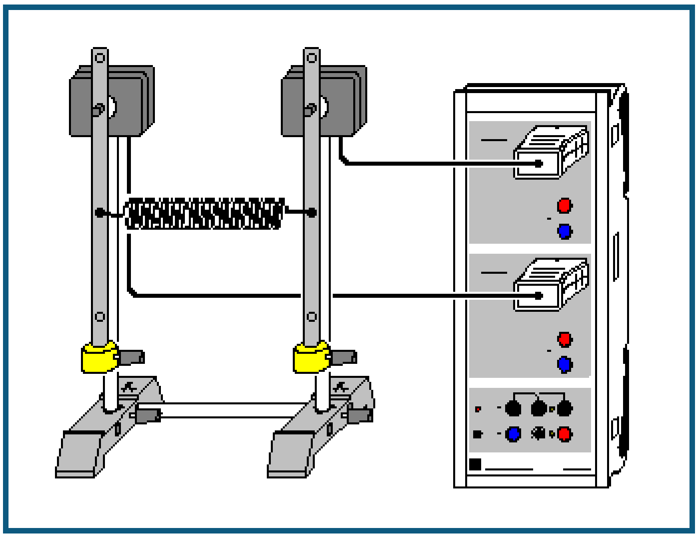
In the latter case we can say:

$x(t) = ½ x_0 ( \cos(\varphi_1 \cdot t) + \cos(\varphi_2 \cdot t) ) = x_0 \cos(½\varphi_s \cdot t) \cos(\varphi_n \cdot t)$

where $\varphi_s = | \varphi_1 – \varphi_2 |$ and $\varphi_n = ½ (\varphi_1 + \varphi_2)$ or $f_s = | f_1 – f_2 |$ and $f_n = ½ (f_1 + f_2)$.

When the difference between frequencies $f_1$ and $f_2$ is small, this equation describes an oscillation with the frequency $f_n$ which is modulated by the slower frequency $f_s$ – i.e. a beat.

## Coupled pendulums with two rotary motion sensors



can also be carried out with Pocket-CASSY

### Experiment description

Two coupled pendulums swing in phase with a frequency $f_1$ when they are deflected from the rest position by the same distance. When the second pendulum is deflected in the opposite direction, the two pendulums oscillate in opposing phase with the frequency $f_2$. Deflecting only one pendulum generates a coupled oscillation with the frequency

$f_n = ½ (f_1 + f_2)$

in which oscillation energy is transferred back and forth between the two pendulums. The first pendulum comes to rest after a certain time, while the second pendulum simultaneously reaches its greatest amplitude. The time from one standstill of a pendulum to the next is called $T_s$. For the corresponding beat frequency, we can say

$f_s = | f_1 – f_2 |$.

### Equipment list

| | | |
|---|---|---|
| 1 | Sensor-CASSY | 524 010 or 524 013 |
| 1 | CASSY Lab 2 | 524 220 |
| 2 | Rotary motion sensors S | 524 082 |
| 2 | Physical pendulums | 346 20 |
| 1 | Helical spring, 3 N/m | 352 10 |
| 1 | Stand rod, 25 cm, d = 10 mm | 301 26 |
| 2 | Stand bases MF | 301 21 |
| 1 | PC with Windows XP/Vista/7 | |

### Experiment setup (see drawing)

The pendulums are screwed on the axle of the rotary motion sensors and the masses are attached to the lower end of the pendulums. To vary the coupling, the coupling spring can be connected at different heights.

### Carrying out the experiment

☐ Load settings

- Define the zero points in the equilibrium position of the pendulums (→ **0** ← in Settings αA1 and αB1)
- Start the measurement with ⏱ and deflect both pendulums in phase (measurement stops after 40 s).
- Start the measurement with ⏱ and deflect both pendulums in opposing phase (measurement stops after 40 s).
- Start the measurement with ⏱and deflect only the first pendulum (measurement stops after 40 s).

## Evaluation

Click on the **Natural Oscillations** display to view the two natural oscillations:

$\alpha_+ = \alpha_A + \alpha_B$

$\alpha_- = \alpha_A - \alpha_B$

When the pendulums are excited in phase, only $\alpha_+$ oscillates with a frequency $f_1$; only $\alpha_-$ oscillates for opposing phase oscillation and has the frequency $f_2$. Only when the single pendulum alone is deflected does the system oscillate with both natural frequencies, thus generating the typical beat in the **Standard** display.

To determine the beat frequency $f_s$ and the new oscillation frequency $f_n$, you can mark e.g. the diagram with vertical lines or measure the difference directly (to increase the accuracy you should average the values over several periods when determining the oscillation frequency $f_n$).

In this example we obtain $f_1$ = 1.059 Hz, $f_2$ = 1.151 Hz, $f_n$ = 1.097 Hz, $f_s$ = 0.092 Hz, which closely confirms the theory $f_n = ½ (f_1 + f_2)$ = 1.105 Hz and $f_s = | f_1 – f_2 |$ = 0.092 Hz.

In the **Frequency Spectrum**, you can compare the frequencies and amplitudes $\alpha_+$, $\alpha_-$ and $\alpha_A$. The easiest way to determine the frequency is to find the peak centers.

## Theory

When we apply suitable approximations (small deflections, negligible weight of coupling spring and pendulum bar, no damping), the motion equations of the pendulum bodies are as follows:

$F_1 = ma_1 = –Dx_1 + C(x_2 – x_1)$
$F_2 = ma_2 = –Dx_2 – C(x_2 – x_1)$

$-Dx_i$ (where D = mg/l) represents the restoring force of the individual pendulum, and $C(x_2 – x_1)$ describes the force of the coupling between the two pendulums. These resolve to the superposition

$x(t) = A \cos(\varphi_1 \cdot t) + B \cos(\varphi_2 \cdot t)$

with the fundamental frequencies $\varphi_1$ and $\varphi_2$. The specific initial conditions provide the values for A and B:

In-phase excitation gives us $A = x_0$, $B = 0$ (harmonic oscillation with $\varphi_1$)
Opposing phase excitation gives us $A = 0$, $B = x_0$ (harmonic oscillation with $\varphi_2$)
Deflection of one pendulum gives us $A = B = ½ x_0$.

In the latter case we can say:

$x(t) = ½ x_0 ( \cos(\varphi_1 \cdot t) + \cos(\varphi_2 \cdot t) ) = x_0 \cos(½\varphi_s \cdot t) \cos(\varphi_n \cdot t)$

where $\varphi_s = | \varphi_1 – \varphi_2 |$ and $\varphi_n = ½ (\varphi_1 + \varphi_2)$ or $f_s = | f_1 – f_2 |$ and $f_n = ½ (f_1 + f_2)$.

When the difference between frequencies $f_1$ and $f_2$ is small, this equation describes an oscillation with the frequency $f_n$ which is modulated by the slower frequency $f_s$ – i.e. a beat.

## Three-body problem (with modeling)

### Experiment description

The three-body problem of celestial mechanics is the calculation of the paths of e.g. sun, earth and moon. The three bodies move on account of the gravitational forces acting between them which in the vector notation can be described as $\mathbf{F}_S$, $\mathbf{F}_E$, $\mathbf{F}_M$ :

$$\mathbf{F}_S = -G \cdot m_S \cdot \left( \frac{m_E}{|\mathbf{r}_S - \mathbf{r}_E|^3} \cdot (\mathbf{r}_S - \mathbf{r}_E) + \frac{m_M}{|\mathbf{r}_S - \mathbf{r}_M|^3} \cdot (\mathbf{r}_S - \mathbf{r}_M) \right)$$

$$\mathbf{F}_E = -G \cdot m_E \cdot \left( \frac{m_S}{|\mathbf{r}_E - \mathbf{r}_S|^3} \cdot (\mathbf{r}_E - \mathbf{r}_S) + \frac{m_M}{|\mathbf{r}_E - \mathbf{r}_M|^3} \cdot (\mathbf{r}_E - \mathbf{r}_M) \right)$$

$$\mathbf{F}_M = -G \cdot m_M \cdot \left( \frac{m_S}{|\mathbf{r}_M - \mathbf{r}_S|^3} \cdot (\mathbf{r}_M - \mathbf{r}_S) + \frac{m_E}{|\mathbf{r}_M - \mathbf{r}_E|^3} \cdot (\mathbf{r}_M - \mathbf{r}_E) \right)$$

The modeling is able to calculate any number of coupled differential equations, including the following 12 differential equations:

$x_S' = vx_S$ $vx_S' = Fx_S/m_S$ $y_S' = vy_S$ $vy_S' = Fy_S/m_S$
$x_E' = vx_E$ $vx_E' = Fx_E/m_E$ $y_E' = vy_E$ $vy_E' = Fy_E/m_E$
$x_M' = vx_M$ $vx_M' = Fx_M/m_M$ $y_M' = vy_M$ $vy_M' = Fy_M/m_M$

With appropriate initial conditions, this solves the three-body problem.

In order for the calculation to be able to run in real time, in this example some of the constants have been modified, e.g.:

$G = 1\ m^3/(s^2 \cdot kg)$
$m_S = 1$ kg
$m_E = 1$ g
$m_M = 0.01$ g

This gives distances of the order of magnitude of 1 m, and a year only takes a few seconds.

### Carrying out the experiment

■ Load settings
- Start the calculation with ⏱.
- Stop the calculation after a few years with ⏱.

### Evaluation

The first two of Kepler's laws can be verified:

1. The planets move on elliptical paths at one of the foci of which is the sun.

2. A line connecting the planet to the sun sweeps out the same area in the same time. For confirmation, the evaluation Diagram → Calculate Integral → Area to Origin can be used. As the calculation is carried out at constant intervals, for calculating the integral an equal number of values always have to be marked.Select Value Display → Show Values , with this as it is already prepared in the display for the **evaluation**.

Kepler's laws apply exactly only for a two-body problem. For a closer approximation the mass of the moon can be selected to be even smaller.

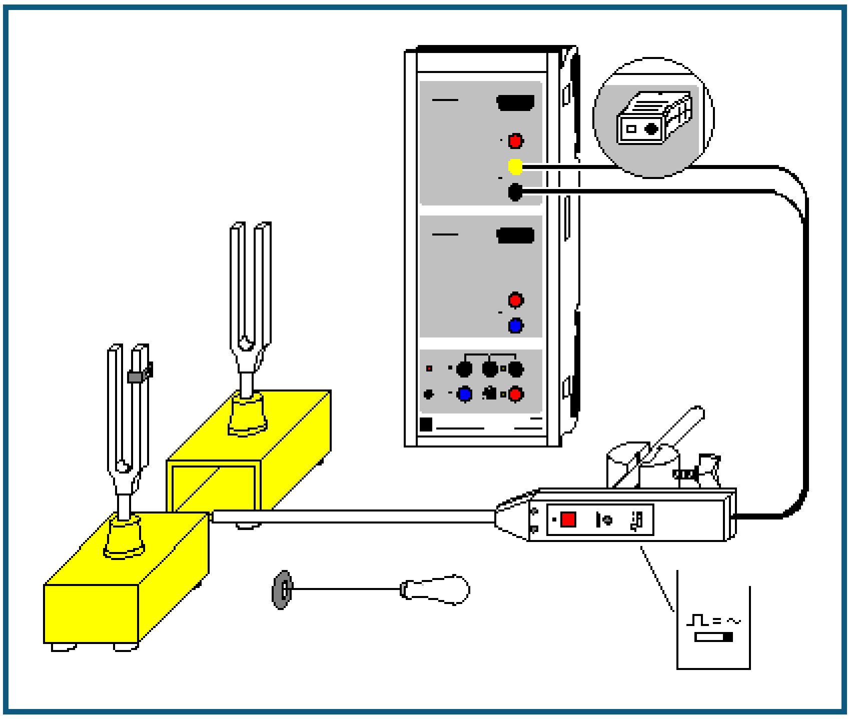
The initial conditions have been chosen so that the centre of gravity of the system is at the origin of the coordinate system.

By means of Diagram → Zoom, the movement of the sun at the origin can be investigated more closely.

### Change to the initial conditions

The initial velocity of Earth $v_{E0}$ or the initial distance of the moon from Earth $d_{EM0}$ can be rapidly modified by dragging the pointer of the corresponding display unit. This also allows unstable solar systems to be simulated.

## Acoustic beats



✓ can also be carried out with Pocket-CASSY

### Experiment description

This experiment records a beat caused by two tuning forks having slightly different frequencies. The individual frequencies $f_1$ and $f_2$, the new oscillation frequency $f_n$ and the beat frequency $f_s$ are determined and compared with the theoretical values

$f_n = ½ (f_1 + f_2)$ and $f_s = | f_1 – f_2 |$.

### Equipment list

| | | |
|---|---|---|
| 1 | Sensor-CASSY | 524 010 or 524 013 |
| 1 | CASSY Lab 2 | 524 220 |
| | | |
| 1 | Multi-purpose microphone | 586 26 |
| | with Base | 300 11 |
| | or | |
| 1 | Microphone S | 524 059 |
| | | |
| 1 | Pair of resonance tuning forks | 414 72 |
| 1 | PC with Windows XP/Vista/7 | |

### Experiment setup (see drawing)

Position the two tuning forks and the multipurpose microphone and connect the latter to input A of Sensor-CASSY (don't forget to set the microphone to "Signal" mode and switch it on). "Mistune" one of the tuning forks slightly by attaching an additional weight.

### Carrying out the experiment

■ Load settings
- Strike the first tuning fork and start the measurement with ⏱.
- Optimize the signal strength using the control on the microphone.
- Determine the frequency $f_1$ (e.g. by marking the **Standard** display with vertical lines or finding the peak center in the **Frequency Spectrum**).
- Delete the measurement with 🗋.
- Strike the second tuning fork and start the measurement with ⏱.

- Find frequency $f_2$.
- Delete the measurement with 🗋.
- Strike both tuning forks equally hard and start the measurement with ⏱.

### Evaluation

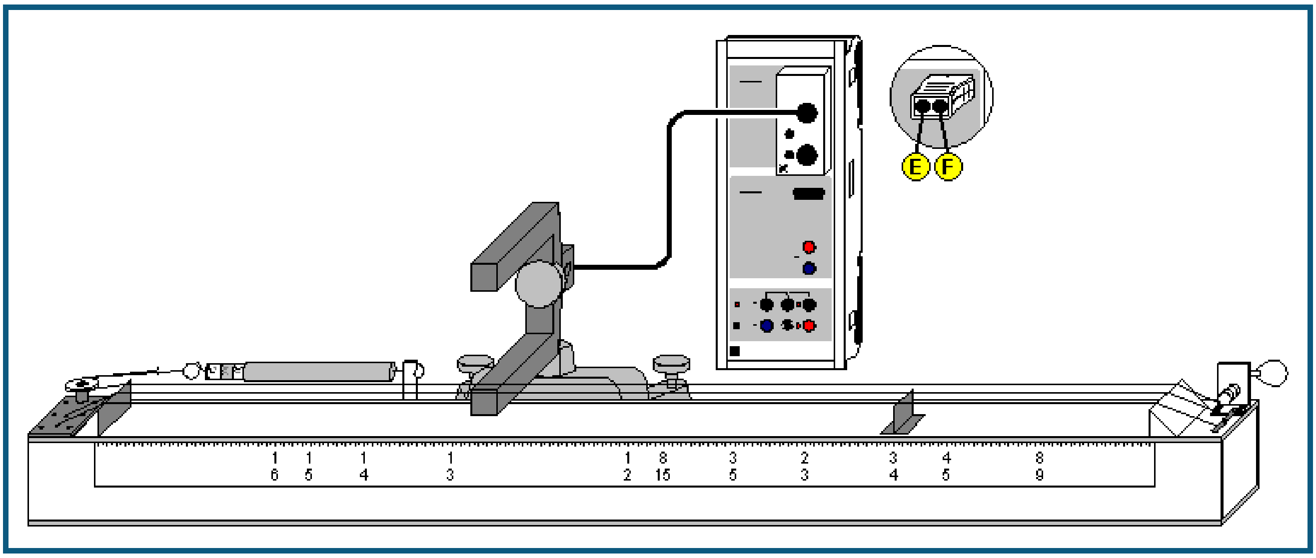
When the amplitudes of the two tuning forks are equal, the nodes and antinodes in the beat become clearly distinguished. The beat frequency $f_s$ is determined from the interval $T_s$ between two nodes as $f_s = 1/T_s$.

To ensure satisfactory accuracy in determining the new oscillation period $T_n$, you should average the measurements over 10 periods before determining the new oscillation frequency as $f_n = 1/T_n$. To determine the time differences you can e.g. insert vertical lines in the diagram or measure the difference directly.

In this example we obtain $f_1$ = 425 Hz, $f_2$ = 440 Hz, $f_n$ = 433 Hz, $f_s$ = 14.5 Hz, which closely confirms the theory $f_n = ½ (f_1 + f_2)$ = 432.5 Hz and $f_s = | f_1 – f_2 |$ = 15 Hz.

Click on the **Frequency Spectrum** to read out the two frequencies $f_1$ and $f_2$ of the tuning forks and their amplitudes. The easiest way to determine the frequency is to find the peak centers.

## String vibrations



can also be carried out with Pocket-CASSY

### Experiment description

When a string is stretched, the string length L is equal to half the wavelength of the fundamental mode: $L = \lambda/2$. Therefore the frequency f of the fundamental tone of the string is

$f = c/(2L)$,

where c is the phase velocity of the string. It depends on the tensile force F, the cross-sectional area A, and the density ρ. This dependence is described by the following relation:

$c^2 = F/(A\rho)$

In this experiment, the vibrational frequency f and thus the pitch of the string is measured as a function of the string length L and the tensile force F. For this the CASSY is used as a high-resolution stopwatch for measuring the period of vibration T. The relations $f^2 \propto F$ and $f \propto 1/L$ are confirmed.

### Equipment list

| | | |
|---|---|---|
| 1 | Sensor-CASSY | 524 010 or 524 013 |
| 1 | CASSY Lab 2 | 524 220 |
| 1 | Timer box or Timer S | 524 034 or 524 074 |
| 1 | Forked light barrier, infrared | 337 46 |
| 1 | Multicore cable, 6-pole, 1.5 m | 501 16 |
| 1 | Monochord | 414 01 |
| 1 | Precision dynamometer, 100 N | 314 201 |
| 1 | Stand base, V-shape, 20 cm | 300 02 |
| 1 | Stand rod, 10 cm | 300 40 |
| 1 | Stand rod, 25 cm | 300 41 |
| 1 | Leybold multiclamp | 301 01 |
| 1 | PC with Windows XP/Vista/7 | |

### Experiment setup (see drawing)

The period of vibration T is measured by means of a forked light barrier, which is positioned between the wooden resonance box of the monochord and the string. The light barrier is connected to the input A of the Sensor-CASSY via the timer box by means of the multicore cable.

### Experiment notes

The period of vibration T is determined unambiguously if the passages of the string through its position of rest are determined. For this the string has to be positioned so that the red LED on the side of the forked light barrier does not shine when the string is in its position of rest. The forked light barrier has two small apertures for the infrared beam. The best results are obtained if the string is positioned immediately over the smaller one of the two apertures (if necessary, turn the light barrier correspondingly).

The string is made vibrate by plucking it parallel to the surface of the resonance box.

The tensile force F is measured manually with the precision dynamometer. For this the hook is replaced with the precision dynamometer. The tension of the string on the monochord can be varied by means of a tuning key. In the first experiment, the best results are obtained if a string tension of 100 N is adjusted at first and then the measurement is carried out starting from high tension to lower tensions.

In the measurement with varying string length L, the string length is varied by displacing the bridge. When plucking the string, do not touch the part which does not vibrate with the other hand. For an optimal measurement of the period of vibration T, always position the forked light barrier in the middle of the vibrating part of the string.

## Carrying out the experiment

a) Variation of the tensile force

■ Load settings
- Adjust the desired string tension F by turning the tuning key.
- Write the force F displayed on the dynamometer in the prepared column of the table.
- Position the forked light barrier under the string at rest and check whether the red LED is out; if necessary, position the forked light barrier anew.
- Make the string vibrate by plucking it (while the string vibrates, the LED shines), and immediately transfer the displayed measured value into the table with ⏱.

b) Variation of the string length

■ Load settings
- Adjust the desired string length by positioning the bridge.
- Read the string length, and write it in the prepared column.
- Check whether the red LED is out; if necessary, position the forked light barrier anew.
- Make the string vibrate by plucking it (while the string vibrates, the LED shines), and immediately transfer the displayed measured value into the table with ⏱.

## Evaluation

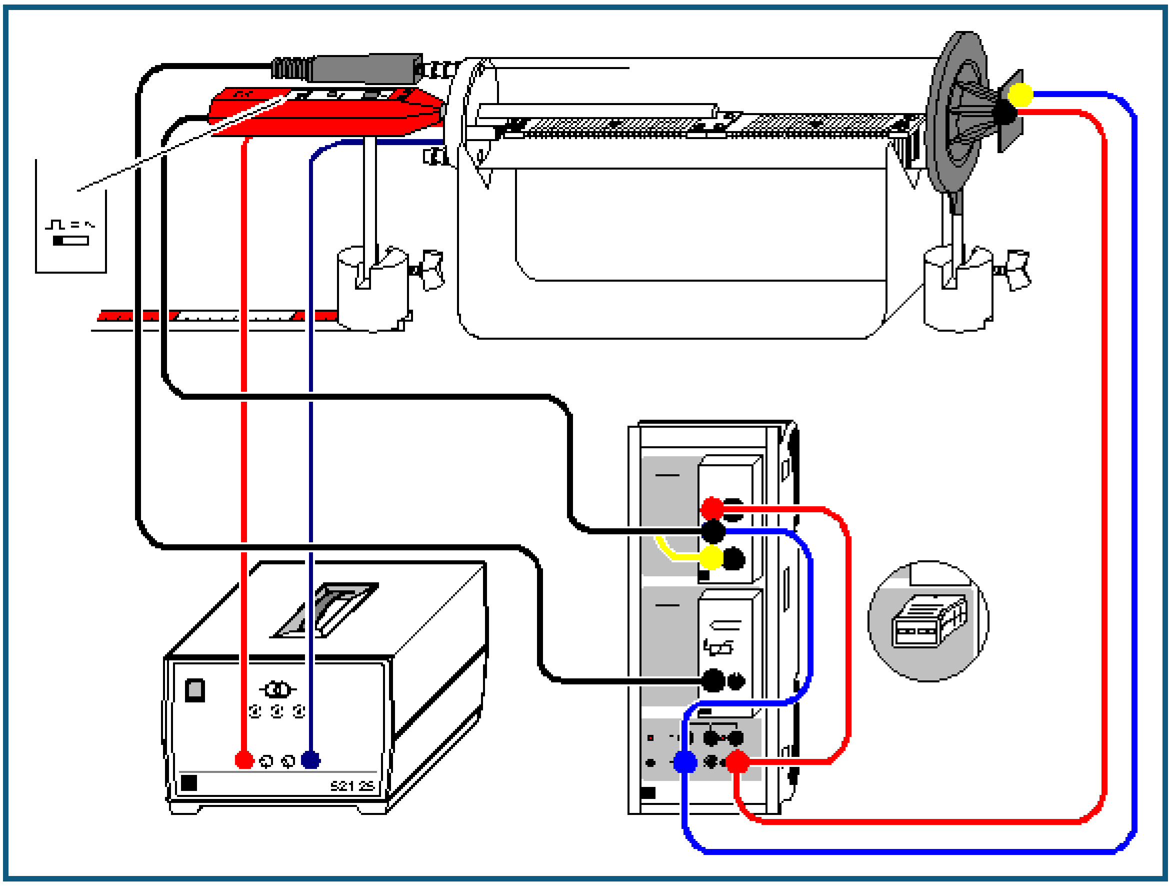
a) Variation of the tensile force

The T(F) and the f(F) diagram already appear while the measurement is running. In the prepared display **Evaluation**, the square of the frequency f is plotted against the tensile force F. The relation $f^2 \propto F$ can be confirmed by fitting a line through the origin (right mouse button). That means, the pitch, and thus the frequency, of a vibrating string increases with increasing string tension. Correspondingly, the pitch of a string can be lowered by decreasing the string tension.

b) Variation of the string length

The T(L) and the f(L) diagram already appear while the measurement is running. In the prepared display **Evaluation**, the square of the frequency f is plotted against 1/L. The relation $f \propto 1/L$ can be confirmed by fitting a line through the origin (right mouse button). That means, the pitch, and thus the frequency, of a vibrating string increases with decreasing length.

## Velocity of sound in air



### Experiment description

This experiment determines the speed of propagation of a sound pulse in air, and thus, since the group and phase velocities coincide, the velocity of sound. The sound pulse is generated by "shaking" the membrane of a loudspeaker with a steep voltage edge; this motion causes the pressure variation in the air. The sound pulse is registered by a microphone at a specified distance from the loudspeaker.

To determine the velocity of sound c, we measure the time t between generation of the pulse at the loudspeaker and registration at the microphone. As the exact point of origin of the sound pulse in the loudspeaker cannot be determined directly, two measurements are conducted, once with the microphone located at point $s_1$, and one at $s_2$. The velocity of sound is determined from the path difference $\Gamma s = s_1 - s_2$ and the corresponding difference in the transit time $\Gamma t = t_1 - t_2$ as $c = \Gamma s / \Gamma t$.

The apparatus for sound and velocity lets you heat the air with a heater; at the same time, this apparatus blocks out ambient effects such as temperature differences and air convection which can interfere with measuring. In this system the pressure p remains constant (actual ambient barometric pressure). As the temperature T rises, the density ρ decreases and the velocity of sound c increases.

### Equipment list

| | | |
|---|---|---|
| 1 | Sensor-CASSY | 524 010 or 524 013 |
| 1 | CASSY Lab 2 | 524 220 |
| 1 | Timer box | 524 034 |
| | | |
| 1 | Temperature box | 524 045 |
| 1 | Temperature sensor NiCr-Ni | 666 193 |
| | or | |
| 1 | NiCr-Ni adapter S | 524 0673 |
| 1 | Temperature sensor NiCr-Ni, type K | 529 676 |
| | | |
| 1 | Apparatus for sound velocity | 413 60 |
| 1 | Stand for tubes and coils | 516 249 |

| | | |
|---|---|---|
| 1 | Tweeter | 587 07 |
| 1 | Multi-purpose microphone | 586 26 |
| 1 | Transformer 12 V/3.5 A, e.g. | 521 25 |
| 1 | Scaled metal rail, 0.5 m | 460 97 |
| 2 | Saddle bases | 300 11 |
| 1 | Pair of cables, 25 cm, red and blue | 501 44 |
| 2 | Pairs of cables, 100 cm, red and blue | 501 46 |
| 1 | PC with Windows XP/Vista/7 | |

### Experiment setup (see drawing)

- Attach the heater of the apparatus for sound and velocity in the plastic tube on the plug pins of the cover.
- Place the plastic tube on the stand for tubes and coils and push the tweeter against it so that it seals the plastic tube as tightly as possible.
- Insert the multipurpose microphone approx. 1 cm deep into the middle hole of the cover and align it so that it moves parallel to the plastic tube when displaced. Set the function switch of the multipurpose microphone to the "Trigger" mode. Do not forget to switch the microphone on.
- Lay the scaled metal rail immediately under the saddle base.
- Plug in the timer box at input A and the temperature box at input B on Sensor-CASSY and set up the circuit as shown in the drawing; set the maximum output voltage at the voltage source S.

### Safety notes

The plastic tube of the apparatus for sound and velocity can be destroyed by excessive temperatures.

- Do not heat it above 80 °C.
- Do not exceed the maximum permissible voltage of 25 V (approx. 5 A) for the heating filament.

### Carrying out the experiment

a) Measuring at room temperature

■ Load settings
- Store multiple single measurements with ⏱.
- Slide the multipurpose microphone all the way into the plastic tube and read off the change in distance Γs from the scaled metal rail.
- Store multiple single measurements with ⏱.
- Determine the velocity of sound using c = Γs/Γt (determine the mean values of the transit times in the diagram using Draw Mean).

b) Measuring as a function of temperature

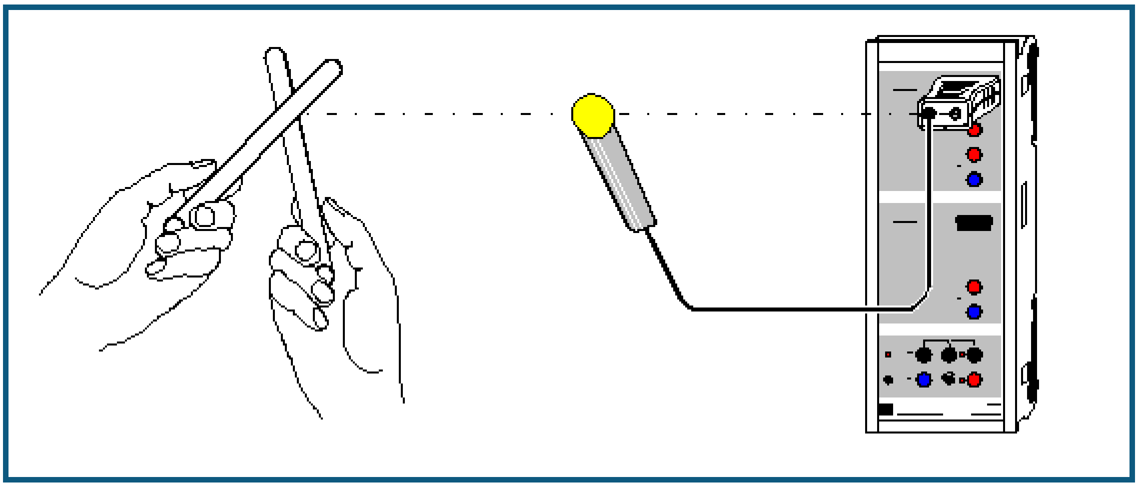
■ Load settings
- Pull out the universal microphone.
- At room temperature, determine the transit time $\Gamma t_{A1}$ again and, using the velocity of sound c already determined, calculate the distance $s=c\cdot\Gamma t_{A1}$ between the microphone and the speaker and write this value in the table (click on the first row in the s-column).
- Connect the heating filament to the voltage supply (12 V / approx. 3.5 A) via the sockets in the cover of the apparatus.
- Save the current transit times with ⏱ (e.g. every 5 °C).

### Evaluation

Once you determine the velocity of sound at room temperature in a) and thus the distance s between the microphone and the speaker in b), the software calculates the correct sound velocity c for each transit time $\Gamma t_{A1}$ simultaneously. The sound velocities are plotted in the **Temperature** display as a function of the temperature while the measurement is running. By fitting a straight line you can easily confirm the literature value of

$c = (331.3 + 0.6 \cdot \vartheta/°C)$ m/s.

## Determining the velocity of sound in air with 2 microphones



can also be carried out with Pocket-CASSY

### Experiment description

This experiment determines the speed of propagation of a sound pulse in air, and thus, since the group and phase velocities coincide, the velocity of sound. The sound pulse is generated by banging two stand rods together. This causes a pressure fluctuation in the air. The sound pulse is recorded in succession by two microphones which are at a distance Γs from each other.

For determining the velocity of sound c the time interval Γt between the two recordings at the microphones is measured. The velocity of sound is then obtained from the path difference Γs and the associated run time difference Γt. It is c = Γs/Γt.

### Equipment list

| | | |
|---|---|---|
| 1 | Sensor-CASSY | 524 010 or 524 013 |
| 1 | CASSY Lab 2 | 524 220 |
| 1 | Microphone S | or |
| 1 | PC microphone | 586 281 |
| 1 | Metal rule, 1 m | 311 02 |
| 2 | Stand rods, 47 cm | 300 42 |
| 1 | PC with Windows XP/Vista/7 | |

### Experiment setup (see drawing)

The external microphone is set up in front of the internal microphone at a distance Γs = 0.50 m. When sound is generated by means of the stand rods, the source of sound has to be located on the direct extension of the line between the two microphones. Moreover, sound coupling via the table should be as weak as possible because otherwise too high velocities may be measured.

### Carrying out the experiment

▢ Load settings
- Start the measurement with ⏱.
- Trigger several measurements by banging the stand rods together. Thereby noise from the surroundings, which might affect the measurement, should be avoided.
- Stop the measurement with ⏱.
- Increase the distance Γs between the microphones.
- Repeat the measurement.

### Evaluation

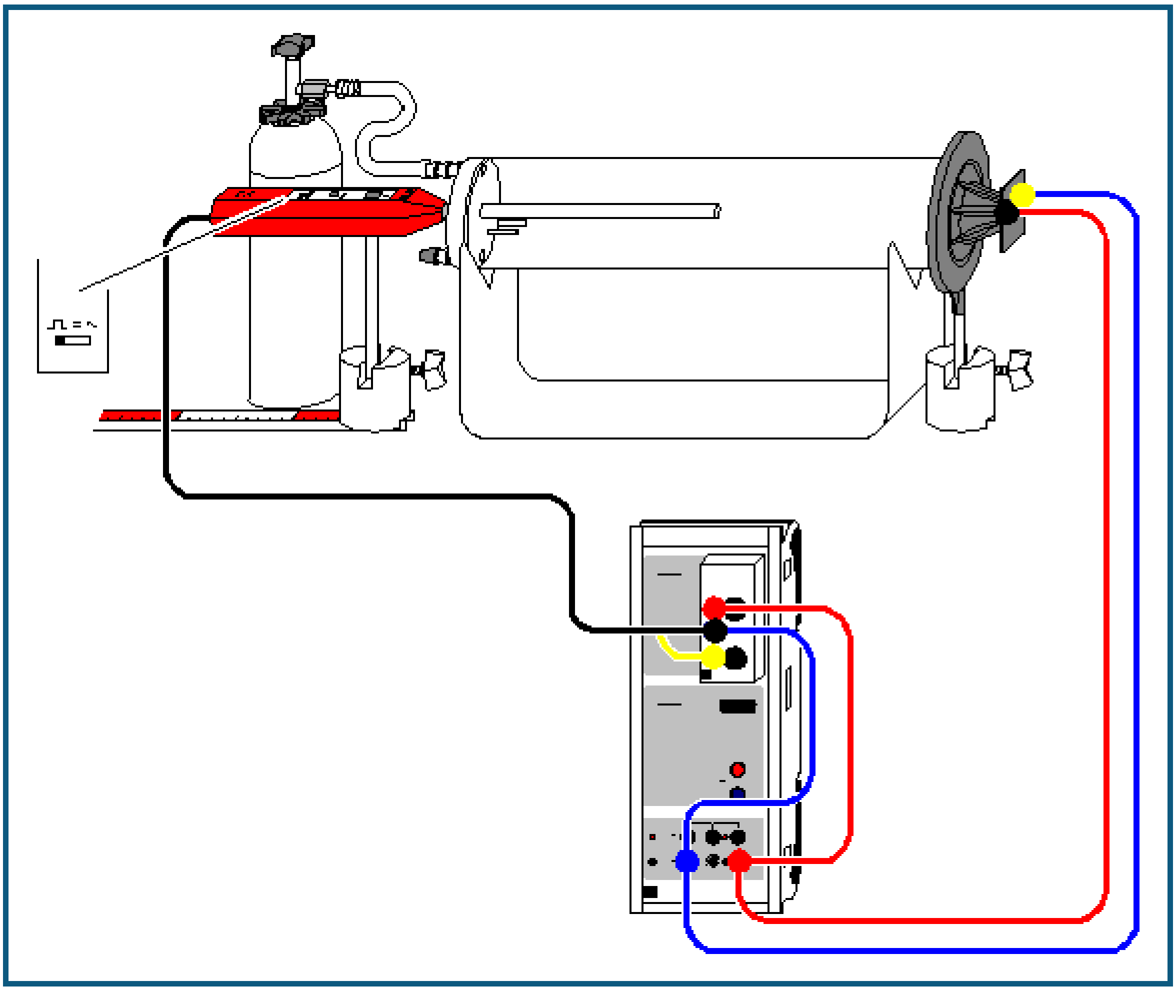
During the measurement, noise from the surroundings may lead to faulty measurements, which can easily be deleted. For this, just click the faulty value and delete it (backspace).

Next determine the mean values of the run times in the diagram using Draw Mean. There is a comfortable way of taking every mean value into the display **Velocity of sound** (mouse click) immediately after it has been calculated by shifting it from the Status line into the new table (Drag & Drop).

In addition, the associated distance $\Gamma s$ between the two microphones is entered into the corresponding column, whereby a $\Gamma s(\Gamma t)$ diagram is generated. The slope of the straight line in this diagram is $c = \Gamma s/\Gamma t$.

The velocity of sound obtained at room temperature is approx. $c = 346$ m/s.

## Velocity of sound in gases



**Be careful when handling Minican gas cans**

- The cans are pressurized; use only the fine regulating valve (660 980) to discharge gas.
- Protect the cans against sun light or warming over 50 °C.
- Do not use force to open the cans.
- Only dispose of completely emptied cans.
- Never refill the cans.

### Experiment description

In this experiment, the velocity of propagation of a sound pulse in carbon dioxide and in the noble gases helium and neon is determined. As sound waves in gases exhibit only little dispersion, – i.e., the group and phase velocity are equal to a good approximation when sound propagates in gases – the velocity of sound c can simply be determined experimentally from the velocity of propagation of a sound pulse:

$c^2 = p\,\theta/\rho$ with $\theta = C_p/C_V$

$\theta$: adiabatic exponent
$\rho$: density
p: pressure
$C_p$, $C_V$: specific heat capacity

The sound pulse is generated by a steep voltage edge which causes the diaphragm of a tweeter to perform a jerky motion. This motion of the diaphragm leads to a pressure variation in the gas, which can be detected by means of a microphone.

For determining the velocity of sound c in a gaseous medium, the travel time t between the pulse generation at the tweeter and the detection at the microphone is measured. As the sound pulse cannot be located exactly at the tweeter, the effective measuring distance is first determined by determining the velocity $c_{air}$ of sound in air. To do this, two travel time measurements are carried out with the microphone being located at the location $s_{A1}$ in one measurement and at the location $s_{A2}$ in the other measurement. The velocity of sound in air is then obtained from the path difference $\Gamma s = s_{A1}-s_{A2}$ and the associated travel time difference $\Gamma t = t_1-t_2$: $c_{air} = \Gamma s/\Gamma t$. This enables the effective measuring distance $s_{eff} = c_{air} \cdot t_1$ to be calculated for the location $s_{A1}$, which eventually enables a direct measurement of the velocity of sound in a gas.

### Equipment list

| | | |
|---|---|---|
| 1 | Sensor-CASSY | 524 010 or 524 013 |
| 1 | CASSY Lab 2 | 524 220 |
| 1 | Timer box | 524 034 |
| 1 | Apparatus for sound velocity | 413 60 |
| 1 | Stand for tubes and coils | 516 249 |
| 1 | Tweeter | 587 07 |
| 1 | Multi-purpose microphone | 586 26 |
| 1 | Scaled metal rail, 0.5 m | 460 97 |
| 2 | Saddle bases | 300 11 |
| 1 | Minican gas can, carbon dioxide | 660 999 |
| 1 | Minican gas can, helium | 660 984 |
| 1 | Minican gas can, neon | 660 985 |
| 1 | Fine regulating valve for Minican gas cans | 660 980 |
| 1 | Silicone tubing, 7 x 1.5 mm, 1 m | 667 194 |
| 1 | Rubber tubing, d = 4 mm | 604 481 |
| 1 | Tubing connector | 604 510 |
| 1 | Pair of cables, 25 cm, red and blue | 501 44 |
| 1 | Pair of cables, 100 cm, red and blue | 501 46 |
| 1 | PC with Windows XP/Vista/7 | |

### Experiment setup (see drawing)

- Lay the plastic tube (without heating coil) on the stand for tubes and coils, and turn it so that the two hose nipples are one above the other.
- Move the tweeter close to the plastic tube so that the plastic tube is closed as tight as possible.
- Insert the multipurpose microphone in the central bore of the cap to a depth of approx. 1 cm, and align it so that it moves parallel to the plastic tube when it is displaced. Set the function switch of the multipurpose microphone to the "Trigger" mode. Do not forget to switch the microphone on.
- Lay the scaled metal rail immediately under the saddle base.
- Plug the timer box on the input A of the Sensor-CASSY, and set up the circuit as shown in the drawing; set the maximum output voltage at the voltage source S.

### Experiment notes

To avoid unintended loss of gas, turn the handwheel of the fine regulating valve to the right stop before screwing the fine regulating valve on the gas can.

Any leakage of the measuring apparatus leads to an escape of gas and thus to a distortion of the measuring result; therefore the tweeter has to be placed as close to the plastic tube as possible.

In order to fill the plastic tube with carbon dioxide, put the silicone tubing on the lower hose nipple of the plastic tube. In this way, the gas is almost completely exchanged because the lighter air is pressed out through the upper hose nipple when carbon dioxide enters. Correspondingly, proceed the other way round when filling the plastic tube with the noble gases helium and neon: when helium or neon, respectively, enters through the upper hose nipple, the air, which is heavier, is pressed out through the lower hose nipple.

Concerning the measurements on helium and neon, keep in mind that the measuring apparatus cannot be perfectly sealed so that part of the highly-volatile gas in the plastic tube escapes. This results in a relatively high proportion of air, which distorts the measurements – therefore the measurements should be carried out quickly.

### Carrying out the experiment

■ Load settings

First determine the effective measuring distance $s_{eff}$:

- Insert the multipurpose microphone in the plastic tube by approx. 1 cm, read the position $s_{A1}$, and write it in the first line of the table. Write the travel time $\Gamma t_{A1}$ in the table with ⏱. Repeat the measurement of the travel time several times to improve the accuracy of measurement.

- Insert the multipurpose microphone entirely in the plastic tube, read the position $s_{A2}$, and write it in the next line of the table. Write the travel time $\Gamma t_{A1}$ in the table with ⏱. Repeat the measurement of the travel time several times to improve the accuracy of measurement.
- In order to determine the average travel times $t_1$ and $t_2$, select Draw Mean, and determine the velocity of sound in air $c_{air} = \Gamma s/\Gamma t = (s_{A1}-s_{A2})/(t_1-t_2)$.
- Determine the effective measuring distance $s_{eff} = c_{air} \cdot t_1$; for this enter the determined travel times $t_1$ and $t_2$ in the Settings seff (right mouse button on $s_{eff}$) in the formula $(s_{A1}-s_{A2})/(t_1-t_2)*t_1$.

Now the velocity of sound in carbon dioxide, helium and neon can be measured directly:

- Shift the multipurpose microphone back to the position $s_{A1}$.
- Let gas in through the hose nipple. Open the fine regulating valve very cautiously until the gas flowing out of the gas can is heard.
- Read the velocity of sound, and write it in the prepared display **Input** in the table or enter it there using drag & drop. In addition, write the density ρ in the table:

| Gas | Density ρ | Adiabatic exponent $\theta = C_p/C_V$ |
|---|---|---|
| Carbon dioxide | 1.98 kg/m$^3$ | 1.29 |
| Nitrogen (air) | 1.25 kg/m$^3$ | 1.40 |
| Neon | 0.90 kg/m$^3$ | 1.64 |
| Helium | 0.18 kg/m$^3$ | 1.63 |

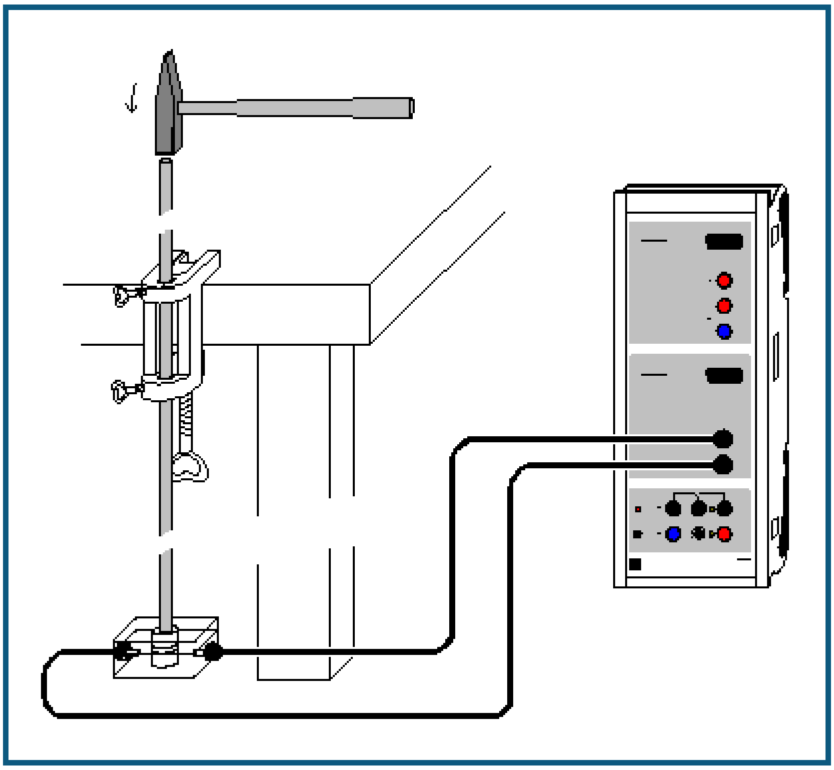
### Evaluation

In the prepared display **Evaluation**, the relation between $c^2$ and 1/ρ is shown. There you can, e.g. by entering the formula 101300*1.4*x in Free fit, draw the straight line which corresponds to the mean adiabatic coefficient θ=1.4 at normal air pressure.

Deviations of the measured values from this straight line are normal, particularly in the case of helium, which is highly volatile, because then the actual density of the gas is higher.

The great differences in the velocity of sound are essentially due to the different densities ρ of the gases as the differences in the adiabatic exponents $C_p/C_V$ are relatively small.

## Velocity of sound in solid bodies



### Experiment description

The object of this experiment is to determine the velocity of sound in aluminum, copper, brass and steel rods. This measurement exploits the multiple reflections of a brief sound pulse at the rod ends. The pulse is initially generated by tapping the top end of the rod with a small hammer, and initially runs downward. The pulse is reflected several times in succession at the two ends of the rod, whereby the pulses arriving at one end are delayed with respect to each other by the time Γt. As Γt is the sum of the transit time out and back, we can calculate the velocity of sound c using the rod length s as

c = 2s / Γt.

### Equipment list

| | | |
|---|---|---|
| 1 | Sensor-CASSY | 524 010 or 524 013 |
| 1 | CASSY Lab 2 | 524 220 |
| 1 | Set of 3 metal rods | 413 651 |
| 1 | Stand rod, 150 cm | 300 46 |
| 1 | Piezoelectric body | 587 25 |
| 1 | Bench clamp, simple | 301 07 |
| 2 | Connecting leads, 2 m, black | 501 38 |
| 1 | Small hammer | |
| 1 | PC with Windows XP/Vista/7 | |

### Experiment setup (see drawing)

The metal rods rest on the piezoelectric body, which converts the pressure oscillations of the sound pulses into electrical oscillations. These are recorded at input B of Sensor-CASSY.

### Carrying out the experiment

▨ Load settings

- Start the measurement with ⏱ (software waits for the trigger signal).
- Tap the top end of the first metal rod with the small hammer (to generate the trigger signal).
- Repeat the experiment with a different metal rod, or delete a faulty measurement with Measurement → Delete Current Measurement Series.

## Evaluation

You can determine the time differences Γt of the minima or maxima e.g. using 230113853vertical lines, finding the peak centers or by measuring the difference directly. As Γt is the sum of the transit time out and back, we can calculate the velocity of sound c using the rod length s as

$c = 2s / \Gamma t$.

This example gives us the following sound velocity values:

| Metal | Measurement | Literature value |
|---|---|---|
| Brass | 3530 m/s | 3500 m/s |
| Copper | 3900 m/s | 3800 m/s |
| Aluminum | 5000 m/s | 5110 m/s |
| Steel | 5170 m/s | 5100 m/s |

# Fourier analysis of simulated signals

## Experiment description

Harmonic analysis is a common method in many applications where time-variant signals (or measured values) occur. In acoustics, for example, exact knowledge of the overtones of a sound is important for the artificial generation of sounds or language.

In this experiment, the Fourier transform of simple periodic signals is studied as an introduction to the topic of Fourier transformation. In a first step, the Fourier transform of a numerically simulated signal is calculated and the frequencies of the associated amplitudes are determined (Fourier analysis). Based on this harmonic analysis, the time-variant signal is composed in a second step according to Fourier's theorem and compared with the theoretically calculated Fourier series and the numerically simulated original signal (Fourier synthesis).

## Experiment setup

Remark: the experiment is a pure simulation experiment on Fourier analysis with CASSY Lab. For an experiment with electric signals of corresponding shapes see the subsequent experiment. The signals $S_1$ investigated in this experiment are generated by the following functions:

| | |
|---|---|
| Delta: | $S_1$ = 4*(1-2*saw(f*t)) |
| Square wave: | $S_1$ = 4*(2*square(f*t)-1) |

with the frequency f = 0.5 Hz.

## Remarks concerning the Fourier transformation

A continuous time-variant signal $S_1$ is sampled during the computer-aided measurement at certain times. In this way, a digitized signal is obtained, which can be further processed using common methods of digital signal processing (improving the signal-to-noise ratio by means of Fourier transformation, smoothing the signal by averaging, etc.). The sampling theorem tells at what time intervals the signal value has to be measured so that the time dependence of the signal can be recovered from the digitized measured values (data points). For a digitization of the signal with a sufficient number of data points, the sampling frequency $f_s$ has to be at least twice the maximum frequency $f_{max}$ that occurs in the signal and determines the width of the frequency spectrum. If this condition, $f_s \geq 2_{fmax}$ is not fulfilled, i.e., if the digitization takes place at a lower sampling frequency $f_s$, the shape of the signal is no longer captured (aliasing). The sampling frequency $f_s$ of the measuring signal is determined by the interval $\Gamma t=1/f_s$ set in the Measuring Parameters (**Window → Show Measuring Parameters**).

Fourier's theorem says that any time-dependent periodic signal $S_1$ can be represented by a weighted sum of sin or cos functions. For the delta and square-wave functions used in this experiment, the series expansions of $S_1$ in trigonometric functions up to order 9 read:

Delta:

$S_3$ = 4*8/3.14^2 * (cos(360*f*t) + 1/9*cos(360*3*f*t) + 1/25*cos(360*5*f*t) + 1/49*cos(360*7*f*t)) + 1/81*cos(360*9*f*t)

Square wave:

$S_3$ = 4*4/3.14 * (sin(360*f*t) + 1/3*sin(360*3*f*t) + 1/5*sin(360*5*f*t) + 1/7*sin(360*7*f*t) + 1/9*sin(360*9*f*t)

Thus a discrete frequency spectrum with different amplitudes corresponds to the time-dependent function $S_1$. The generalization of this decomposition to non-periodic signals leads to the Fourier integral, which assigns a continuous frequency spectrum $F_1$ to the time-dependent signal $S_1$.

The numerical computation of the frequency spectrum $F_1$ is particularly efficient if a digitized signal of $N=2^p$ data points is taken as a basis. In this case, only approx. N · log2(N) arithmetic operations have to be carried out instead of approx. $N^2$ operations. This procedure, which is significantly less time consuming, is called fast Fourier transformation (FFT).

CASSY Lab computes the frequency spectrum $F_1$ using such an algorithm. However, first of all the given measured points are weighted so that non-periodic portions on the boundaries do not play an important role (on the boundaries 0, in the middle maximum, Kaiser-Bessel window(4.0)). In order that always exactly $2^p$ measuring points are available, zeros are added for measuring points that may be missing.

As a result of the FFT, CASSY Lab displays a total of N/2+1 amplitudes (i.e., phase differences are not evaluated). These amplitudes are represented as "excess" amplitudes, i.e. $A_i := A_{i-1} + A_i + A_{i+1}$, in order that the amplitudes of sharp peaks are in approximate agreement with theory. Without this excess, an amplitude determination as it is carried out in this experiment would require the calculation of the sum over all amplitudes of a peak.

There are limitations to the use of FFT for frequency analysis due to two basic relations. The first one relates the highest frequency $f_{max}$ that can be analyzed to the sampling frequency $f_s$:

$f_{max} = f_s/2$.

Any frequency which is greater than $f_{max}$ appears in the frequency spectrum between zero and $f_{max}$ and can then no longer be distinguished from the frequency contributions which really arise from the range between 0 and $f_{max}$. The resulting change in the signal shape is called aliasing.

The second relation relates the resolution of the frequency spectrum $\Gamma f$ (= distance of neighbouring points of the frequency spectrum) to the sampling frequency $f_s$:

$\Gamma f = f_{max}/(N/2) = f_s/N = 1/\Gamma t/N = 1/T$

with $T = N \cdot \Gamma t$.

That means that the resolution of the frequency spectrum can only be increased by a longer measuring time.

### Carrying out the experiment

▨ Load settings

- Using the mouse, set the pointer of the display instrument f to the desired frequency.
- ⏱ simulates the recording of measured values of the function $S_1$. The simulation takes 50 s and records 500 values ($\Gamma t$ = 100 ms).

Longer recording times increase the frequency resolution of the FFT step by step whereas shorter recording times decrease the resolution.

### Evaluation

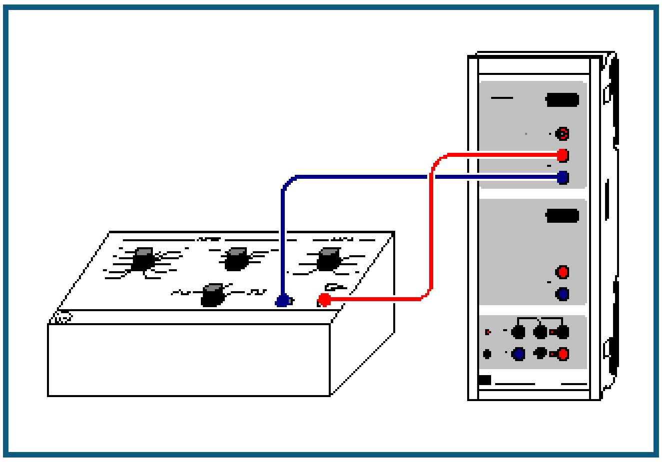
The $S_1(t)$ diagram of the numerically simulated signal appears already during the simulation of the measurement. After the simulation, the Fourier transform $F_1$ is available in the display **Frequency Spectrum**.

The frequency spectrum exhibits peaks at odd multiples of the set signal frequency f, i.e. at f, 3*f, 5*f, 7*f, etc.. The amplitudes of the peaks can be read by clicking the curve or from the coordinate display.

Now enter the first 5 amplitudes as coefficients of the sin(360*n*f*t) functions in the Settings A1, A3, A5, A7 and A9 for the analysis. In the display **Fourier Analysis**, the time dependence of the individual terms $A_1$, $A_3$, $A_5$, $A_7$ and $A_9$ is shown.

In the diagram **Fourier Synthesis**, the series $S_2 = A_1 + A_3 + A_5 + A_7 + A_9$ which has been determined experimentally is compared with theoretical Fourier series $S_3$ and the numerically simulated function $S_1$. It turns out that in practical applications the periodic signal $S_1$ is satisfactorily approximated by a trigonometric polynomial $S_2$ or $S_3$, respectively, containing only a few terms.

## Fourier analysis of signals of a function generator



can also be carried out with Pocket-CASSY

### Experiment description

Harmonic analysis is a common method in many applications where time-variant signals (or measured values) occur. In acoustics, for example, exact knowledge of the overtones of a sound is important for the artificial generation of sounds or language. In metrology, Fourier analysis is used, for example, for checking electromagnetic compatibility (EMC) of electronic devices.

In this experiment, the Fourier transform of simple periodic signal shapes is studied as an introduction to the topic of Fourier transformation. Electric (analog) signals of a function generator are read, and the Fourier transform of the digitized signal is calculated. From the frequency spectrum the amplitudes of the different harmonics (Fourier analysis) are calculated and compared with the theoretical values.

### Equipment list

| | | |
|---|---|---|
| 1 | Sensor-CASSY | 524 010 or 524 013 |
| 1 | CASSY Lab 2 | 524 220 |
| 1 | Function generator S12 | 522 621 |
| 1 | Pair of cables, 50 cm, red and blue | 501 45 |
| 1 | PC with Windows XP/Vista/7 | |

### Experiment setup (see drawing)

Connect the continuously adjustable signal of the function generator to the input A of the Sensor-CASSY.

Remark: This experiment concerns the Fourier analysis of digitized signals of a function generator. For remarks concerning fast Fourier analysis and the treatment of the Fourier synthesis of corresponding signal shapes see the previous simulation experiment.

### Experiment notes

For some types of function generators it may be necessary to set the DC offset exactly to zero in order to avoid distorted frequency spectra.

### Carrying out the experiment

☐ Load settings

- Set the desired signal shape and a frequency of approx. 500 Hz at the function generator (set the DC offset to zero).
- Start the measurement with ⏱ for recording the signal.
- If necessary, adjust the sampling rate (interval) and the number of measuring points in the Measuring Parameters (**Window → Show Measuring Parameters**) corresponding to the selected signal frequency in order to obtain a frequency spectrum of sufficient resolution.

## Evaluation

While the signal is recorded, the $U_{A1}(t)$ diagram already appears, representing a digitized version of the analog signal of the function generator. After the signal $U_{A1}$ has been recorded, the Fourier transform of $U_{A1}$ is available for the harmonic analysis in the display **Frequency Spectrum**.

For determining the amplitudes of the harmonics, carry out the following steps one after another:

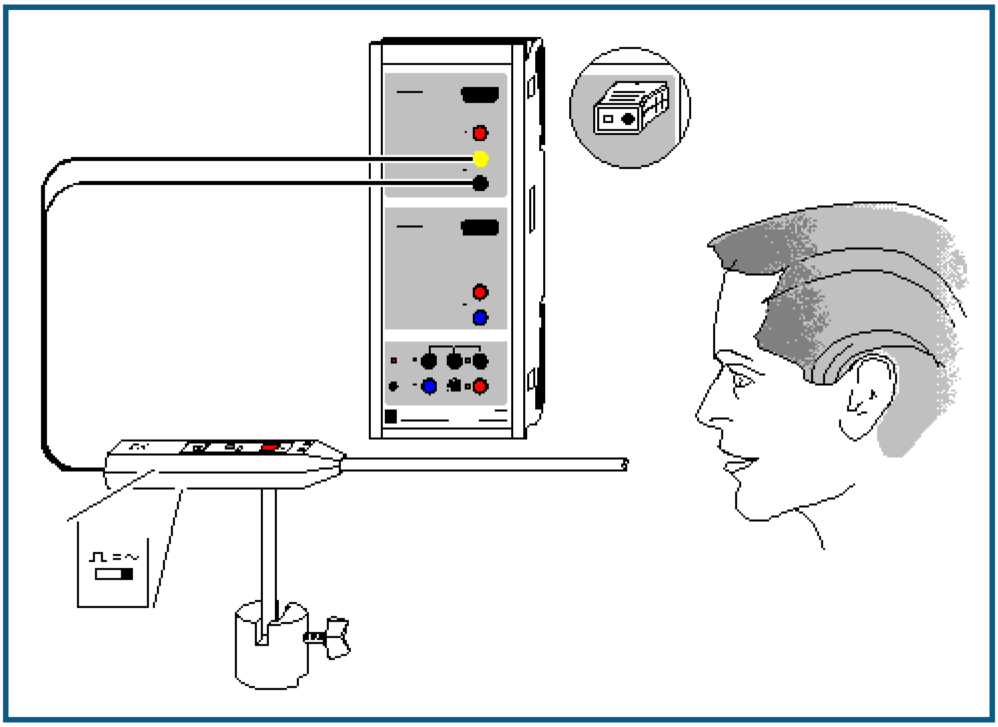
- Select the display **Frequency Spectrum**, and determine the amplitudes of the harmonics of order N with a horizontal line.
- Go to the display **Evaluation**, transfer the value of the amplitude from the status line into the prepared table in column A using the mouse (drag & drop), and enter the order N of the N-th harmonic.

The theoretical dependence of the amplitudes of the N-th harmonics can be confirmed for the respective signal shape by a subsequent free fit to a hyperbola $A/x^2$ (delta: N = 1, 3, 5, ...) or A/x (square wave: N = 1, 3, 5, ...; sawtooth: N = 1, 2, 3, 4, ...), respectively. Alternatively, the dependence of the amplitudes on N obtained by way of theoretical calculations can be checked by converting the x-axis into $1/x^2$ (delta) or 1/x (square wave, sawtooth) and a subsequent fit to a line through the origin.

Depending on the signal shape selected, the frequency spectrum also exhibits contributions of small amplitudes at frequencies between the theoretical frequencies (e.g. between N = 1, 3, 5, ... in the case of the delta signal). This is due to the fact that the signal shape is not ideal and that the signal is not strictly periodic over the range covered by the recording time window.

Remark: for an example of using Power CASSY as a function generator see the experiment on sonic synthesis.

## Sound analysis



can also be carried out with Pocket-CASSY

### Experiment description

The object of this experiment is the analysis of sounds having different tones and pitches (e.g. sounds of the human voice or of musical instruments) by means of Fourier analysis. The resulting frequency spectrum shows the fundamental frequency $f_0$ and the harmonics.

The various vowels of a language differ mainly in the amplitudes of their harmonics. The fundamental frequency $f_0$ depends on the pitch of the voice. This is approx. 200 Hz for high-pitched voices and approx. 80 Hz for low-pitched voices. The vocal tone is determined by variations in the excitation of the harmonics. The same applies for the tone of musical instruments.

### Equipment list

| | | |
|---|---|---|
| 1 | Sensor-CASSY | 524 010 or 524 013 |
| 1 | CASSY Lab 2 | 524 220 |
| | | |
| 1 | Multi-purpose microphone | 586 26 |
| | with Base | 300 11 |
| | or | |
| 1 | Microphone S | 524 059 |
| | | |
| 1 | PC with Windows XP/Vista/7 | |

### Experiment setup (see drawing)

Connect the multipurpose microphone to input A of Sensor-CASSY (don't forget to set the microphone to "Signal" mode and switch it on).

### Carrying out the experiment

☐ Load settings
- Start the measurement with ⏱.
- Select the **Standard** display and optimize the signal strength using the control on the microphone.
- Record and compare different sounds (**Standard** shows the signal form and **Frequency Spectrum** shows the Fourier analysis).

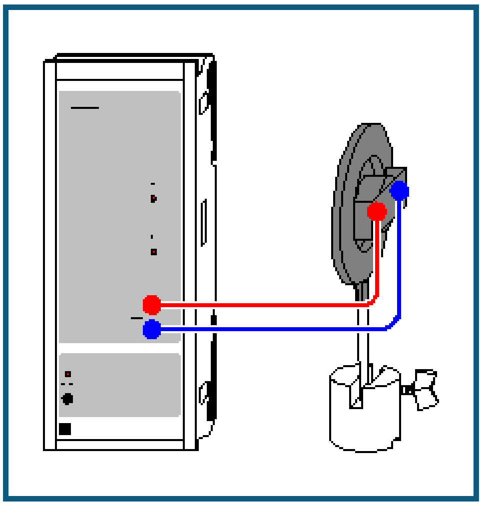
- To stop the measurement, deactivate **Repeating Measurement** in the Measuring Parameters window or press ⏱ immediately after the end of a recording.
- To compare different frequency spectra, select **Measurement** → **Append New Measurement Series** and restart the measurement with ⏱.

## Evaluation

The fundamental frequency and each harmonic can be determined easily in the **Frequency Spectrum** (click with the mouse) using the coordinate display or by finding the peak centers. The amplitudes of the harmonics determine the tone of the recorded sound.

As the human ear perceives sound intensities in a logarithmic fashion, the logarithmic display of the frequency spectrum is better suited to the sensitivity of the human ear than a linear representation. Select the logarithmic representation by clicking on the y-axis of the frequency spectrum with the right mouse button (increase the lower limit, e.g. to –3).

## Sonic synthesis



### Experiment description

This experiment generates sounds of different timbre and pitch by defining the fundamental frequency $f_0$ as well as the amplitude ratio between the fundamental frequency and its harmonics. The result is visible as an oscillogram and a frequency spectrum, and audible as a tone.

This experiment verifies that the timbre of a sound is determined by the specific excitation of harmonics. Also, the experiment illustrates how periodic functions can be generated through the harmonic combination of sinusoidal oscillations.

### Equipment list

| | | |
|---|---|---|
| 1 | Power-CASSY | 524 011 |
| 1 | CASSY Lab 2 | 524 220 |
| 1 | Broad band speaker | 587 08 |
| 1 | Saddle base | 300 11 |
| 1 | Pair of cables, 100 cm, red and blue | 501 46 |
| 1 | PC with Windows XP/Vista/7 | |

### Experiment setup (see drawing)

Connect the speaker to the output of Power-CASSY.

### Carrying out the experiment

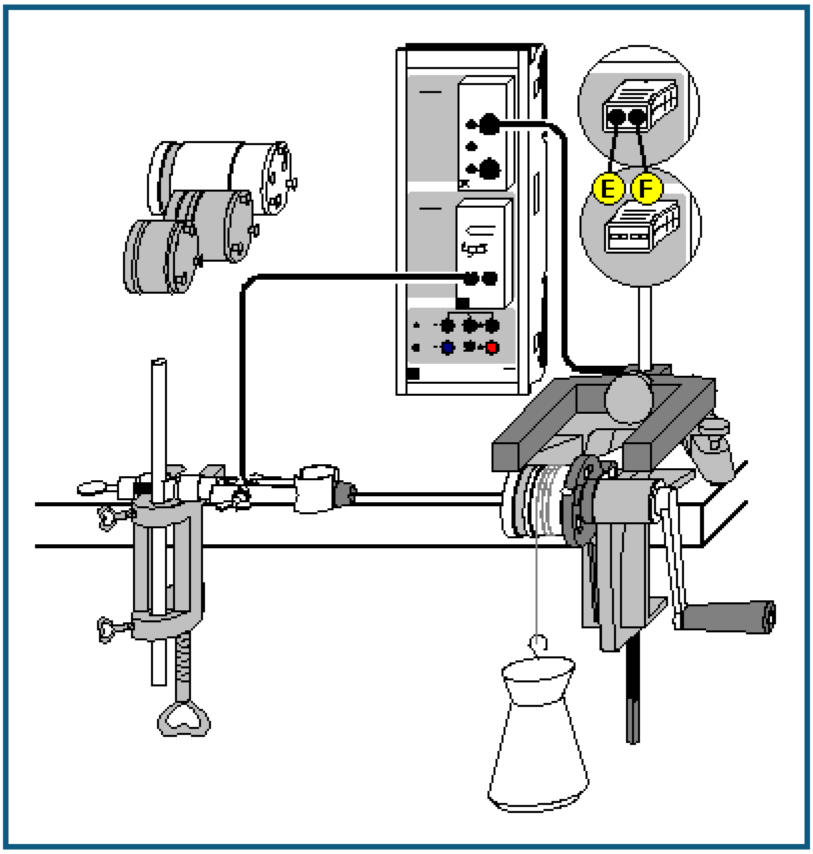
■ Load settings

- A square-wave oscillation approximated using sinusoidal oscillations is output at the loudspeaker. The formula for the curve form was defined as **synth(1:0:1/3:0:1/5:0:1/7:0:1/9:0:1/11:0:1/13:0: 1/15:0:1/17:0:1/19).** This is an abbreviation for the long form **1***sin(360*x)+ **0***sin(2*360*x)+ **1/3***sin(3*360*x)+ **0***sin(4*360*x)+ **1/5***sin(5*360*x)+ **0***sin(6*360*x)+ **1/7***sin(7*360*x)+ **0***sin(8*360*x)+ **1/9***sin(9*360*x)+ **0***sin(10*360*x)+ **1/11***sin(11*360*x)+ **0***sin(12*360*x)+ **1/13***sin(13*360*x)+ **0***sin(14*360*x)+ **1/15***sin(15*360*x)+ **0***sin(16*360*x)+ **1/17***sin(17*360*x)+ **0***sin(18*360*x)+ **1/19***sin(19*360*x), which could also be entered.
- You can change the amplitudes of individual harmonics in the Settings U1. You can set the fundamental frequency and the amplitude here as well. The result is immediately audible, as well as visible using ⏱ after the start of the measurement.
- To approximately synthesize a triangular signal, we can use the formula **synth(1:0:-1/3^2:0:1/5^2:0:-1/7^2:0: 1/9^2:0:-1/11^2:0:1/13^2)**. You do not need to type in this formula; simply copy it from this help text and insert it in the formula box (right mouse button).

### Evaluation

After recording with ⏱, we can readily observe a change in the ratios of the amplitudes of the harmonics in the **Frequency Spectrum** display (click on this tab with the mouse).

## Conversion of mechanical energy into thermal energy



can also be carried out with Pocket-CASSY

### Safety note

Make sure that the experimenter stands so that he or she cannot be injured when the 5 kg weight is dropped inadvertently.

### Experiment description

Energy is one of the fundamental quantities in physics. Energy occurs in different forms, which can be converted one into the other. In a closed system, the total energy is conserved in the course of conversion processes.

In this experiment, the equivalence of mechanical energy $E_m$ and thermal energy $E_{th}$ is established experimentally. Mechanical work $E_m$ is expended by turning a crank handle against the frictional force. This leads to a temperature rise of the calorimeter and thus to an increase in the thermal energy $E_{th}$. The two energy forms can be registered quantitatively in units of newton meter (Nm) and Joule (J) by measuring the temperature $\vartheta$ and the number of revolutions so that their numerical equivalence can be demonstrated experimentally: $E_m = E_{th}$.

### Equipment list

| | | |
|---|---|---|
| 1 | Sensor-CASSY | 524 010 or 524 013 |
| 1 | CASSY Lab 2 | 524 220 |
| 1 | Timer box or Timer S | 524 034 or 524 074 |
| | | |
| 1 | Temperature box | 524 045 |
| 1 | Temperature sensor NiCr-Ni | 666 193 |
| | or | |
| 1 | NiCr-Ni adapter S | 524 0673 |
| 1 | Temperature sensor NiCr-Ni, type K | 529 676 |
| | | |
| 1 | Forked light barrier, infrared | 337 46 |
| 1 | Multicore cable, 6-pole, 1.5 m | 501 16 |
| 1 | Equivalent of heat, basic apparatus | 388 00 |

| | | |
|---|---|---|
| 1 | Calorimeter | |
| | e.g. | |
| | water calorimeter | 388 01 |
| | or | |
| | copper calorimeter with heating | 388 02 |
| | or | |
| | aluminum calorimeter with heating | 388 03 |
| | or | |
| | large aluminum calorimeter with heating | 388 04 |
| 1 | Bench clamp, simple | 301 07 |
| 1 | Stand base, V-shape, 20 cm | 300 02 |
| 1 | Stand rod, 10 cm | 300 40 |
| 1 | Stand rod, 25 cm | 300 41 |
| 1 | Clamp with jaw clamp | 301 11 |
| 1 | Weight, 5 kg | 388 24 |
| 1 | PC with Windows XP/Vista/7 | |

### Experiment setup (see drawing)

- Fasten the equivalent of heat basic apparatus to a corner of the table.
- Fasten the bench clamp at the edge of the table at a distance of approx. 40 cm from the plastic mounting of the basic apparatus. Clamp the clamp with jaw clamp with the aid of the stand rod 25 cm in order to be able to fix the temperature sensor as shown in the drawing.
- Set up the calorimeter so that the bore points upwards and pour water into the opening.
- Insert the gasket in the bore, and hold it with the locking screw.
- Attach the filled calorimeter body to the basic apparatus by inserting the rivet pins in the sockets of the plastic mounting and twisting the calorimeter body to lock the pins in place.
- Insert the temperature sensor as deeply as possible in the opening of the calorimeter, and tighten the locking screw of the calorimeter. Fix the temperature sensor by means of the stand material that has already been prepared as shown in the drawing.
- Put the 5 kg weight under the calorimeter body.
- Wind the nylon band approx. 4 times (6 at maximum) around the calorimeter, and attach it to the weight on the floor. The weight has to hang down on the side of the crank on the front.
- Operate the crank handle, and check whether the 5 kg weight is lifted a few centimeters and is kept at a constant height when the handle is turned further. If it is lifted too high, reduce the number of turns of the nylon band; if it does not lift at all, increase the number of turns.
- For measuring the number of revolutions $N_{A1}$ (=number of obscurations), position the forked light barrier with the aid of the stand base as shown in the drawing, and connect it to the input A of the Sensor-CASSY via the timer box.
- Connect the temperature sensor to the input B of the Sensor-CASSY via the temperature box (socket $T_1$) for measuring the temperature $\vartheta_{B11}$.

### Carrying out the experiment

■ Load settings
- Set the number of revolutions to zero by clicking → **0** ← in Settings NA1.
- Start the measurement with ⏱.
- Turn the crank handle, and measure the increase in temperature as a function of the number of revolutions.
- Stop the measurement with ⏱ at the desired final temperature $\vartheta_{B11}$.

### Evaluation

The temperature $\vartheta_{B11}$ is already displayed graphically as a function of the number of revolutions $N_{A1}$ during the measurement. In the prepared diagram **Evaluation**, the thermal energy is plotted against the mechanical energy that has been provided by turning the crank against the friction. The mechanical energy $E_m$ is equal to the product of the frictional force and the covered path s:

$E_m = F \cdot s$

with $F = m \cdot g$

F = frictional force
m = mass of the weight = 5 kg
g = acceleration of gravity = 9.81 $m/s^2$

and $s = N \cdot d \cdot \pi$

s = frictional path
N = number of revolutions
d = diameter of the calorimeter = 0.047 m

Thus the mechanical energy is: $E_m = m·g·d·π·N$.

The increase in thermal energy as a result of the temperature increase is given by:

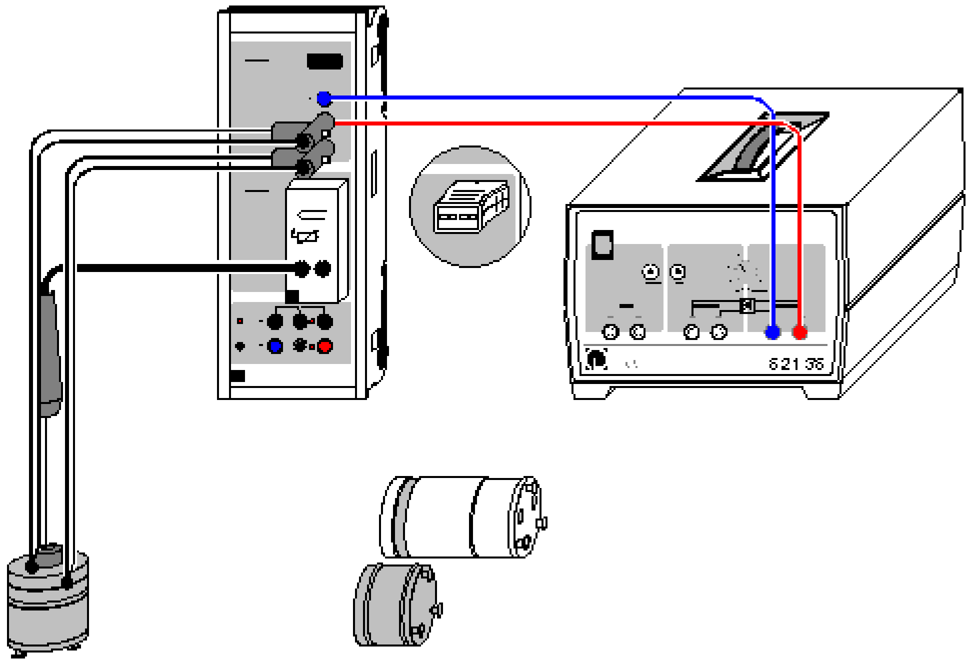
$E_{th} = C·(ϑ_2 - ϑ_1)$

The heat capacity C depends on the calorimeter used and has to be entered in the Settings C according to the following table:

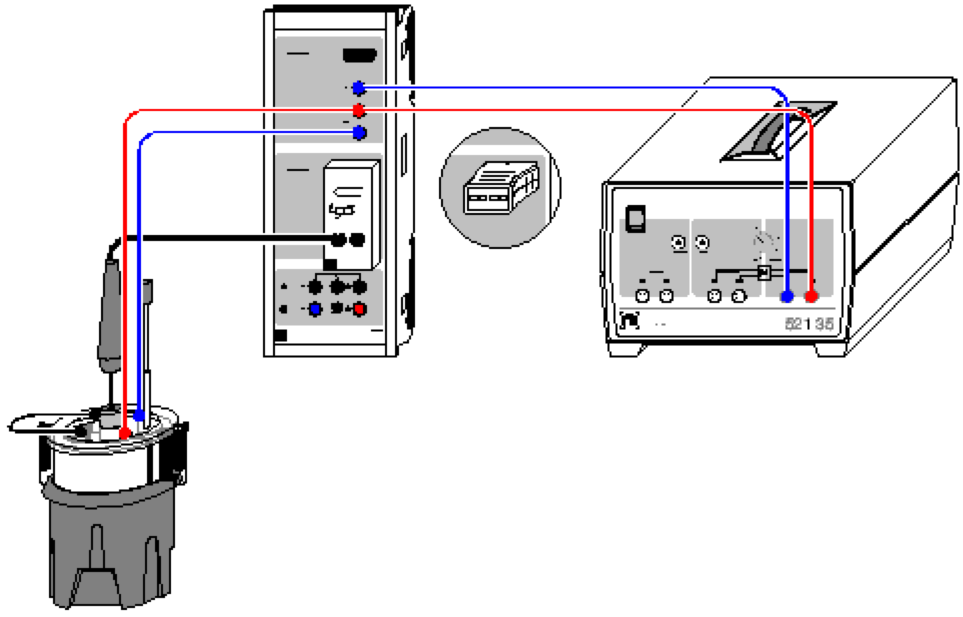
| Calorimeter | Heat capacity C/(J/K) |
|---|---|
| Water (388 01) | 40 + $m_{H2O}$/g · 4.2 (mass of the water in g) |
| Copper (388 02) | 264 + 4.2 (for 1 g water in the bore) |
| Aluminum (388 03) | 188 + 4.2 (for 1 g water in the bore) |
| Aluminum, large (388 04) | 384 + 4.2 (for 1 g water in the bore) |

The equivalence of the mechanical energy $E_m$ and the thermal energy $E_{th}$ can be confirmed by means of a fit to a line through the origin. Usually the slope of the straight line through the origin is somewhat smaller than 1. This is due to heat loss which is not registered, e.g. by thermal contact of the calorimeter with the nylon band or the plastic mounting.

## Conversion of electrical energy into thermal energy



Alternatively:



**Safety note**

Danger of implosion: the Dewar vessel is a thin-walled, highly evacuated glass vessel which can break under mechanical stress.

Do not knock or drop the Dewar vessel.

Do not allow any hard objects to fall on or into the glass mantle.

Do not scratch the glass mantle with sharp objects.

### Experiment description

Energy is a measure of stored work. It occurs in different forms, which can be converted one into the other. In a closed system, the total energy is conserved in conversion processes. therefore the energy is one of the fundamental quantities of physics.

In this experiment, the equivalence of electrical energy $E_{el}$ and thermal energy $E_{th}$ is established experimentally. The supplied electrical energy $E_{el}$ is converted into heat $E_{th}$ in the heating coil (or heating spiral). This leads to a temperature rise in the calorimeter (or water, in which the heating spiral is immersed). As the current I and the temperature $\vartheta$ are measured simultaneously as functions of the time, the constant voltage U being known, the two energy forms can be registered quantitatively in units of wattsecond (Ws) and Joule so that their numerical equivalence can be demonstrated experimentally: $E_{el} = E_{th}$.

### Equipment list

| | | |
|---|---|---|
| 1 | Sensor-CASSY | 524 010 or 524 013 |
| 1 | CASSY Lab 2 | 524 220 |
| | | |
| 1 | Temperature box | 524 045 |
| 1 | Temperature sensor NiCr-Ni | 666 193 |
| | or | |
| 1 | NiCr-Ni adapter S | 524 0673 |
| 1 | Temperature sensor NiCr-Ni, type K | 529 676 |
| | | |
| 1 | Voltage source, 0...12 V, e.g. | |
| | Variable extra-low voltage transformer S | 521 35 |
| 1 | Calorimeter with connecting cables, e.g. | |
| | copper calorimeter with heating | 388 02 |
| | pair of connecting cables for calorimeter | 388 06 |
| | or | |
| | aluminum calorimeter with heating | 388 03 |
| | pair of connecting cables for calorimeter | 388 06 |
| | or | |
| | large aluminum calorimeter with heating | 388 04 |
| | pair of connecting cables for calorimeter | 388 06 |
| | or | |
| | Electric calorimeter attachment | 384 20 |
| | Dewar vessel | 386 48 |
| | Beaker, squat shape, Duran, 250 ml | 664 103 |
| | Graduated cylinder, plastic base, 250 ml | 665 755 |
| | Pair of cables, 50 cm, red and blue | 501 45 |
| | Connecting lead, 50 cm, black | 501 28 |
| 1 | Pair of cables, 50 cm, red and blue | 501 45 |
| 1 | PC with Windows XP/Vista/7 | |

### Experiment setup with calorimeter (see drawing)

- Set up the calorimeter so that the bore points upwards and pour water into the opening.
- Insert the gasket in the bore, and hold it with the locking screw.
- Insert the temperature sensor as deeply as possible in the opening of the calorimeter, and tighten the locking screw of the calorimeter.
- For the current and voltage measurement, connect the CASSY to the variable extra-low voltage transformer S as shown in the drawing.
- Connect the heating coil of the calorimeter to the input A of the Sensor-CASSY (plug the large banana plugs together and connect one cable to the blue safety socket and one cable to the red safety socket).
- Connect the temperature sensor to the input B of the Sensor-CASSY via the temperature box (socket $T_1$) for measuring the temperature $\vartheta_{B11}$.

### Experiment setup with electric calorimeter attachment (see drawing)

- Using the graduated cylinder, pour approx. 200 ml of water into the Dewar vessel.
- Put the electric calorimeter attachment into the Dewar vessel, and fix the cover with the aid of the springs.

- Immerse the temperature sensor with the sealing washer in the Dewar vessel through the rubber stopper. The temperature sensor has to be held by the sealing washer so that the tip of the sensor is below the heating spiral. However, the tip of the temperature sensor must not touch the bottom of the Dewar vessel.
- For the current and voltage measurement, connect the CASSY to the variable extra-low voltage transformer S as shown in the drawing.
- Connect the heating spirals in series to the input A of the Sensor-CASSY (lay a cable from one heating spiral to the red safety socket and another cable from the other heating spiral to the blue safety socket, and connect the free connectors with a black cable).
- Connect the temperature sensor to the input B of the Sensor-CASSY via the temperature box (socket $T_1$) for measuring the temperature $\vartheta_{B11}$.

## Experiment note

If the experiment is carried out with the electric calorimeter attachment, the water has to be stirred while the voltage is switched on in order that the warming takes place uniformly. Slowly move the stirrer up and down during the measurement.

## Carrying out the experiment

■ Load settings

- Select the **Voltage U**$_{A1}$ as measurement quantity in Settings IA1.
- Switch the variable extra-low voltage transformer S on, and set the voltage $U_{A1}$ to approx. 9 V (calorimeter) or approx. 4 V (electric calorimeter attachment).
- Read the exact value of $U_{A1}$, and enter it in Settings U as parameter.
- Switch the variable extra-low voltage transformer S off, and select the **Current I**$_{A1}$ as measurement quantity and **0...2.1 A** as range in Settings UA1.
- When the initial temperature $\vartheta_{B11}$ is constant, start the measurment with ⏱.
- Switch the variable extra-low voltage transformer S on, and switch it off again at the desired final temperature $\vartheta_{B11}$.
- Stop the measurement with ⏱ when a constant final temperature is reached.

## Evaluation

The temperature $\vartheta_{B11}$ and the current $I_{A1}$ are already displayed graphically as functions of the time during the measurement. The thermal energy $E_{th} = C \cdot (\vartheta_{B11} - \vartheta_1)$ is plotted against the electrical energy $E_{el} = \sum U \cdot I \cdot \Gamma t$ in the prepared diagram **Evaluation**. The heat capacity C depends on the calorimeter used and has to be entered in the Settings C according to the following table:

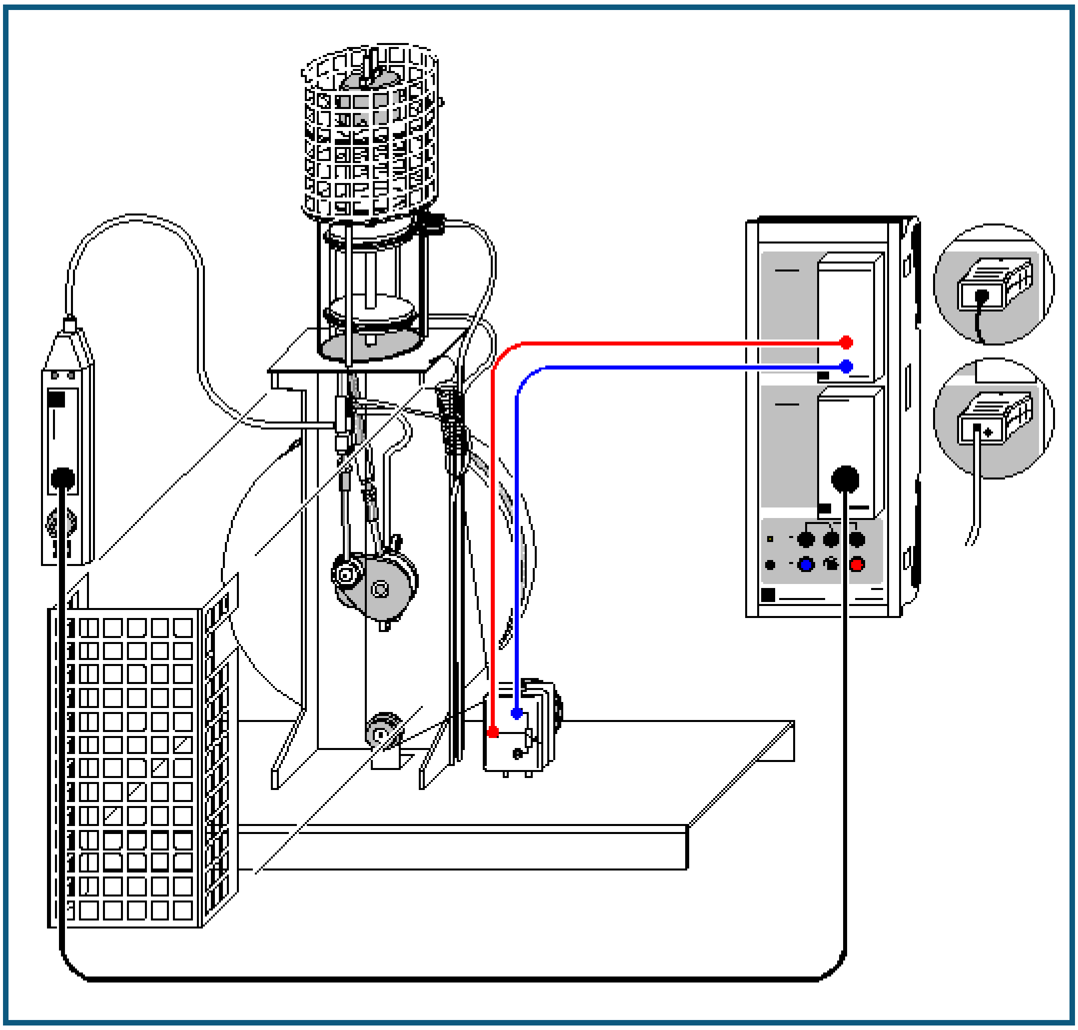
| Calorimeter | Heat capacity C/(J/K) |
|---|---|
| Copper (388 02) | 264 + 4.2 (for 1 g water in the bore) |
| Aluminum (388 03) | 188 + 4.2 (for 1 g water in the bore) |
| Aluminum, large (388 04) | 384 + 4.2 (for 1 g water in the bore) |
| Electr. calorimeter attachment (384 20) with Dewar vessel (386 48) | $(m_{H2O}/g + 24) \cdot 4.2$ (with the mass of the water in g and the water equivalent $m_D$ = 24 g of the Dewar vessel) |

The equivalence of the electrical energy $E_{el}$ and the thermal energy $E_{th}$ can be confirmed by fitting a line through the origin. Usually the slope of the straight line through the origin is somewhat smaller than 1 because of heat loss due to emission of heat radiation. This becomes particularly obvious in the case of long measuring times, where the measuring data deviate significantly from the straight line through the origin.

## Hint

As an alternative, the measurement can be evaluated manually: determine the mean value of the initial temperature $\vartheta_1$ and the final temperature $\vartheta_2$ (select Draw Mean with the right mouse button), and calculate the thermal energy $E_{th} = C \cdot (\vartheta_2 - \vartheta_1)$. Determine the time of electrical energy supply with Set Marker → Measure Difference, calculate $E_{el} = U \cdot I \cdot \Gamma t$, and compare it with $E_{th}$.

## pV diagram of a hot-air engine



can also be carried out with Pocket-CASSY

### Safety notes

- Before each experiment, make sure that the hot plate is seated in the notches and the heating filament does not touch the displacement piston.
- The heating head of the hot air engine can become very hot and the connecting rods of the drive and displacement pistons can cause injury when the engine is running. Therefore always use the touch protection covers when the engine is in operation.
- Never use the engine without a cooling water flow. You can connect the engine to tap water or use a circulation pump with reservoir; in this case the use of distilled or boiled (scale-free) water is recommended.
  If the flow should drop off when using tap water, flush the entire system with a warm scale-removing compound.
- Lubricate the two cylinders of the hot air engine regularly with silicone oil. The easiest way to do this to remove the hot plate, move the displacement piston to bottom dead center and, using a straw, drip silicone oil from a squeeze bottle so that it runs down the wall of the cylinder onto the top piston ring. As the seal is not fully tight, sufficient oil will reach the lower piston ring in a short time.
  When lubrication is insufficient the engine becomes loud and only runs at a reduced speed!
- Never connect the mains coil (562 21) without the transformer core.

### Experiment description

Thermodynamic cycles are often described as a closed curve in a pV diagram (p: pressure, V: volume). The work added to or withdrawn from the system (depending on the direction of rotation) corresponds to the area enclosed by the curve.

This experiment records the pV diagram of a hot air engine operated as a heat engine. The pressure sensor measures the pressure p in the cylinder and a displacement sensor measures the position s, from which the volume is calculated, as a function of the time t. The measured values are displayed on the screen directly in a pV diagram. In the further evaluation, the mechanical work performed as piston friction per cycle

$$W = -\int p \cdot dV$$

is calculated.

## Equipment list

| | | |
|---|---|---|
| 1 | Sensor-CASSY | 524 010 or 524 013 |
| 1 | CASSY Lab 2 | 524 220 |
| 1 | Current source box | 524 031 |
| | with Displacement transducer and | 529 031 |
| | Pair of cables, 100 cm, red and blue | 501 46 |
| | or | |
| 1 | Rotary motion sensor S | 524 082 |
| 1 | B box | 524 038 |
| | with Pressure sensor and | 529 038 |
| | Multi-core cable, 6-pole | 501 16 |
| | or | |
| 1 | Pressure sensor S, ±2000 hPa | 524 064 |
| 1 | Hot air engine | 388 182 |
| 1 | Fishing line | from 309 48ET2 |
| 1 | Helical spring | from 352 08ET2 |
| 1 | U-core with yoke | 562 11 |
| 1 | Clamping device with spring clip | 562 121 |
| 1 | Mains coil, 500 turns | 562 21 |
| 1 | Low-voltage coil, 50 turns | 562 18 |
| 2 | PVC tubings, ∅ 8 mm | 307 70 |
| 1 | Immersion pump 12 V | 388 181 |
| 1 | Low-voltage power supply | 521 231 |
| 1 | Can | 604 307 |
| 2 | Connecting leads, 100 cm, black | 501 33 |
| 1 | Water reservoir 10 l | |
| 1 | PC with Windows XP/Vista/7 | |

## Experiment setup (see drawing)

Set up the demountable transformer and clamp the yoke onto it.

Set up the hot plate as described in the experiment setup and connect the heater to the two outermost sockets of the low-voltage coil using the two connecting leads.

Connect the hose of the pressure sensor to the pressure fitting of the working-piston connecting rod. The pressure sensor is connected to the B box at input B of Sensor-CASSY. Attach the displacement transducer to the base plate with two coupling plugs and connect it to input A via the current source box; wind a cord as shown in the diagram. The working piston is provided with a pin with eyelet at the bottom end for attaching the cord. Hang the restoring spring in the hole on the frame head. This must be under tension when the cylinder is at bottom dead center. Wind the cord two times around the pulley of the displacement transducer to prevent slip! Set the potentiometer so that a volume of approx. 50 cm$^3$ is indicated when the working cylinder is at top dead center.

## Carrying out the experiment

☐ Load settings

- Test the displacement transducer to ensure that it is working properly: turn the motor once by hand and observe whether the volume display is within the measuring range. If it is not, loosen the cord slightly and turn the wheel of the displacement transducer until the displayed value is correct.
- Turn on the heating using the switch at the mains coil. When starting the first time, you should wait approx. 1 minute before pushing the motor, until the gas is hot enough for easy starting. In subsequent experiments you can start the motor when the heating coil begins to glow.
- Start the measurement with ⏱. The software automatically records and displays the predefined number of measuring points; the measurement is set to run for just a few cycles to simplify the subsequent integration.

## Evaluation

Determination of volume (already conducted in example): the inside diameter of the working cylinder is 60 mm, which gives us a piston surface area of 28.3 $cm^2$. Together with the path $s_{A1}$, we obtain the formula for the volume with the corresponding measuring instrument.

The work per cycle is determined from the enclosed area. We obtain this as follows: select Calculate Integral (Peak Area) in the Evaluations menu (click the right mouse button in the diagram) and mark one cycle (click on the starting point, hold down the left mouse button and drag the pointer along the cycle). The measuring points used for integration are highlighted. It is usually not possible to capture all measuring points of a cycle; however, it has no effect on the calculation of the area if one or two measuring points are substituted by a straight line. When you release the mouse button, the area is filled in and the corresponding value is displayed in the status line.

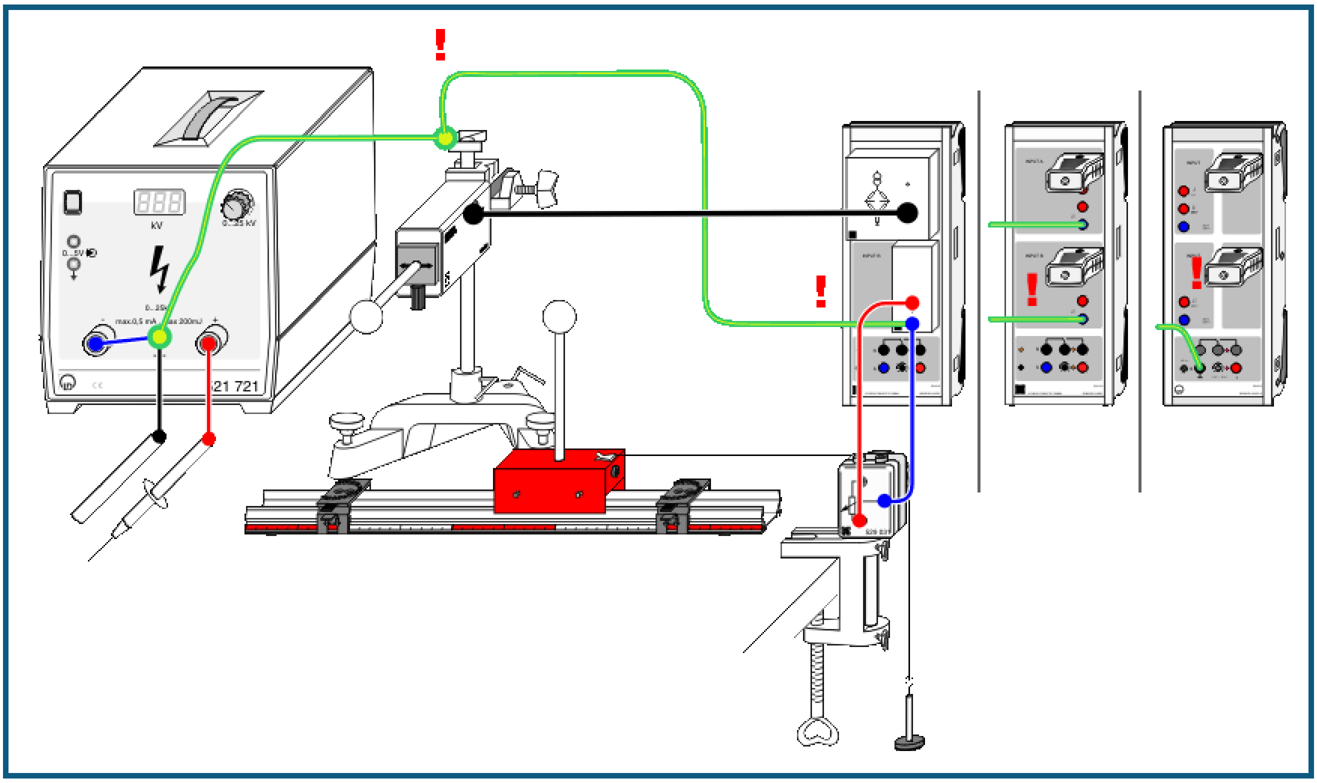
In this example, we obtain a value for work $W = 18{,}900\ hPa \cdot cm^3 = 1.89\ Nm$.

## Remark

The power of the motor is $P = W \cdot f$ with the f being the no-load frequency or speed.

You can determine the frequency f using a light barrier and a counter. Another way is to use the **Frequency Spectrum** display (click on this tab with the mouse). However, better frequency resolution requires more measured values than recorded in the example (increase the number from 125 to e.g. 2000 in the Measuring Parameters dialog).

## Coulomb's law



can also be carried out with Pocket-CASSY and Mobile-CASSY

### Use caution when working with high voltage

The plug pin is under high voltage and must never be allowed to touch either the experimenter or any parts of the experiment setup! In particular, neither the force sensor nor Sensor-CASSY are protected against high voltage.

Furthermore, the distance between the high voltage cable and the other insulated cables should be kept at its maximum value while the length of time the high voltage is switched on be kept to a minimum.

### Earthing of experimental setup and experimenter

In order to reduce the risk of damage from high voltage, the force sensor and the Sensor-CASSY should be earthed. With the Sensor-CASSY 1 (524 010), both ground sockets of the analog inputs are to be connected to earth if at all possible. With Sensor-CASSY 2 (524 013), the black socket on the voltage source S is suitable for this.

Please do not mistake the earth socket (yellow-green) on the high voltage power unit for the negative socket (blue).

In order to prevent interference from induced charges, during the experiment the experimenter should hold an earthed rod in his/her hand.

### Experiment description

Two spheres with identical or opposing charges exert a force on each other. This force is proportional to the charge Q on each sphere and inversely proportional to the square of the distance x between the spheres. The experiment verifies the proportionality $F \propto 1/x^2$.

### Equipment list

| | | |
|---|---|---|
| 1 | Sensor-CASSY | 524 010 or 524 013 |
| 1 | CASSY Lab 2 | 524 220 |
| | | |
| 1 | Bridge box | 524 041 |
| | with Force sensor and | 314 261 |
| | Multicore cable, 6-pole, 1.5 m | 501 16 |
| | or | |
| 1 | Force sensor S, ±1 N | 524 060 |

| | | |
|---|---|---|
| 1 | Current source box | 524 031 |
| | with Displacement transducer and | 529 031 |
| | Pair of cables, 100 cm, red and blue | 501 46 |
| | or | |
| 1 | Rotary motion sensor S | 524 082 |
| 1 | High voltage power supply 25 kV | 521 721 |
| 1 | High-voltage cable | 501 05 |
| 1 | Set of bodies for electric charge | 314 263 |
| 1 | Precision metal rail | 460 82 |
| 1 | Trolley 1 | 337 00 |
| 2 | Clamp riders | from 460 95ET5 |
| 1 | Small clip plug | from 590 02ET2 |
| 1 | Connection rod | 532 16 |
| 1 | Stand rod, 25 cm | 300 41 |
| 1 | Stand base, V-shape, 20 cm | 300 02 |
| 1 | Leybold multiclamp | 301 01 |
| 1 | Set of driving weights | 337 04 |
| 1 | Bench clamp, simple | 301 07 |
| 1 | Fishing line | 309 48 |
| 1 | Connecting lead, 25 cm, black | 500 414 |
| 3 | Connecting leads, 100 cm, black | 500 444 |
| 1 | PC with Windows XP/Vista/7 | |

### Experiment setup (see drawing)

The force sensor is connected to the bridge box at input A of Sensor-CASSY. Place one of the spheres from the set of bodies for electric charge on the force sensor using the insulating spacer. Place the second sphere on the trolley, which should be able to move freely along the precision metal rail as far as the clamp rider.

The distance between the spheres is measured by the displacement transducer connected to the current supply box at input B of Sensor-CASSY. To this end, lay a thread from the trolley over the deflection pulley of the motion transducer and tie a weight to it. Make sure the path indicator $s_{B1}$ increases with the distance and reads approx. 0 cm at contact.

For safety reasons the current supply box and the force sensor have to be grounded. Connect the force sensor to the ground socket of the high voltage power supply using a clip plug and a connecting lead.

### Experiment notes

Imparting sufficient charge to the spheres, and maintaining this charge (at least during the brief period of this experiment), is an essential prerequisite for the success of this experiment. After charging the two spheres, you should be able to measure a force of at least 5 mN at a distance of 0.5 cm, and this force should remain constant for a few seconds. If not:

- Clean the insulators and spheres (e.g. with water and dish soap; rinse with distilled water)
- Dry the insulators and spheres (e.g. carefully with the non-luminous flame of a Bunsen burner or with hot air from a blow dryer).
- Avoid open flames in the vicinity of the experiment while conducting the experiment (otherwise this ionizes the air).
- You can try other charge sources (e.g. a PVC rod rubbed in freshly washed hair) as an alternative to the high voltage source.
- However, you need dry weather for this.

### Carrying out the experiment

☐ Load settings
- Calibrate the path zero point: allow the spheres to touch, select **Correct** in the Settings sB1 dialog, set the first target value to 3.8 cm (distance between sphere centers) and click on **Correct Offset**.
- Put the spheres in the starting position with a gap of about 0.5 cm between them.
- Discharge both spheres using the grounded connection rod.
- Set the force zero point in Settings FA1 with → **0** ← (repeat as required) and, where necessary, switch on the smoothing LED of the bridge box with **LED On/Off.**
- Charge the spheres with like or unlike charges by connecting one pole of the high voltage supply to ground and placing the other against the sphere for a few seconds. This should produce a force of at least 5 mN (see experi-

ment notes above). If necessary, you can change the zero point of the force instrument (and thus the y-axis of the diagram) in Settings FA1 from center to left or right.

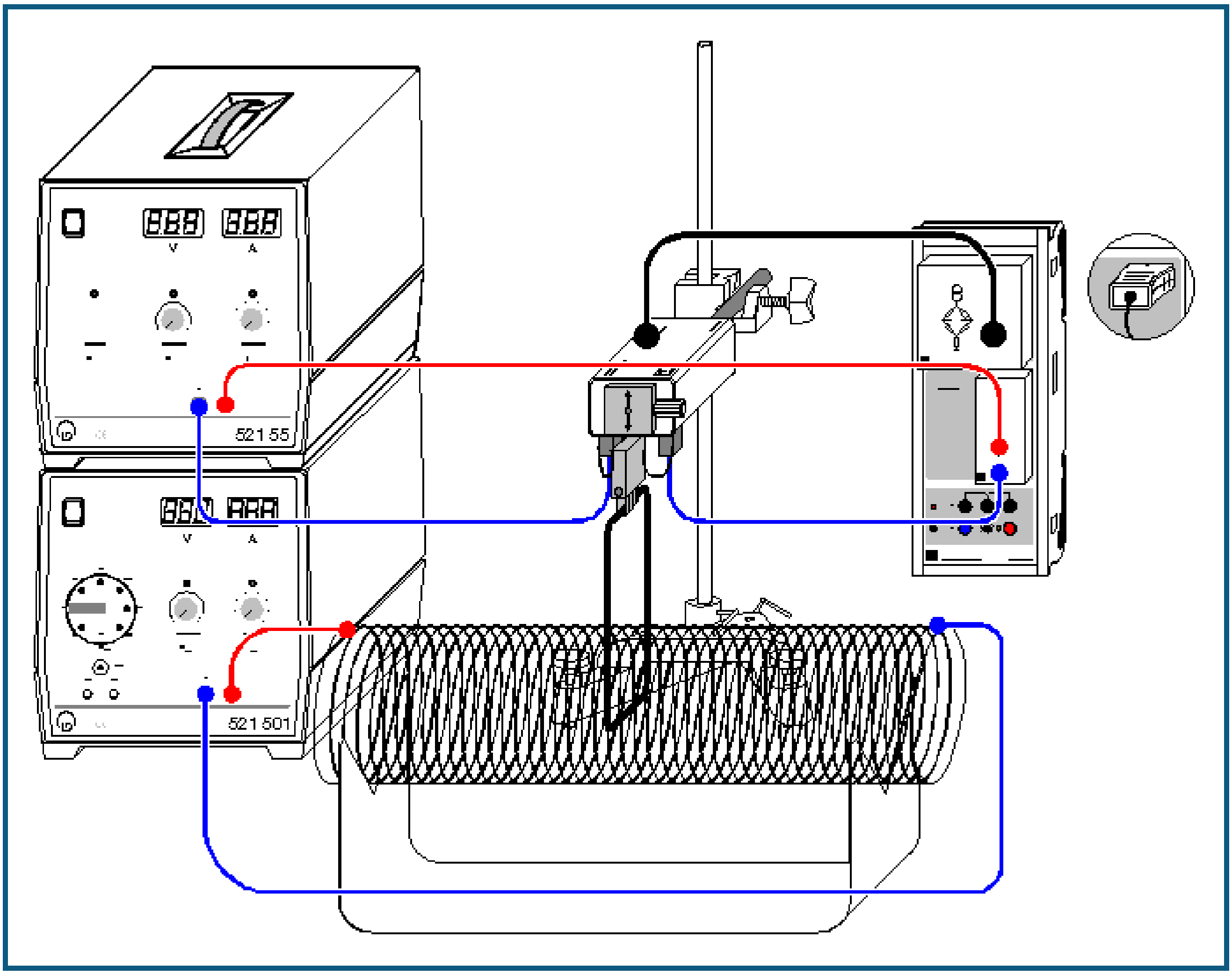
- Start the measurement with ⏱.
- Slowly move the trolley away from the force sensor by hand.
- Stop the measurement with ⏱ at approx. 15 cm.

### Evaluation

The F(x) diagram appears during the measurement. You can verify Coulomb's law by fitting a hyperbola $1/x^2$ or by converting the x-axis to $1/x^2$ (click on the axis with the right mouse button) and then fitting a straight line.

It becomes apparent that the proportionality $F \propto 1/x^2$ does not apply until a distance of approx. 6 cm between the two sphere centers is reached. At shorter distances the spacing would have to be corrected, as these are not point-shaped charges.

## Force in the magnetic field of an air coil



can also be carried out with Pocket-CASSY and Mobile-CASSY

### Experiment description

Magnetic flux density, or more simply the magnetic field **B**, is a vectorial quantity. A force **F** acts on a charge q passing through a magnetic field **B** with a velocity **v**; the size of the force depends on the strength and direction of the magnetic field. We can say

$\mathbf{F} = q \cdot (\mathbf{v} \times \mathbf{B})$.

The Lorentz force **F** is also a vectorial quantity, and is perpendicular to the plane defined by **v** and **B**.

We can understand the force acting on a current-carrying conductor in a magnetic field as the sum of the individual forces acting on the moving charge carriers which make up the current. The Lorentz force **F** acts on every single charge carrier q moving with the drift velocity **v.** For a straight conductor, this gives us the total force

$\mathbf{F} = q \cdot nAs \cdot (\mathbf{v} \times \mathbf{B})$,

as the number of charge carriers in the conductor is the product of the density n of the charge carriers, the conductor cross-section A and the length s of the section of the conductor within the magnetic field.

It is common to introduce the vector **s**, which points along the direction of the conductor segment. Also, the product qnAv is equivalent to the current I. Thus, the force of a magnetic field on a straight, current-carrying conductor section is defined by

$\mathbf{F} = I \cdot (\mathbf{s} \times \mathbf{B})$

and the absolute value of the force by

$F = I \cdot s \cdot B$,

when **s** and **B** are perpendicular to each other. The force F and the current I are thus proportional to each other, and the proportionality factor is B.

This experiment measures the force on a conductor loop in a homogeneous magnetic field of an air coil as a function of the conductor loop current I. The homogeneous magnetic field is generated in a long, slotted air coil, and the conductor loop with the length s = 8 cm attached to the force sensor is inserted in the slit. Only the horizontal part of the conductor generates a force component that can be measured by the force sensor. Thus, the proportionality between force F and conductor loop current I can be used to determine the magnetic flux density B.

The advantage of the air coil is that the magnetic flux density B within it can be calculated easily and compared with the value arrived at through experiment. For a long air coil, we can say

$B = \kappa_0 \cdot N \cdot I_C / L$

with the magnetic field constant $\kappa_0 = 4\pi \cdot 10^{-7}$ Vs/Am, the number of turns N of the coils, the coil current $I_C$ and the length L of the air coil.

## Equipment list

| | | |
|---|---|---|
| 1 | Sensor-CASSY | 524 010 or 524 013 |
| 1 | CASSY Lab 2 | 524 220 |
| 1 | Bridge box | 524 041 |
| | with Force sensor and | 314 261 |
| | Multicore cable, 6-pole, 1.5 m | 501 16 |
| | or | |
| 1 | Force sensor S, ±1 N | 524 060 |
| 1 | 30-A box | 524 043 |
| 1 | Support for conductor loops | 314 265 |
| 1 | Conductor loops for force measurement | 516 34 |
| 1 | Field coil, d = 120 mm | 516 244 |
| 1 | Stand for tubes and coils | 516 249 |
| 1 | High current power supply | 521 55 |
| 1 | AC/DC power supply 0...15 V | 521 501 |
| 1 | Stand base, V-shape, 20 cm | 300 02 |
| 1 | Stand rod, 47 cm | 300 42 |
| 1 | Leybold multiclamp | 301 01 |
| 1 | Connecting lead, 50 cm, blue | 501 26 |
| 2 | Connecting leads, 100 cm, red | 501 30 |
| 2 | Connecting leads, 100 cm, blue | 501 31 |
| 1 | PC with Windows XP/Vista/7 | |

## Experiment setup (see drawing)

The force sensor holds the 8 cm long conductor loop via the support and is positioned so that the conductor loop is inserted in the slot of the air coil. The conductor loop must not touch the air coil. The two 4-mm sockets on the bottom of the force sensor are intended for supplying the conductor loop support. They are not connected internally. The force sensor is connected to the bridge box at input A of Sensor-CASSY.

The current flows from the 20 A supply unit via the 30 A box on input B of Sensor-CASSY through the conductor loop and back to the power supply. The current of the second 5 A power supply flows through the air coil.

## Carrying out the experiment

■ Load settings

- Set the force zero point in Settings Force FA1 with → **0** ← and, where necessary, switch on the smoothing LED of the bridge box with **LED On/Off**.
- You may want to set the current zero point in Settings IB1 with → **0** ←.
- At the power supply of the air coil, set about $I_C = 5$ A.
- Increase the conductor loop current I from 0-20 A in steps of 2 to 5 A, and record a measured value with ⏱ each time. You can delete a faulty measurement from the table with Table → Delete Last Table Row.
- If only negative forces are measured, reverse the connections on the conductor loop support.
- Carry out the experiment rapidly, as the conductor loop and support may be subjected to loads of 20 A only briefly.
- At the end of the experiment, set the conductor loop current to 0 A.

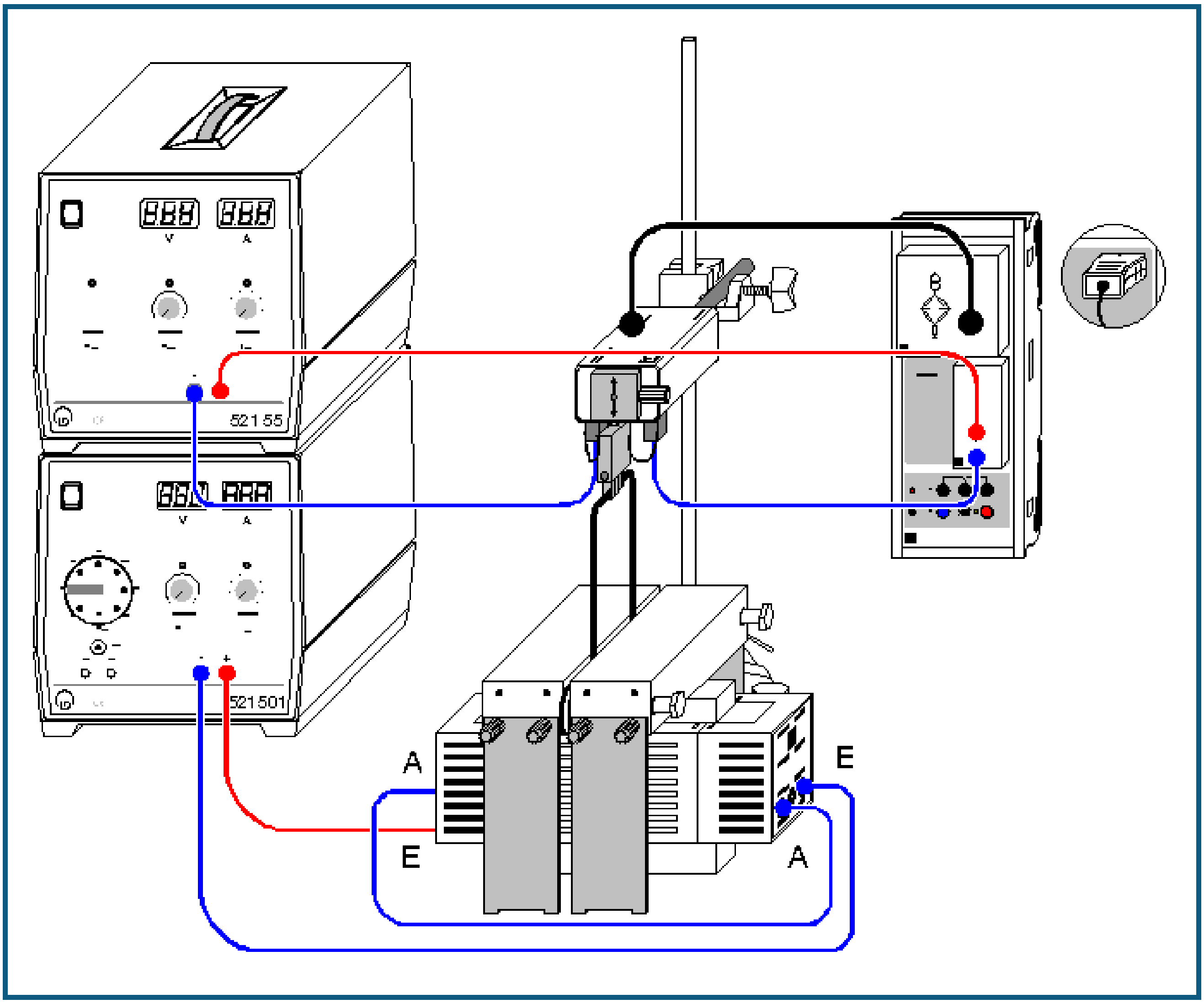
## Evaluation

The force increases linearly with the current. The proportionality factor F/I = B·s is derived from the slope of the straight line fit. This in turn enables us to determine the magnetic field strength B.

In this example F/I = 0.138 mN/A and with s = 0.08 m it follows that B = 1.725 mT.

Using $B = \kappa_0 \cdot N \cdot I_C / L$ the values $\kappa_0$ = 1.257 κVs/Am, N = 120, $I_C$ = 4.75 A and L = 0.41 m give us the calculated value B = 1.75 mT. The two results agree very well within the limits of measuring accuracy.

## Force in the magnetic field of an electromagnet



can also be carried out with Pocket-CASSY and Mobile-CASSY

### Experiment description

In this experiment, a homogeneous magnetic field B is generated using an electromagnet with U core and pole-shoe yoke. The object is to measure the force F acting on a conductor loop as a function of the current I (F proportional to I). The measuring results for different conductor lengths s are compiled and evaluated in the overview graph (F/I proportional to s). The ultimate aim is to verify

$F = I \cdot s \cdot B$

By means of differentiation we verify Faraday's law of induction

### Equipment list

| | | |
|---|---|---|
| 1 | Sensor-CASSY | 524 010 or 524 013 |
| 1 | CASSY Lab 2 | 524 220 |
| | | |
| 1 | Bridge box | 524 041 |
| | with Force sensor and | 314 261 |
| | Multicore cable, 6-pole, 1.5 m | 501 16 |
| | or | |
| 1 | Force sensor S, ±1 N | 524 060 |
| | | |
| 1 | 30-A box | 524 043 |

| | | |
|---|---|---|
| 1 | Support for conductor loops | 314 265 |
| 1 | Conductor loops for force measurement | 516 34 |
| 1 | U-core with yoke | 562 11 |
| 2 | Coils with 500 turns | 562 14 |
| 1 | Pole-shoe yoke | 562 25 |
| 1 | High current power supply | 521 55 |
| 1 | AC/DC power supply 0...15 V | 521 501 |
| 1 | Stand base, V-shape, 20 cm | 300 02 |
| 1 | Stand rod, 47 cm | 300 42 |
| 1 | Leybold multiclamp | 301 01 |
| 2 | Connecting leads, 50 cm, blue | 501 26 |
| 2 | Connecting leads, 100 cm, red | 501 30 |
| 2 | Connecting leads, 100 cm, blue | 501 31 |
| 1 | PC with Windows XP/Vista/7 | |

### Experiment setup (see drawing)

Slide the two coils onto the U-core. Place the two heavy pole pieces transversely on top of them. You can adjust the height using the lateral stand. The gap can be changed by moving one of the two pole pieces and adjusted with non-magnetic spacers.

The force sensor holds a conductor loop via the support and is positioned so that the conductor loop is inserted in the gap between the pole pieces of the electromagnet. The conductor loop must not touch the pole pieces. The two 4-mm sockets on the bottom of the force sensor are intended for supplying the conductor loop support. They are not connected internally. The force sensor is connected to the bridge box at input A of Sensor-CASSY.

The current flows from the 20 A supply unit via the 30 A box on input B of Sensor-CASSY through the conductor loop and back to the power supply. The current of the second 5 A power supply flows through the two coils on series. Make sure that the magnetic fields of the two coils add together (connect A to A and both E to the power supply as shown in the drawing).

### Carrying out the experiment

▨ Load settings

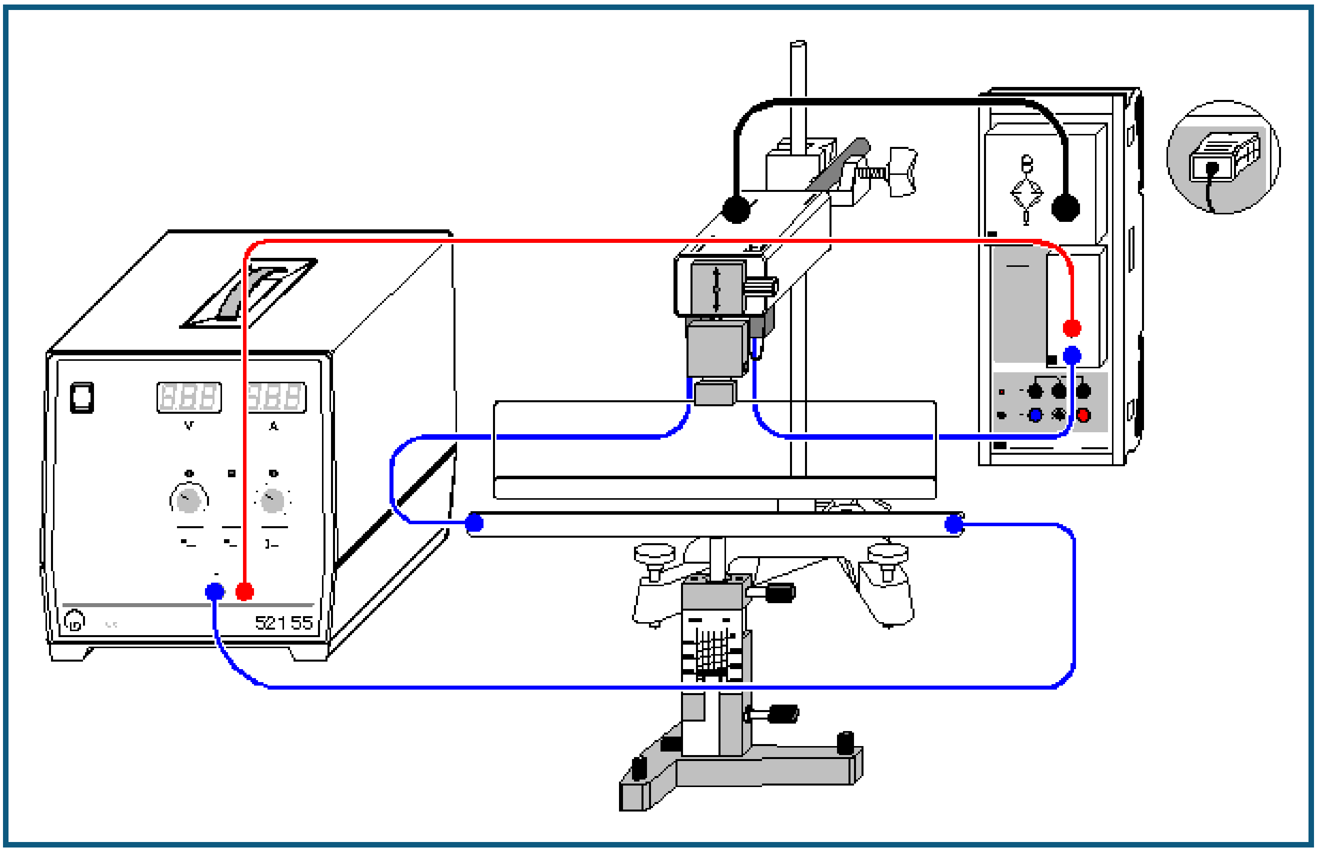
- Set the force zero point in Settings Force FA1 with → **0** ← and, where necessary, switch on the smoothing LED of the bridge box with **LED On/Off**.
- You may want to set the current zero point in Settings IB1 with → **0** ←.
- At the power supply of the coils, set about 2.5 A.
- Increase the conductor loop current I from 0-20 A in steps of 2 to 5 A, and record a measured value with ⏱ each time. You can delete a faulty measurement from the table with Table → Delete Last Table Row.
- If only negative forces are measured, reverse the connections on the conductor loop support.
- Carry out the experiment rapidly, as the conductor loop and support may be subjected to loads of 20 A only briefly.
- At the end of the experiment, set the conductor loop current to 0 A.
- Record additional measurement curves with a different conductor loop length s. Select **Measurement** → **Append new Measurement Series**.

### Evaluation

Fit a straight line to each measurement series F(I). After each best-fit straight line, switch to the display **Magnetic Field** (click the tab with the mouse). Here, an additional table is filled out by dragging the slope F/I just determined from the status line using the mouse and dropping it next to the respective conductor loop length (drag & drop). Enter the conductor loop length s directly via the keyboard. The desired diagram is generated as you enter the values.

In this display, the slope of the best-fit straight line gives us the magnetic field strength B between the pole pieces, as F/I = B·s (in this example, B = 164 mN/(A·m) = 164 mT).

## Force between two current-carrying conductors (ampere definition)



can also be carried out with Pocket-CASSY and Mobile-CASSY

### Experiment description

The force F acting on a conductor with the length s and carrying a current I in a field with the magnetic flux density B is

$F = I \cdot s \cdot B$.

If the flux density B is generated by a long conductor at a distance r, we say

$B = \text{const.} \cdot I / r$.

Thus, the force F acting between two parallel conductors carrying the same current I is determined using

$F = \text{const.} \cdot I^2 \cdot s / r$.

Electrical current (the ampere) is defined as follows: the current I has the value 1 A when the absolute value of the force per unit of length s between two parallel, straight and infinitely long conductors with a diameter tending to zero and carrying the identical current is

$F / s = 2 \cdot 10^{-7}$ N/m.

const.

$\text{const.} = 2 \cdot 10^{-7}$ N/A$^2$

is expressed as $\kappa_0/2\pi$, which gives us:

$F = \kappa_0/2\pi \cdot I^2 \cdot s / r$

where $\kappa_0 = 4\pi \cdot 10^{-7}$ N/A$^2$ $= 4\pi \cdot 10^{-7}$ Vs/Am.

In this experiment a conductor with the length s = 0.30 m is suspended at a distance r of just a few millimeters above a somewhat longer conductor. This experiment measures the force F acting on the suspended conductor at different currents I and distances r. The result verifies the ampere definition.

## Equipment list

| | | |
|---|---|---|
| 1 | Sensor-CASSY | 524 010 or 524 013 |
| 1 | CASSY Lab 2 | 524 220 |
| 1 | Bridge box | 524 041 |
| | with Force sensor and | 314 261 |
| | Multicore cable, 6-pole, 1.5 m | 501 16 |
| | or | |
| 1 | Force sensor S, ±1 N | 524 060 |
| 1 | 30-A box | 524 043 |
| 1 | Support for conductor loops | 314 265 |
| 1 | Set of conductors for ampere definition | 516 33 |
| 1 | Vertically adjustable stand | 516 31 |
| 1 | High current power supply | 521 55 |
| 1 | Stand base, V-shape, 20 cm | 300 02 |
| 1 | Stand rod, 47 cm | 300 42 |
| 1 | Leybold multiclamp | 301 01 |
| 2 | Connecting leads, 50 cm, blue | 501 26 |
| 1 | Connecting lead, 100 cm, red | 501 30 |
| 1 | Connecting lead, 100 cm, blue | 501 31 |
| 1 | PC with Windows XP/Vista/7 | |

## Experiment setup (see drawing)

The force sensor holds the top conductor loop with the support and is positioned so that the distance between the two conductor loops is about 5 mm for medium extension of the vertically adjustable stand.

The two 4-mm sockets on the bottom of the force sensor are intended for supplying the conductor loop support. They are not connected internally. The force sensor is connected to the bridge box at input A of Sensor-CASSY. The current flows from the 20 A supply unit via the 30 A box on input B of Sensor-CASSY through the two conductor loops in series and back to the power supply.

Now, slowly bring the conductor loop on the stand closer to the suspended conductor loop until the two are just touching (the wire centers now have the distance $r = 2$ mm). Check to make sure that the vertically adjustable stand is still parallel to the conductor loop, and adjust it if necessary using the adjusting screws.

Set the zero-point slider of the vertically adjustable stand to a defined mark and set the desired distance between the two conductor loops using the height adjustment mechanism (e.g. $r = 4$ mm).

Good measuring results require careful adjustment here.

## Carrying out the experiment

☐ Load settings
- Set the force zero point in Settings Force FA1 with → **0** ← and, where necessary, switch on the smoothing LED of the bridge box with **LED On/Off.**
- You may want to set the current zero point in Settings IB1 with → **0** ←.
- Increase the conductor loop current I from 0-20 A in steps of 2 A, and record measured values with ⏱ each time. You can delete a faulty measurement from the table with Table → Delete Last Table Row.
- If only negative forces are measured, reverse the connections on the conductor loop support.
- Carry out the experiment rapidly, as the conductor loop and support may be subjected to loads of 20 A only briefly.
- At the end of the experiment, set the conductor loop current to 0 A.
- Record additional measurement curves with different conductor spacings r. Select **Measurement** → **Append new Measurement Series**.

## Evaluation

Fit a parabola to each measurement series F(I). After each best-fit straight line, switch to the display **Ampere Definition** (click the tab with the mouse). Here, an additional table is filled out by dragging the parameter $F/I^2$ of the parabola just determined from the status line using the mouse and dropping it next to the respective conductor loop spacing r in the table (drag & drop). Enter the conductor loop spacing r directly via the keyboard. The desired diagram is generated as you enter the values.

In this display, the parameter $F/I^2 \cdot r$ of a hyperbola 1/x gives us the constant for the ampere definition as

$\kappa_0/2\pi = F/I^2 \cdot r / s = F/I^2 \cdot r / 0.3$ m.

In our example this means

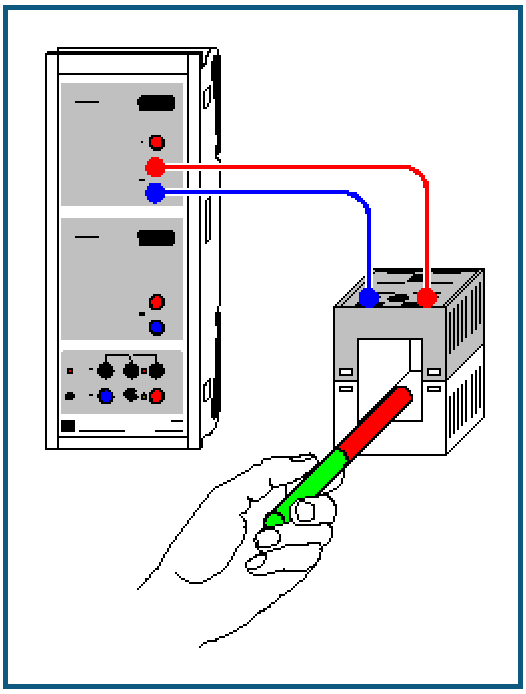
$\kappa_0/2\pi = 0.000062$ mN·m/A$^2$ / 0.3 m = 2.1·10$^{-7}$ N/A$^2$ = 2.1·10$^{-7}$ Vs/Am.

Alternatively, you can convert the x-axis from r to 1/r in the ampere definition display (click on the axis with the right mouse button). In this display, we obtain the value $\kappa_0/2\pi$ by fitting a straight line.

**Remark**

This measurement contains systematic errors. For one thing, the conductor has a finite length. That means that the assumed magnetic field does not exist at the end of the conductor, so that the forces are less. Additionally, a minute opposing force component acts on the suspended conductor due to the conductor segment running upward.

## Impulse of voltage (Faraday's law of induction)



✓ can also be carried out with Pocket-CASSY

### Experiment description

In 1831, Faraday discovered that each change in the magnetic flux Φ through a closed conductor loop generates an electrical voltage in that loop. The magnetic flux here is given by the integral of the conductor-loop area of the magnetic flux density resp. induction **B**:

$$\Phi = \int_A \mathbf{B} \cdot \mathrm{d}\mathbf{A}$$

In particular, he demonstrated that this induced voltage is proportional to the derivation of the magnetic flux Φ over time, and thus that the voltage impulse

$$\int_1^2 U(t) \cdot \mathrm{d}t \propto \Phi_2 - \Phi_1 = \Delta\Phi$$

is dependent only on the change in the magnetic flux. He thus discovered Faraday's law of induction

$$U = -\frac{\mathrm{d}\Phi}{\mathrm{d}t}.$$

This experiment measures the induced voltage U(t) for various magnetic flux densities B and numbers of turns N for various coils, determines the time integral and thus the voltage impulse in the evaluation of a recorded curve and ultimately verifies Faraday's law of induction.

### Equipment list

| | | |
|---|---|---|
| 1 | Sensor-CASSY | 524 010 or 524 013 |
| 1 | CASSY Lab 2 | 524 220 |
| 2 | Round bar magnets | 510 11 |
| 1 | Coil with 250 turns | 562 13 |
| 1 | Coil with 500 turns | 562 14 |
| 1 | Coil with 1000 turns | 562 15 |
| 1 | Pair of cables, 100 cm, red and blue | 501 46 |
| 1 | PC with Windows XP/Vista/7 | |

### Experiment setup (see drawing)

Connect a coil to input A of Sensor-CASSY.

### Carrying out the experiment

a) Measuring as a function of the magnetic flux Φ

☐ Load settings

- Connect the coil with 250 turns to input A.
- Start the measurement with ⏱.
- Insert one magnet half-way and remove it.
- Stop the measurement with ⏱ (or the measurement stops automatically after 10 seconds).
- Start the measurement with ⏱ and wait until the new measurement has proceeded far enough so that it no longer covers the old measurement.
- Insert two magnets half-way and remove them.
- Stop the measurement with ⏱ (or the measurement stops automatically after 10 seconds).

b) Measuring as a function of the number of turns N

☐ Load settings

- Connect the coil with 250 turns to input A.
- Start the measurement with ⏱.
- Insert the magnet half-way and remove it.
- Stop the measurement with ⏱ (or the measurement stops automatically after 10 seconds).
- Connect the coil with 500 turns to input A.
- Start the measurement with ⏱ and wait until the new measurement has proceeded far enough so that it no longer covers the old measurement.
- Insert the magnet half-way and remove it.
- Stop the measurement with ⏱ (or the measurement stops automatically after 10 seconds).
- Connect the coil with 1000 turns to input A.
- Start the measurement with ⏱ and wait until the new measurement has proceeded far enough so that it no longer covers the old measurement.
- Insert the magnet half-way and remove it.
- Stop the measurement with ⏱ (or the measurement stops automatically after 10 seconds).

### Evaluation

In experiment part a), the integral quickly reveals that the voltage impulses have the same absolute value but different signs when the magnet is inserted in and withdrawn from the coil, i.e.

$$\int_{\downarrow} U(t) \cdot \mathrm{d}t = -\int_{\uparrow} U(t) \cdot \mathrm{d}t$$

The use of two magnets additionally verifies the proportionality between the voltage impulses and the number of magnets used resp.

$$\int_1^2 U(t) \cdot \mathrm{d}t \propto \Phi_2 - \Phi_1 = \Delta\Phi .$$

the difference in the magnetic flux produced in this manner:

$$U = -\frac{\mathrm{d}\Phi}{\mathrm{d}t}$$

By means of differentiation we verify Faraday's law of induction

The magnetic flux through a coil depends on the number of turns, as each individual turn causes a flux difference $\Gamma\Phi_0$ and the total flux is calculated as $\Gamma\Phi = \mathrm{N} \cdot \Gamma\Phi_0$.

When we look at experiment part b), the relationship between a voltage impulse and the number of turns N of the respective coil, we can also confirm this relationship. To do this we determine e.g. all positive areas and enter these in the **Number of Turns** display together with the number of turns N (click on the correct table cells). Once again, the proportionality gives us

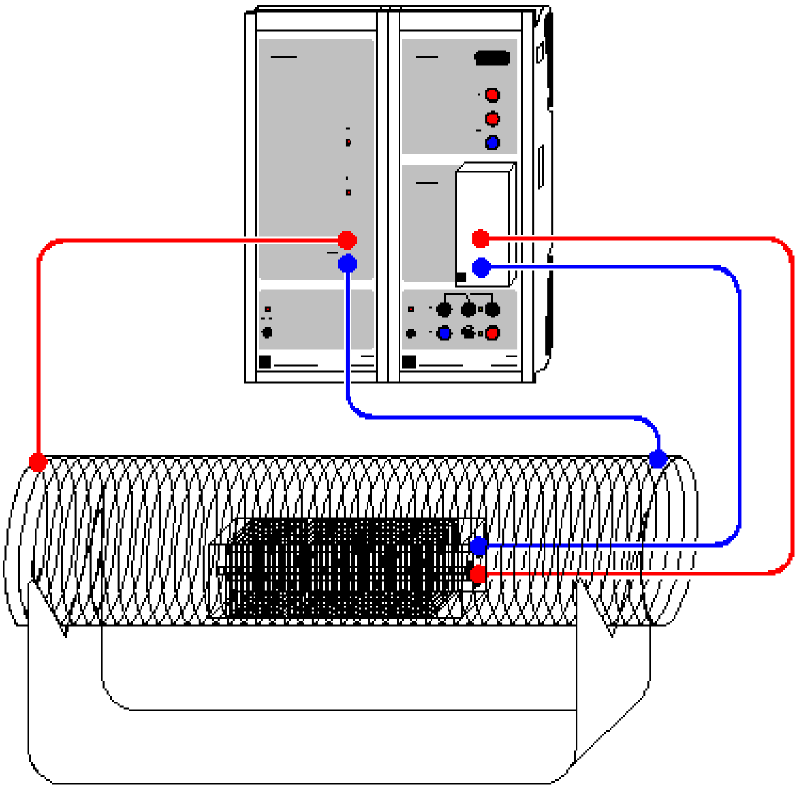
$$\int_1^2 U(t) \cdot \mathrm{d}t \propto N \cdot \Delta\Phi_0 = \Delta\Phi .$$

The slope of the straight line in the display of voltage impulses as a function of the number of turns corresponds to the magnetic flux $\Phi_0$ generated by the magnet in each individual coil winding.

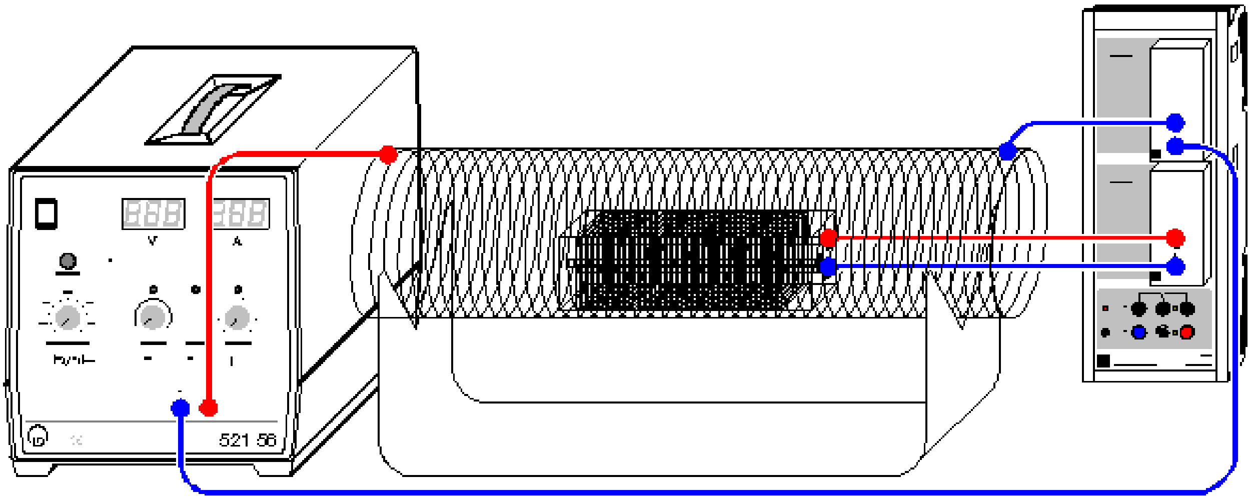
### Hints on integration

To integrate, you need to find the start of the range, which is not always easy when multiple curves are superimposed. It is easier when the measurement is stopped with ⏱ immediately following the voltage impulse (do not wait for the 10 seconds to elapse) and the integral is calculated immediately after measuring. If you wait until after the end of the previous measuring curve before starting the next voltage impulse measurement, no curve covers the others while integrating.

## Induction in a variable magnetic field



Alternatively (without Power-CASSY):



can also be carried out with Pocket-CASSY and Mobile-CASSY

### Experiment description

Voltages and currents which are produced as a result of variations in magnetic fields are called induction voltages and currents, and the phenomenon itself is referred to as electromagnetic induction. When a conductor loop is placed within a magnetic field **B**, the magnetic flux permeating the loop is determined by the integral of the conductor loop area:

$$\Phi = \int_A \mathbf{B} \cdot d\mathbf{A}$$

If instead of a conductor loop we use a coil with $N_1$ turns, all perpendicular to the magnetic field, Φ increases correspondingly to

$$\Phi = B \cdot A \cdot N_1.$$

If the magnetic field B does not vary, the magnetic flux Φ remains constant. When the magnetic field, and thus the magnetic flux through the area of the coil, changes over time, a voltage and consequently a current as well are induced in the coil; their magnitude and direction depend on how the field varies. Faraday's law of induction applies:

$$U = -\frac{\mathrm{d}\Phi}{\mathrm{d}t}$$

and thus

$$U = -\frac{\mathrm{d}B}{\mathrm{d}t} \cdot A \cdot N_1 .$$

Conversely, an electric current generates a magnetic field, e.g. when a current I flows through a coil. For the magnetic field inside a large cylindrical coil with the length L and the number of turns $N_2$, the following applies:

$$B = \mu_0 \frac{N_2}{L} I$$

where $\kappa_0 = 4\pi \cdot 10^{-7}$ Vs/Am (magnetic field constant).

This experiment uses a large cylindrical coil as a field coil through which a varying current I(t) flows, which generates a varying magnetic field B(t) within the coil. Rectangular induction coils having different cross-sections (areas) A and numbers of turns $N_1$ are placed inside this field coil. A voltage U is induced in these coils, which can be calculated as:

$$U = -\frac{\mathrm{d}I}{\mathrm{d}t} \cdot \mu_0 \cdot A \cdot \frac{N_2}{L} \cdot N_1$$

This experiment verifies the proportionalities between the induced voltage U and the change over time dI/dt of the field-coil current I, the area A of the induction coils and the number of turns $N_1$ of the induction coils. Power-CASSY (524 011) or the triangular wave form power supply (521 56) are particularly suitable for this experiment, as the output current I over time can be controlled so that the slope | dI/dt | is constant. The slope | dI/dt | is continuously adjustable from 0.2 A/s to 2.2 A/s. Three induction coils are also provided, with $N_1$ = 300 turns each. Coil 1 has the cross-section A = 50 × 50 $\text{mm}^2$, coil 2 A = 30 × 50 $\text{mm}^2$ and coil 3 A = 20 × 50 $\text{mm}^2$. Coil 1 is also provided with additional taps at $N_1$ = 100 and $N_1$ = 200 turns.

## Equipment list

| | | |
|---|---|---|
| 1 | Sensor-CASSY | 524 010 or 524 013 |
| 1 | Power-CASSY | 524 011 |
| 1 | CASSY Lab 2 | 524 220 |
| 1 | κV box | 524 040 |
| 1 | Field coil, d = 120 mm | 516 244 |
| 1 | Stand for tubes and coils | 516 249 |
| 1 | Set of induction coils | 516 241 |
| 2 | Connecting leads, 100 cm, red | 501 30 |
| 2 | Connecting leads, 100 cm, blue | 501 31 |
| 1 | PC with Windows XP/Vista/7 | |

## Alternatively (without Power-CASSY)

| | | |
|---|---|---|
| 1 | Sensor-CASSY | 524 010 or 524 013 |
| 1 | CASSY Lab 2 | 524 220 |
| 1 | κV box | 524 040 |
| 1 | 30-A box | 524 043 |
| 1 | Field coil, d = 120 mm | 516 244 |
| 1 | Stand for tubes and coils | 516 249 |
| 1 | Set of induction coils | 516 241 |
| 1 | Triangular wave form power supply | 521 56 |
| 1 | Connecting lead, 50 cm, blue | 501 26 |
| 2 | Connecting leads, 100 cm, red | 501 30 |
| 2 | Connecting leads, 100 cm, blue | 501 31 |
| 1 | PC with Windows XP/Vista/7 | |

## Experiment setup (see drawing)

The large coil is supplied with a constant | dI/dt | using either Power-CASSY or the triangular wave form power supply. In the latter case, the flowing current must be measured at input A of Sensor-CASSY using the 30 A box. The induced voltage of the induction coils is measured using the κV box at input B.

## Carrying out the experiment

a) Measuring the induction voltage U as a function of the area (cross-section) A of the induction coils

■ Load settings

- Place coil 1 ($A = 0.0025\ m^2$, $N_1 = 300$ turns) in the large field coil and connect it to the κV box.
- Execute the measurement with ⏱.
- Repeat the measurement with coils 2 ($A = 0.0015\ m^2$) and 3 ($A = 0.0010\ m^2$).

b) Measuring the induction voltage U as a function of the number of turns $N_1$ of the coils

■ Load settings

- Connect coil 1 ($N_1 = 100$ turns) in the large field coil to the κV box.
- Execute the measurement with ⏱.
- Repeat the measurement with $N_1 = 200$ and $N_1 = 300$ of coil 1.

c) Measuring the induction voltage U as a function of dI/dt

■ Load settings

- Connect coil 1 ($N_1 = 300$ turns) in the large field coil to the κV box.
- Execute the measurement with ⏱.
- Repeat the measurement with the reduced maximum current $I_{max}$ or dI/dt respectively; to do this, move the pointer of the display instrument to the desired position using the mouse.

## Alternatively (without Power-CASSY)

a) Measuring the induction voltage U as a function of the area (cross-section) A of the induction coils

■ Load settings

- Place coil 1 ($A = 0.0025\ m^2$, $N_1 = 300$ turns) in the large field coil and connect it to the κV box.
- Turn the voltage knob on the triangular wave form power supply all the way to the right, and turn up the current knob until the power limiting (LED $P_{max}$) is just below the cut-in threshold.
- Choose the middle setting for dI /dt and press the key to activate triangle mode.
- Start the measurement with ⏱ (the measurement begins with a rising edge of the induction voltage $U_{B1}$; you may need to deactivate the trigger).
- Stop the measurement with ⏱ after a few current periods.
- Repeat the measurement with coils 2 ($A = 0.0015\ m^2$) and 3 ($A = 0.0010\ m^2$).

b) Measuring the induction voltage U as a function of the number of turns $N_1$ of the coils

■ Load settings

- Connect coil 1 ($N_1 = 100$ turns) in the large field coil to the κV box.
- Turn the voltage knob on the triangular wave form power supply all the way to the right, and turn up the current knob until the power limiting (LED $P_{max}$) is just below the cut-in threshold.
- Choose the middle setting for dI /dt and press the key to activate triangle mode.
- Start the measurement with ⏱ (the measurement begins with a rising edge of the induction voltage $U_{B1}$; you may need to deactivate the trigger).
- Stop the measurement with ⏱ after a few current periods.
- Repeat the measurement with $N_1 = 200$ and $N_1 = 300$ of coil 1.

c) Measuring the induction voltage U as a function of the frequency of the excitation field

■ Load settings

- Connect coil 1 ($N_1 = 300$ turns) in the large field coil to the κV box.
- Turn the voltage knob on the triangular wave form power supply all the way to the right, and turn up the current knob until the power limiting (LED $P_{max}$) is just below the cut-in threshold.
- Choose the middle setting for dI /dt and press the key to activate triangle mode.
- Start the measurement with ⏱ (the measurement begins with a rising edge of the induction voltage $U_{B1}$; you may need to deactivate the trigger).
- During the measurement increase dI/dt in steps of about 0.4 A/s.
- Stop the measurement with ⏱.

## Evaluation

Depending on the experiment section, activate the appropriate display (click on **Area**, **Number of Turns** or **dI/dt**) with the mouse. A further table is filled out in which the induction voltage is determined for the respective parameter A, $N_1$ or dI/dt (by entering via the keyboard; dI/dt can be determined by fitting a straight line). You can find the induction voltage U e.g. by determining the mean value. You can then use the mouse to drag this value from the status line and drop it into the table (drag & drop). The desired diagram is generated as you enter the values.

All three diagrams confirm the proportionalities between the induction voltage U and the area A, number of turns $N_1$ and dI/dt.

In this example, we obtain the proportionality factor U/A = 101 mV/m$^2$ (or 129 mV/m$^2$ without Power-CASSY) between the induction voltage U and the coil cross-section A. Theory expects the proportionality factor

$$\frac{U}{A} = -\frac{dI}{dt} \cdot \mu_0 \cdot \frac{N_2}{L} \cdot N_1 .$$

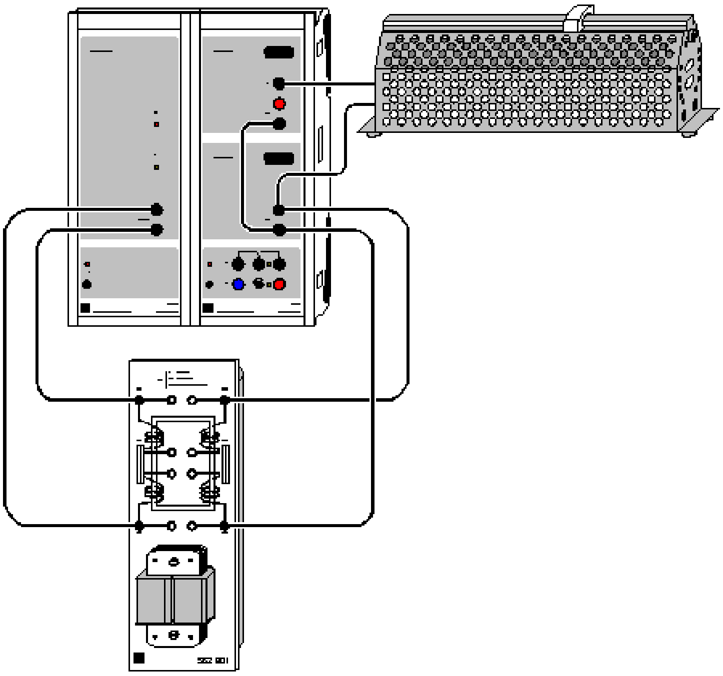
By comparison, the number of turns of the induction coil $N_1$ = 300 and $N_2$ = 120 of the air coil, the air coil length L = 0.41 m, the calculated current increase dI/dt = 1.00 A/s (resp. 1.19 A/s) and the magnetic field constant $\kappa_0 = 4\pi \cdot 10^{-7}$ Vs/Am taken together give us the proportionality factor U/A = - 110 mV/m$^2$ (resp. -131 mV/m$^2$), which agrees with the experiment result. The sign depends on the direction of the turns and the connection to the κV box.

## Notes

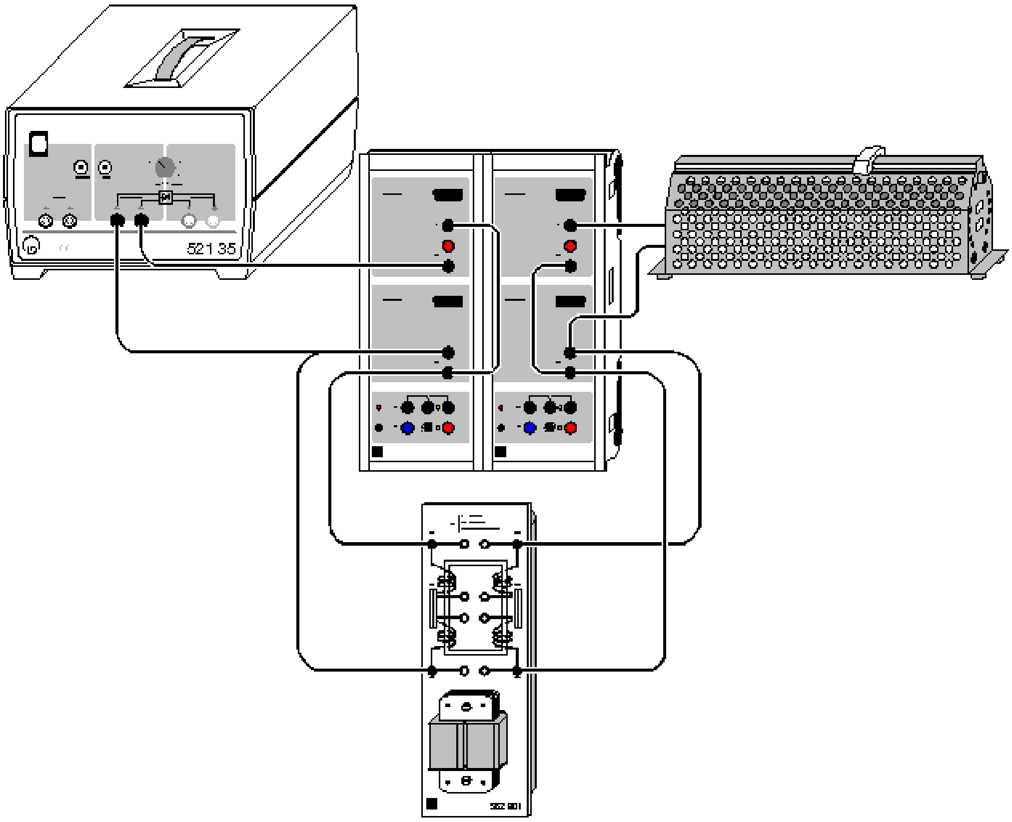
The κV box may have a slight offset, which can be corrected in Settings by selecting **Correct**, setting value 0 mV and choosing **Correct Offset**; be sure to interrupt the circuit of the air coil first.

Power-CASSY can also output a significantly higher frequency, and thus make the κV box unnecessary. However, note that in this case the current regulation of Power-CASSY tends to slight overshoots at higher frequencies and inductive loads, which negatively affect the induced voltage (1st derivation of the current). You can resolve this by connecting a resistor of around 10 Ω in series.

## Voltage and current curves of a transformer as a function of time



Alternatively (without Power-CASSY):



can also be carried out with Pocket-CASSY

### Experiment description

This experiment records the primary and secondary currents and voltages of a transformer under load as time-dependent quantities. From these, CASSY Lab directly calculates the time-dependent power values in the primary and secondary circuit, as well as the RMS values of current and voltage, the phase relation and the active power values.

### Equipment list

| | | |
|---|---|---|
| 1 | Power-CASSY | 524 011 |
| 1 | Sensor-CASSY | 524 010 or 524 013 |
| 1 | CASSY Lab 2 | 524 220 |
| 1 | Transformer for students' experiments | 562 801 |
| 1 | Rheostat 100 Ω | 537 34 |
| 1 | Connecting lead, 25 cm, black | 500 414 |
| 6 | Connecting leads, 100 cm, black | 500 444 |
| 1 | PC with Windows XP/Vista/7 | |

### Alternatively (without Power-CASSY)

| | | |
|---|---|---|
| 2 | Sensor-CASSYs | 524 010 or 524 013 |
| 1 | CASSY Lab 2 | 524 220 |
| 1 | Variable extra-low voltage transformer S | 521 35 |
| 1 | Transformer for students' experiments | 562 801 |
| 1 | Rheostat 100 Ω | 537 34 |
| 2 | Connecting leads, 25 cm, black | 500 414 |
| 8 | Connecting leads, 100 cm, black | 500 444 |
| 1 | PC with Windows XP/Vista/7 | |

### Experiment setup (see drawing)

The primary side of the transformer is supplied by Power-CASSY or by the variable transformer (approx. 6 V AC). In the latter case, the primary voltage, primary current and phase relation (cos θ) must be measured using a second Sensor-CASSY unit.

Sensor-CASSY performs the necessary measurements of voltage, current and phase relation (cos θ) on the secondary side. The transformer is under resistive load (cos θ = 1) in the form of a rheostat. However, where available the transformer can also be operated under inductive or capacitive load (cos θ < 1). You can improve the response of the transformer to load by connecting two coils each in parallel on the primary and secondary side of the transformer for students' experiments.

In place of the transformer for students' experiments, you can also use the demountable transformer.

### Carrying out the experiment

■ Load settings
- Start the measurement with ⏱.
- Vary the load (e.g. also inductive or capacitive load) and observe the effect on the secondary and primary circuits.
- Vary the number of coils on the primary and secondary side of the transformer and observe the behavior under load.
- If desired, alter the curve form or the frequency of the primary voltage in Settings U1 on Power-CASSY and observe the result.
- Stop the measurement with ⏱.

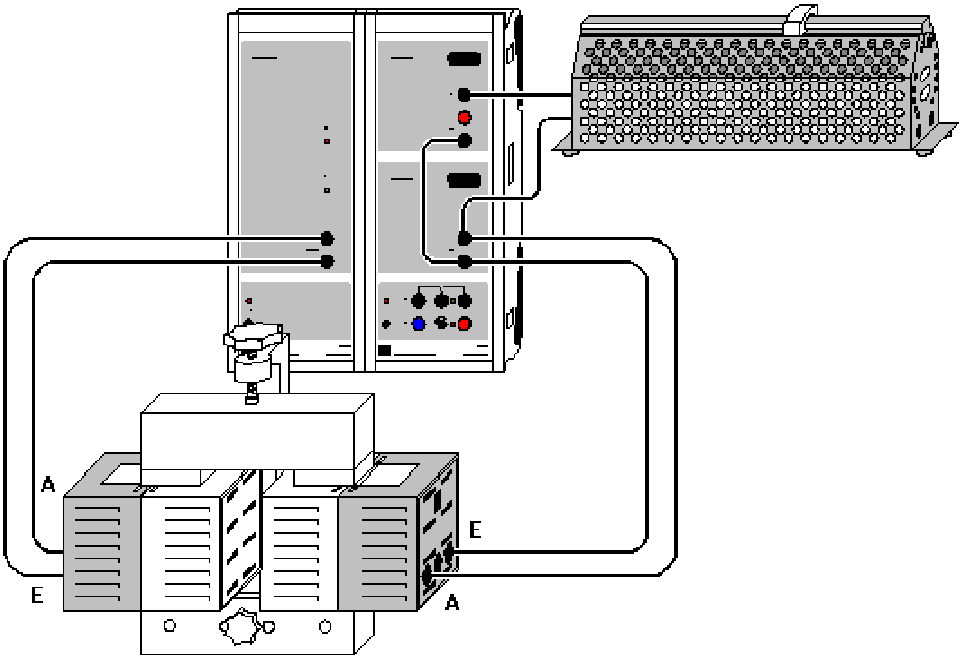
### Evaluation

You can change to the **Power** display with the mouse during or after measuring. This display shows both power values as a function of time.

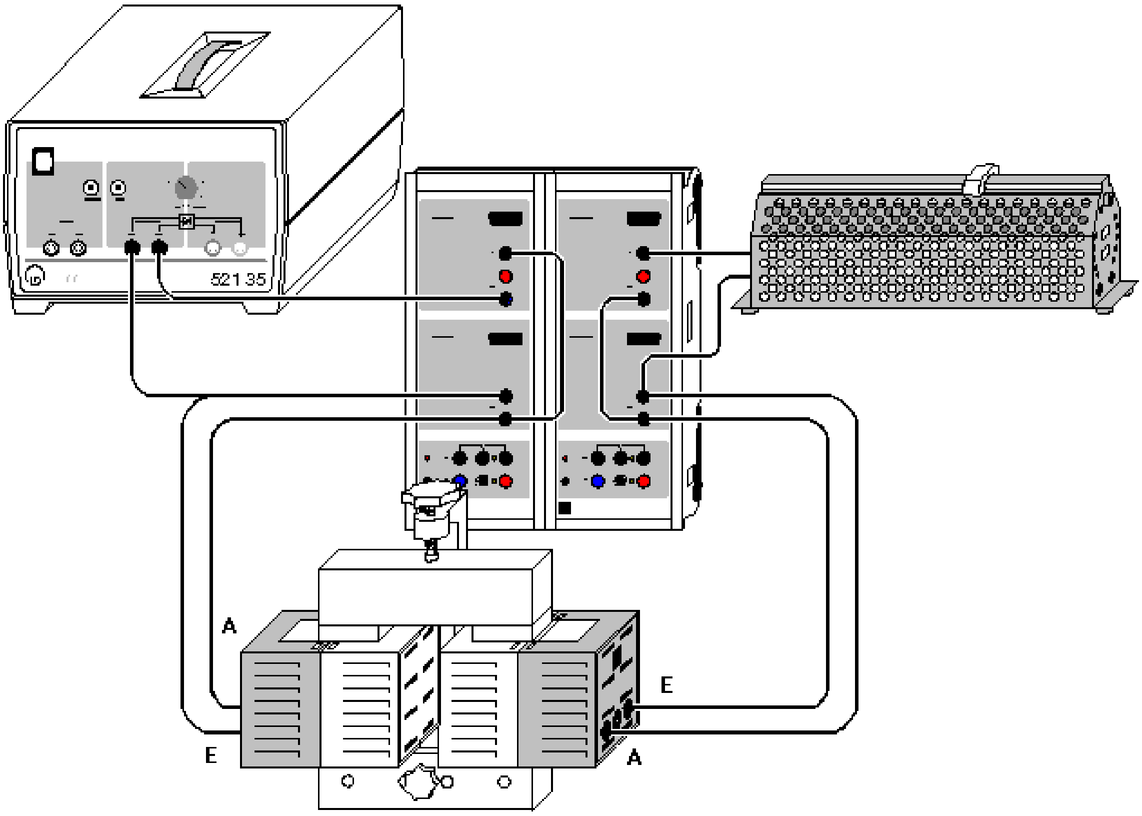
### Hint

You can show and hide all measuring instruments simultaneously with ⧉.

## Power transfer of a transformer



Alternatively (without Power-CASSY):



can also be carried out with Pocket-CASSY

## Experiment description

This experiment examines the power transfer of a transformer. This is done by simultaneously measuring the RMS values of the primary and secondary voltage as well as the primary and secondary current for a variable load resistor R = 0-100 Ω. The experiment also determines the phase shift between the voltage and current on the primary and secondary side. The evaluation determines the primary power $P_1$, the secondary power $P_2$ and the efficiency $\varepsilon = P_2/P_1$ and plots these as a function of the load resistance R.

## Equipment list

| | | |
|---|---|---|
| 1 | Power-CASSY | 524 011 |
| 1 | Sensor-CASSY | 524 010 or 524 013 |
| 1 | CASSY Lab 2 | 524 220 |
| 1 | U-core with yoke | 562 11 |
| 1 | Clamping device with spring clip | 562 121 |
| 2 | Coils with 250 turns | 562 13 |
| 1 | Rheostat 100 Ω | 537 34 |
| 1 | Connecting lead, 25 cm, black | 500 414 |
| 6 | Connecting leads, 100 cm, black | 500 444 |
| 1 | PC with Windows XP/Vista/7 | |

## Alternatively (without Power-CASSY)

| | | |
|---|---|---|
| 2 | Sensor-CASSYs | 524 010 or 524 013 |
| 1 | CASSY Lab 2 | 524 220 |
| 1 | Variable extra-low voltage transformer S | 521 35 |
| 1 | U-core with yoke | 562 11 |
| 1 | Clamping device with spring clip | 562 121 |
| 2 | Coils with 250 turns | 562 13 |
| 1 | Rheostat 100 Ω | 537 34 |
| 2 | Connecting leads, 25 cm, black | 500 414 |
| 8 | Connecting leads, 100 cm, black | 500 444 |
| 1 | PC with Windows XP/Vista/7 | |

## Experiment setup (see drawing)

The primary side of the transformer is supplied by Power-CASSY or by the variable transformer (approx. 6 V AC). In the latter case, the primary voltage, primary current and phase relation (cos θ) must be measured using a second Sensor-CASSY unit.

Sensor-CASSY performs the necessary measurements of the RMS values of voltage, current and their phase relation (cos θ) on the secondary side. The transformer is under resistive load (cos θ = 1) in the form of a rheostat.

Instead of the demountable transformer, you can use the transformer for students' experiments.

## Carrying out the experiment

■ Load settings
- Set the rheostat to the minimum position (approx. 0 Ω).
- Start the measurement with ⏱.
- Increase the resistance in steps and record measured values for each step with ⏱.

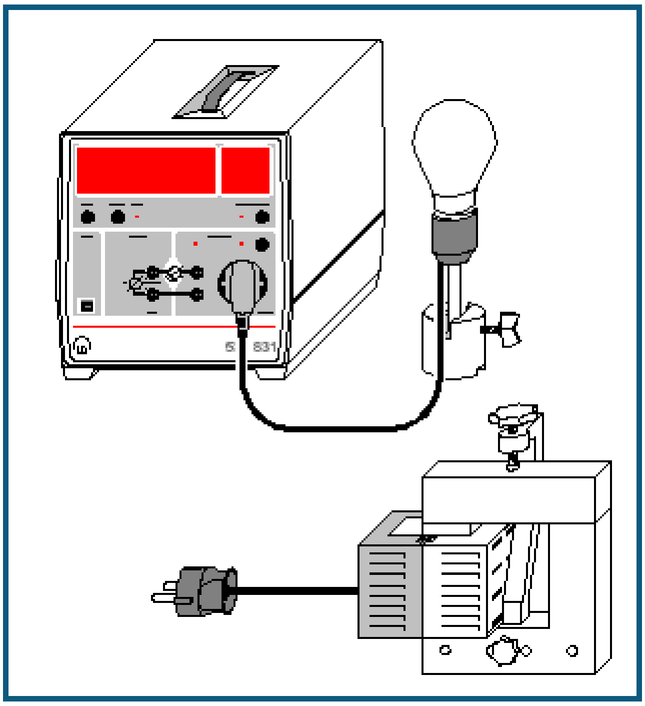
## Evaluation

The points of maximum power output and maximum efficiency can be easily read from the diagram.

## Hint

You can show and hide all measuring instruments simultaneously with ⧉.

## Power of arbitrary loads operated with mains AC voltage



### Safety note

At the socket of the joule and wattmeter, the mains voltage is present. Even though this voltage can be switched off through the software settings, it remains a potential danger. The voltage is present again at the latest when the software is left.

### Experiment description

The time dependent quantities U(t), I(t) and P(t) are recorded for several loads connected to the mains AC voltage. In addition, the active power P, the apparent power S, the reactive power Q and the power factor cosθ are displayed and can be compared with one another.

The active power P is the mean value of the instantaneous power P(t)=U(t)·I(t). The apparent power S is defined as the product of the two RMS values U and I, i.e. S=U·I. The power factor cosθ is the ratio of the active and the apparent power, i.e. cosθ = P/S. This also applies in the case of an arbitrary shape of the voltage U(t) and the current I(t). Yet, θ cannot be interpreted as the phase shift between the current and the voltage in this case. Finally, the reactive power Q is calculated from the active power P and the apparent power S:

$$Q = \sqrt{S^2 - P^2}$$

### Equipment list

| | | |
|---|---|---|
| 1 | Joule and wattmeter | 531 831 |
| 1 | Lamp socket E27 | 451 17 |
| 1 | Incandescent lamp 60 W, E27 | 505 301 |
| 1 | Energy-saving lamp 14 W, E27 | 505 3181 |
| 1 | Saddle base | 300 11 |
| 1 | U-core with yoke | 562 11 |
| 1 | Clamping device | 562 12 |
| 1 | Mains coil, 230 V | 562 21 |
| 1 | PC with Windows XP/Vista/7 | |

### Experiment setup (see drawing)

Screw the lamps into the lamp socket or put the mains coil onto the U-core, close the U-core with the yoke and fasten the yoke firmly using the clamping device.

Connect the plug of the lamp socket or the mains coil (switch the mains coil on) to the socket of the joule and wattmeter.

## Carrying out the experiment

- ▨ Load settings
- Switch the load on by clicking on the display instrument Switch X.
- Start the measurement with ⏱.
- Switch the load off again.

## Evaluation

The mains AC voltage U(t) has always an approximately sinusoidal shape.

Incandescent lamp

The functions I(t) and P(t) are approximately sinusoidal. The instantaneous power P(t) takes only positive values. The active and the apparent power are identical. The reactive power is negligible. The power factor cosθ is 1.

Energy-saving lamp

The functions I(t) and P(t) are not sinusoidal. The instantaneous power P(t) takes only positive values. The active power is smaller than the apparent and the reactive power. The power factor cosθ is approximately 0.64.

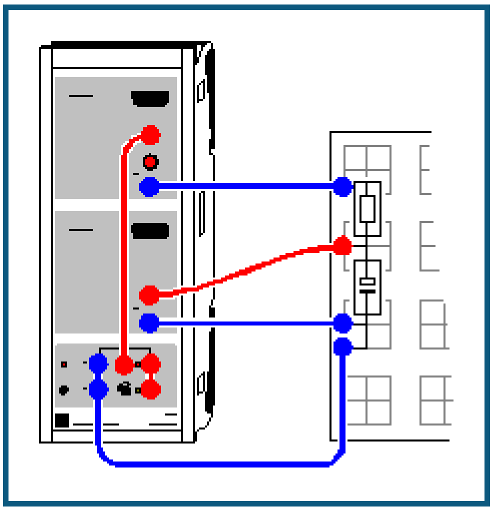
Mains coil with iron core

The functions I(t) and P(t) are not sinusoidal. The instantaneous power P(t) takes both positive and negative values. The active power is much smaller than the apparent und the reactive power. The power factor cosθ is approximately 0.18.

## Remark

Other loads can be investigated as well. However, it may be necessary to adjust the measuring range of the current (right mouse button on the I button). Then formulas and units for S and Q may have to be adjusted (e.g. U*I/1000, if U and I are to be displayed in V and A, but S in kW).

## Charging and discharging of a capacitor



### Experiment description

A capacitor is charged or discharged via a resistor. This experiment measures the voltage curves at the capacitor and the charging or discharge current. From these it is possible to calculate the time constant η = RC and the energy content of the capacitor.

### Equipment list

| | | |
|---|---|---|
| 1 | Sensor-CASSY | 524 010 or 524 013 |
| 1 | CASSY Lab 2 | 524 220 |
| 1 | Plug-in board DIN A4 | 576 74 |
| 3 | STE capacitors 100 κF | 578 39 |
| 1 | Resistor 100 Ω STE 2/19 | 577 32 |
| 1 | Connecting lead, 50 cm, blue | 500 422 |
| 1 | Pair of cables, 25 cm, red and blue | 501 44 |
| 2 | Pairs of cables, 50 cm, red and blue | 501 45 |
| 1 | PC with Windows XP/Vista/7 | |

### Experiment setup (see drawing)

Connect the charging and discharging circuit to Sensor-CASSY inputs A (current) and B (voltage) as shown in the drawing. The relay R charges the capacitor with the voltage from the voltage source S in the ON position (LED on) and discharges the capacitor in the OFF position (LED off).

### Carrying out the experiment

a) Discharging

■ Load settings

- Set the charging voltage $U_{B1}$ at the capacitor to about 9.5 V using the knob on the voltage source S.
- Start the discharge with ⏱.
- Repeat the discharge with different capacitances (e.g. 200 κF and 300 κF).

b) Charging

- Switch the relay manually: in Settings Relay R1 change the formula from **1** to **0** and press Enter.
- Start charging with ⏱.
- Repeat charging with different capacitances (e.g. 200 κF and 300 κF).

### Evaluation

To determine the time constant η = RC you can apply a logarithmic representation to the **Voltage** and **Current** displays. Simply click on the y-axis with the right mouse button to convert it. To optimize the display, you may want to specify the minima manually when applying logarithmic representation (e.g. 0.1 for log U and 0.001 for log I). In both cases, the slope A of a best-fit straight line is A = -log e/RC = -0.4343/RC or RC = -0.4343/A.

The time constant is obtained either from a fit to an exponential function or a free fit of the function A*exp(-x/B) or A*(1-exp(-x/B)) with suitable starting values for the charging voltage A and the time constant B = RC = η.

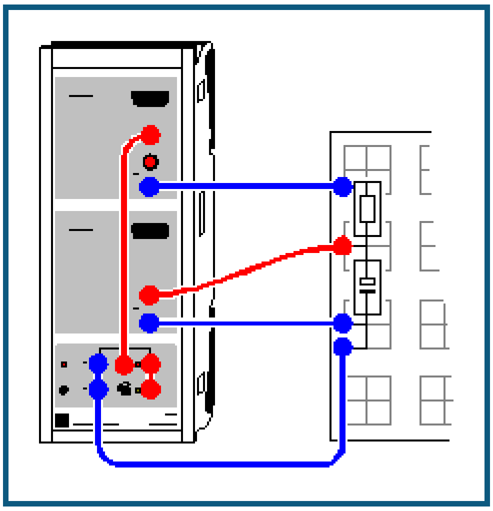
However, you can also determine the capacitances C from the applied or discharged charges Q. The charge Q is determined from the integral of the I(t) diagrams, and Q = CU (where U is the charging voltage).

The stored energy E = ½CU$^2$ is the integral of the P(t) diagrams in the display **Power**.

### Hint

The easiest way to define a time zero point is by setting a trigger. The most suitable quantity is the current $I_{A1}$ (when charging e.g. 0.001 A, rising edge, when discharging e.g. –0.001 A, falling edge). When the trigger is switched on, an external changeover switch can be used instead of the relay for more clarity of the circuit.

## Charging and discharging of a capacitor (with modeling)



### Experiment description

A capacitor is charged or discharged via a resistor. The voltage curve at the capacitor is measured.

As a supplement to the previous experiment, the measured voltage curve is compared with the voltage curve $U_C(t)$.

For a capacitor applies:

$U_C(t) = Q_C(t) / C$

and the model equation is:

$Q_C'(t) = I_C(t) = (U - U_C(t)) / R$

U is the voltage supplied by an external source and is equal to the voltage at the end of the charging or discharging process. The constants R and C correspond to the resistor and to the capacitor used.

### Equipment list

| | | |
|---|---|---|
| 1 | Sensor-CASSY | 524 010 or 524 013 |
| 1 | CASSY Lab 2 | 524 220 |
| 1 | Plug-in board DIN A4 | 576 74 |
| 3 | STE capacitors 100 κF | 578 39 |
| 1 | Resistor 100 Ω STE 2/19 | 577 32 |
| 1 | Connecting lead, 50 cm, blue | 500 422 |
| 1 | Pair of cables, 25 cm, red and blue | 501 44 |
| 2 | Pairs of cables, 50 cm, red and blue | 501 45 |
| 1 | PC with Windows XP/Vista/7 | |

### Experiment setup (see drawing)

Connect the charging and discharging circuit to Sensor-CASSY inputs A (current) and B (voltage) as shown in the drawing. The relay R charges the capacitor with the voltage from the voltage source S in the ON position (LED on) and discharges the capacitor in the OFF position (LED off).

### Carrying out the experiment

a) Discharging

☐ Load settings

- Set the charging voltage $U_{B1}$ at the capacitor to about 9.5 V using the knob on the voltage source S.
- Start the discharge with ⏱.
- Repeat the discharge with different capacitances (e.g. 200 κF and 300 κF).

b) Charging

☐ Load settings

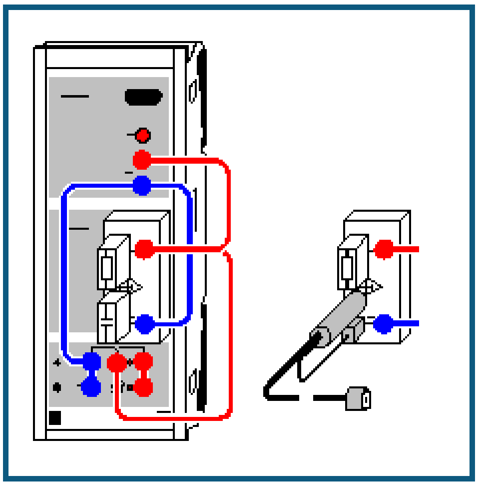
- Start charging with ⏱.
- Repeat charging with different capacitances (e.g. 200 κF and 300 κF).

### Modeling

When the capacitor is charged, the initial condition is $Q_C(t=0)=0$. The constants R (resistance) and C (capacitance) and the voltage U supplied by an external source can be altered by dragging the pointer of the corresponding display instrument (or by clicking to the left or to the right of the pointer) until the model agrees with the measurement.

When the capacitor is discharged, the initial condition is $Q_C(t=0)=C\cdot U_0$. The constants R (resistance) and C (capacitance) and the initial voltage $U_0$ of the capacitor can be altered by dragging the pointer of the corresponding display instrument (or by clicking to the left or to the right of the pointer) until the model agrees with the measurement.

## Charging and discharging of a small capacitor (cable capacitances)



### Experiment description

A capacitor is charged or discharged via a resistor. This experiment measures the voltage curves $U_B(t)$ at the capacitor and the charging or discharge current $I_A(t)=(U_A-U_B(t))/R$. From these it is possible to calculate the time constant η = RC and the energy content of the capacitor.

Small STE capacitors or a BNC cable, whose cable capacitance can be determined, are used as capacitors.

For the high-resistance measurement on a capacitor, the electrometer box is used.

### Equipment list

| | | |
|---|---|---|
| 1 | Sensor-CASSY | 524 010 or 524 013 |
| 1 | CASSY Lab 2 | 524 220 |
| 1 | Electrometer box | 524 054 |
| 1 | STE resistor 1 GΩ | 577 02 |
| 1 | STE capacitor 47 pF | 578 21 |
| 1 | STE capacitor 100 pF | 578 22 |
| 1 | STE capacitor 220 pF | 578 23 |
| 1 | Screened cable BNC/4 mm, 120 pF | 575 24 |
| 3 | Pairs of cables, 25 cm, red and blue | 501 44 |
| 1 | PC with Windows XP/Vista/7 | |

### Experiment setup (see drawing)

Connect the charging and discharging circuit to Sensor-CASSY inputs A and B as shown in the drawing. The relay R charges the capacitor with the voltage from the voltage source S in the ON position (LED on) and discharges the capacitor in the OFF position (LED off).

### Carrying out the experiment

a) Discharging

▨ Load settings

- Set the charging voltage $U_{B1}$ at the capacitor to about 7.5 V using the knob on the voltage source S.
- Start the discharge with ⏱.
- Repeat the discharge with different capacitances (e.g. 100 pF and 220 pF).

b) Charging

- Switch the relay manually: in Settings Relay R1 change the formula from **1** to **0** and press Enter.
- Start charging with ⏱.
- Repeat charging with different capacitances (e.g. 100 pF and 220 pF).

### Evaluation

To determine the time constant η = RC you can apply a logarithmic representation to the **Voltage** and **Current** displays. Simply click on the y-axis with the right mouse button to convert it. To optimize the display, you may want to specify the minima manually when applying logarithmic representation (e.g. 0.1 for log U and 0.001 for log I). In both cases, the slope A of a best-fit straight line is A = -log e/RC = -0.4343/RC or RC = -0.4343/A.

The time constant is obtained either from a fit to an exponential function or a free fit of the function A*exp(-x/B) or A*(1-exp(-x/B)) with suitable starting values for the charging voltage A and the time constant B = RC = η. For R = 1 GΩ, the time constant in s corresponds to the capacitance in nF.

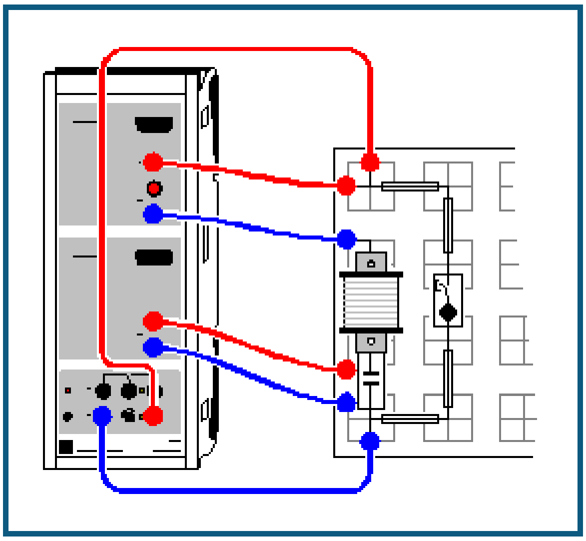
However, you can also determine the capacitances C from the applied or discharged charges Q. The charge Q is determined from the integral of the I(t) diagrams, and Q = CU (where U is the charging voltage).

The stored energy $E = ½CU^2$ is the integral of the P(t) diagrams in the display **Power**.

## Hint

The easiest way to define a time zero point is by setting a trigger. The most suitable quantity is the voltage $U_{A1}$ (when charging e.g. 0.5 V, rising edge, when discharging e.g. 0.5 V, falling edge). When the trigger is switched on, an external changeover switch can be used instead of the relay for more clarity of the circuit.

## Damped oscillator circuit



### Experiment description

An electrical oscillator is excited and the free oscillation is recorded. The damping and the phase difference between U(t) and I(t) become apparent. In the evaluation the calculated frequency φ and damping coefficient δ of the oscillation are compared with theory.

### Equipment list

| | | |
|---|---|---|
| 1 | Sensor-CASSY | 524 010 or 524 013 |
| 1 | CASSY Lab 2 | 524 220 |
| 1 | Plug-in board DIN A4 | 576 74 |
| 1 | STE coil, 1000 turns | 590 84 |
| 1 | STE capacitor 1 κF, 5 % | 578 15 |
| 1 | STE key switch (n.o.) | 579 10 |
| 1 | Set of bridging plugs | 501 48 |
| 3 | Pairs of cables, 50 cm, red and blue | 501 45 |
| 1 | PC with Windows XP/Vista/7 | |

### Experiment setup (see drawing)

Set up the oscillator circuit on the plug-in board as shown in the drawing. The current flows via input A of Sensor-CASSY and the capacitor voltage is measured at input B. At the start of the experiment the capacitor is charged from voltage source S. The oscillation is started with the key switch, which shorts the voltage source S.

### Remark

You can also use relay R instead of the key switch. However, this can bounce so hard when switching that the oscillation is disturbed in the first few milliseconds.

### Carrying out the experiment

▪ Load settings

- Set the charging voltage $U_{B1}$ at the capacitor to about 9.5 V using the knob at voltage source S.
- Start the measurement with ⏱ (software waits for the trigger signal).
- Close the oscillator circuit with the key switch (generates trigger signal).

### Evaluation

The easiest way to determine the frequency f is in the **Frequency Spectrum** display (click on this tab and calculate the peak center). The initial amplitude and time constant of the damping can be determined from parameters A and B by fitting an envelope.

These parameters can demonstrate impressive agreement of U(t) with y(t) = A*exp(-t/B)*sin(f*t*360). To realize this, change parameters A, B and f in the formula settings and select the display tab **Matching**.

### Example

From the U(t) envelope the experiment example gives us the initial amplitude A = 6.64 V and the time constant B = 1.77 ms. The oscillation frequency is determined to be 1235 Hz. The function of the oscillation is thus

y(t) = 6.64*exp(-t/0.00177)*sin(1235*t*360)

and is entered as the function for matching to U(t). The same time constant and frequency apply for I(t), but with a different initial amplitude and phase relation.

The calculated parameters also enable conclusions regarding the parameters R, L and C of the oscillator circuit, as in a damped oscillator the following applies:

$U(t) = U_0 \exp(-\delta t) \sin(\varphi t)$ where

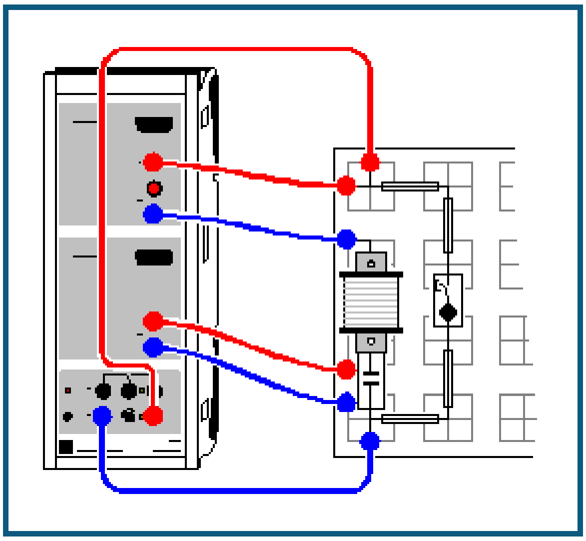
(1) $\varphi^2 = \varphi_0^2 - \delta^2$,
(2) $\varphi_0^2 = 1/LC$ and
(3) $\delta = R/2L$ (= 1/B of envelope).

When we insert the determined values we obtain:

$\varphi = 2\pi f = 7760$ /s
$\delta = 565$ /s
$\varphi_0 = 7781$ /s from (1).

(2) now allows us to calculate the inductance L of the coil when the capacitance C is known. In this example we obtain L = 0.0165 H (with C = 1 κF). (3) gives us the damping resistance R = 18.6 Ω. This agrees well with the specification of the coil used here (R = 18 Ω).

## Damped oscillator (with modeling)



### Experiment description

An electrical oscillator is excited and the free oscillation is recorded.

As a supplement to the previous experiment, the measured voltage curve is compared with the voltage curve $U_C(t)$.

For the oscillator circuit the following applies:

$U_C(t) = Q_C(t) / C$
$0 = U_C(t) + R \cdot I_C(t) + L \cdot I_C'(t)$

and the model equations are:

$Q_C'(t) = I_C(t)$
$I_C'(t) = (-U_C(t) - R \cdot I_C(t)) / L$

The constants R, L and C correspond to the resistor, the coil and the capacitor used.

### Equipment list

| | | |
|---|---|---|
| 1 | Sensor-CASSY | 524 010 or 524 013 |
| 1 | CASSY Lab 2 | 524 220 |
| 1 | Plug-in board DIN A4 | 576 74 |
| 1 | STE coil, 1000 turns | 590 84 |
| 1 | STE capacitor 1 κF, 5 % | 578 15 |
| 1 | STE key switch (n.o.) | 579 10 |
| 1 | Set of bridging plugs | 501 48 |
| 3 | Pairs of cables, 50 cm, red and blue | 501 45 |
| 1 | PC with Windows XP/Vista/7 | |

### Experiment setup (see drawing)

Set up the oscillator circuit on the plug-in board as shown in the drawing. The current flows via input A of Sensor-CASSY and the capacitor voltage is measured at input B. At the start of the experiment the capacitor is charged from voltage source S. The oscillation is started with the key switch, which shorts the voltage source S.

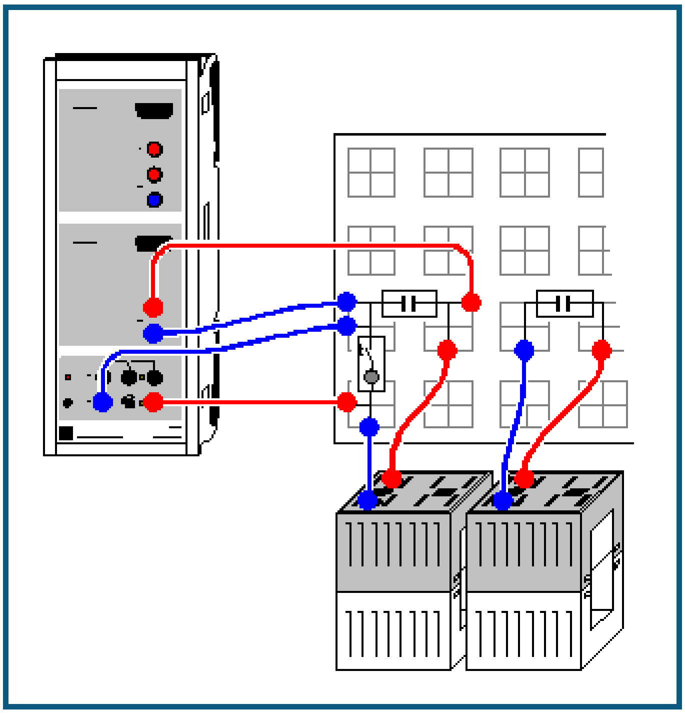
### Carrying out the experiment

▨ Load settings
- Set the charging voltage $U_{B1}$ at the capacitor to about 9.5 V using the knob at voltage source S.
- Start the measurement with ⏱ (software waits for the trigger signal).
- Close the oscillator circuit with the key switch (generates trigger signal).

### Modeling

The initial condition for the charge Q of the capacitor is $Q(t=0)=-U_0 \cdot C$ with the initial voltage $U_0$. This voltage $U_0$ is not exactly the charging voltage of the capacitor because the measurement is only triggered somewhat later. Therefore the second initial condition is simply I(t=0)=0. The constants R (resistance), C (capacitance) and L (inductance) and the initial voltage $U_0$ can be altered by dragging the pointer of the corresponding display instrument (or by clicking to the left or to the right of the pointer) until the model agrees with the measurement. The ohmic resistance of the coil (approx. 20 Ω) has to be taken into account when the attenuation resistance R is determined.

## Coupled oscillators



### Experiment description

The frequency spectrum of coupled electric oscillator circuits is compared with the spectrum of an uncoupled oscillator circuit. The Fourier-transformed signal of the coupled oscillator circuits shows the split into two distributions lying symmetrically around the uncoupled signal, with their spacing depending on the coupling of the oscillator circuits.

### Equipment list

| | | |
|---|---|---|
| 1 | Sensor-CASSY | 524 010 or 524 013 |
| 1 | CASSY Lab 2 | 524 220 |
| 1 | Plug-in board DIN A4 | 576 74 |
| 1 | STE key switch | 579 10 |
| 2 | STE capacitors 1 κF, 5 % | 578 15 |
| 2 | Coils with 500 turns | 562 14 |
| 4 | Pairs of cables, 50 cm, red and blue | 501 45 |
| 1 | PC with Windows XP/Vista/7 | |

### Experiment setup (see drawing)

Assemble the first oscillator circuit as shown in the drawing. The capacitor voltage is measured at input B of Sensor-CASSY. At the start of the experiment the capacitor is charged from voltage source S. The oscillation is started with the key switch, which shorts the voltage source S.

Assemble the second oscillator circuit separately. To couple the oscillators, place its coil directly beside the first coil.

### Remark

You can also use relay R instead of the key switch. However, this can bounce so hard when switching that the oscillation is disturbed in the first few milliseconds.

### Carrying out the experiment

Load settings

- Set the charging voltage $U_{B1}$ at the capacitor to about 9.5 V using the knob at voltage source S.
- Start the measurement with ⏱ (software waits for the trigger signal).
- Close the oscillator circuit with the key switch (generates trigger signal).
- Place the coil of the second oscillator directly beside that of the first to couple the oscillators.
- Start the measurement with ⏱ (software waits for the trigger signal).
- Close the oscillator circuit with the key switch (generates trigger signal).

## Evaluation

The uncoupled case produces a damped harmonic oscillation. The coupled oscillation is a beat with the same envelope and the same oscillation frequency.

In the uncoupled case, the **Frequency Spectrum** display shows only one peak, for which the frequency can be calculated as the peak center.

In the coupled case the frequency splits symmetrically into two frequencies. The amplitudes are just half as great as in the uncoupled case, and the interval depends on the coupling.

Given the differential equations of the coupled oscillation circuits

$$L\ddot{I}_1 + kL\ddot{I}_2 + I_1 / C = 0$$

$$L\ddot{I}_2 + kL\ddot{I}_1 + I_2 / C = 0$$

with coupling k ($0 \le k < 1$), we can calculate the two natural frequencies $\varphi_1$ and $\varphi_2$ as

$$\frac{\omega_0}{\sqrt{1+k}} = \omega_1 < \omega_0 < \omega_2 = \frac{\omega_0}{\sqrt{1-k}}.$$

In particular, the oscillation frequency of the coupled system is equal to

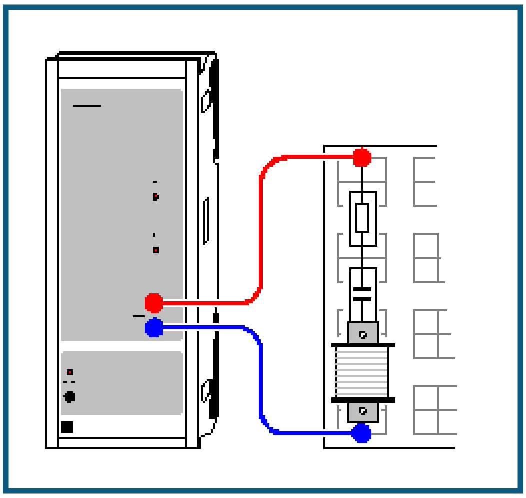
$$\frac{\omega_1 + \omega_2}{2} = \frac{\omega_0}{\sqrt{1-k^2}} \approx \omega_0$$

and is thus practically unchanged with respect to the uncoupled system (for small k values).

## Remark

The split into two peaks of precisely the same size is only possible with completely identical oscillators. This is not always precisely the case due to the tolerances of the inductances L and capacitances C.

## Forced oscillations (resonance)



### Experiment description

A sinusoidal oscillation with the frequency f and a constant amplitude is applied to an electric RLC series oscillator circuit. After a short settling time, the oscillator also oscillates with the frequency f.

This experiment investigates the RMS value of the flowing current I and the phase relation θ of the current to the applied voltage as a function of the frequency f and the attenuating resistance R. The loci illustrate the addition of complex resistances.

### Equipment list

| | | |
|---|---|---|
| 1 | Power-CASSY | 524 011 |
| 1 | CASSY Lab 2 | 524 220 |
| 1 | Plug-in board DIN A4 | 576 74 |
| 1 | STE coil, 500 turns | 590 83 |
| 1 | STE capacitor 4.7 κF, 5 % | 578 16 |
| 2 | STE resistors 1 Ω | 577 19 |
| 1 | STE resistor 5.1 Ω | 577 21 |
| 1 | STE resistor 10 Ω | 577 20 |
| 1 | STE resistor 20 Ω | 577 23 |
| 1 | Resistor 47 Ω STE 2/19 | 577 28 |
| 1 | Pair of cables, 50 cm, red and blue | 501 45 |
| 1 | PC with Windows XP/Vista/7 | |

### Experiment setup (see drawing)

Set up the oscillator as shown in the drawing and connect it to Power-CASSY. Connect additional attenuating resistors in series as needed.

### Carrying out the experiment

■ Load settings

- Start the measurement with ⏱. The frequency f is automatically increased in small steps. After a short settling time, the software measures and displays the RMS value of the current I and the phase relation cos θ between the current and the voltage for each frequency.
  The step size is variable and depends on the specifications of the number $n_0$, the starting frequency $f_0$ and the approximate value $f_1$ of the resonance frequency. Between the two frequencies $f_0$ and $f_1$, $n_0$ measuring values are recorded. Then the frequency f is further increased in a way that around $f=f_1$, i.e. the resonance frequency, values are recorded at a particularly high density. Thereby the measuring time required is considerably reduced as compared with equally spaced frequency steps. The specifications can be changed by shifting the pointer with the mouse or by changing the parameter value after clicking with the right mouse key.
  The measuring condition **delta t > 2/f+2** provides a settling time of 2/f+2 s after the frequency has been increased.
  The stop condition **f > 5000 or f > 5*f1** terminates the measurement at 5 kHz or 5 times the resonance frequency.
- Repeat the measurement with other attenuation resistances as necessary.

## Evaluation

The resonance frequency can be exactly determined, for example, by determining the peak center in the display **Resonance**.

In other displays, also the **Power** and the **Phase** are shown as functions of the frequency.

The last two displays show the **Loci** for the complex resistance Z of the oscillating circuit and the complex conductance Y. In the Z representation, the addition of complex resistances in series connection is nicely displayed: $Z = R + i\varphi L + 1/i\varphi C$. As in the example only the frequency $\varphi$, that is the imaginary part of Z, is varied for each damping resistance, the real ohmic part remains constant. Thus vertical lines are generated in the complex plane whose distance from the imaginary axis is equal to the ohmic resistance R. The coil in the example has an ohmic internal resistance of approximately 4 Ω. Therefore the distance from the imaginary axis is larger than the individual damping resistances by approximately 4 Ω.

## Remark

For an AC circuit we can write

$U = |U| * e^{i\varphi t}$ and $I = |I| * e^{i(\varphi t-\theta)}$

where the complex resistance Z = U/I no longer depends on t

$Z = |U|/|I| * e^{i\theta} = |Z| * e^{i\theta}$ (Z locus)

On the other hand we have

$Y = 1/Z = 1/|Z| * e^{-i\theta}$ (Y locus)

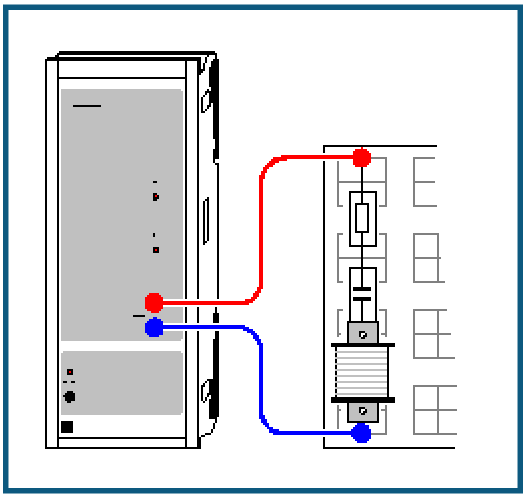
The Y locus corresponds to the complex inversion of the Z locus (r -> -r, θ -> -θ). This transformation turns the straight lines $Z = R + i\varphi L + 1/i\varphi C$ of the Z loci into circles in the Y representation (inversion with respect to the unit circle).

## Hints

You can show and hide all measuring instruments simultaneously with ⧉.

You can logarithmically scale the frequency axis or the current axis easily by clicking on the corresponding axis with the right mouse button.

## Forced oscillations (resonance, with modeling)



### Experiment description

A sinusoidal oscillation with the frequency f and a constant amplitude is applied to an electric RLC series oscillator circuit. After a short settling time, the oscillator also oscillates with the frequency f.

As a supplement to the previous experiment, the measured current curve is compared with the current curve $I_C(t)$.

For the oscillator circuit the following applies:

$U_C(t) = Q_C(t) / C$
$U(t) = L \cdot I_C'(t) + U_C(t) + R \cdot I_C(t)$

and the model equations are:

$Q_C'(t) = I_C(t)$
$I_C'(t) = (U(t) – U_C(t) – R \cdot I_C(t)) / L$

The constants R, L and C correspond to the resistor, the coil and the capacitor used.

### Equipment list

| | | |
|---|---|---|
| 1 | Power-CASSY | 524 011 |
| 1 | CASSY Lab 2 | 524 220 |
| 1 | Plug-in board DIN A4 | 576 74 |
| 1 | STE coil, 500 turns | 590 83 |
| 1 | STE capacitor 4.7 κF, 5 % | 578 16 |
| 2 | STE resistors 1 Ω | 577 19 |
| 1 | STE resistor 5.1 Ω | 577 21 |
| 1 | STE resistor 10 Ω | 577 20 |
| 1 | STE resistor 20 Ω | 577 23 |
| 1 | Resistor 47 Ω STE 2/19 | 577 28 |
| 1 | Pair of cables, 50 cm, red and blue | 501 45 |
| 1 | PC with Windows XP/Vista/7 | |

### Experiment setup (see drawing)

Set up the oscillator as shown in the drawing and connect it to Power-CASSY. Connect additional attenuating resistors in series as needed.

### Carrying out the experiment

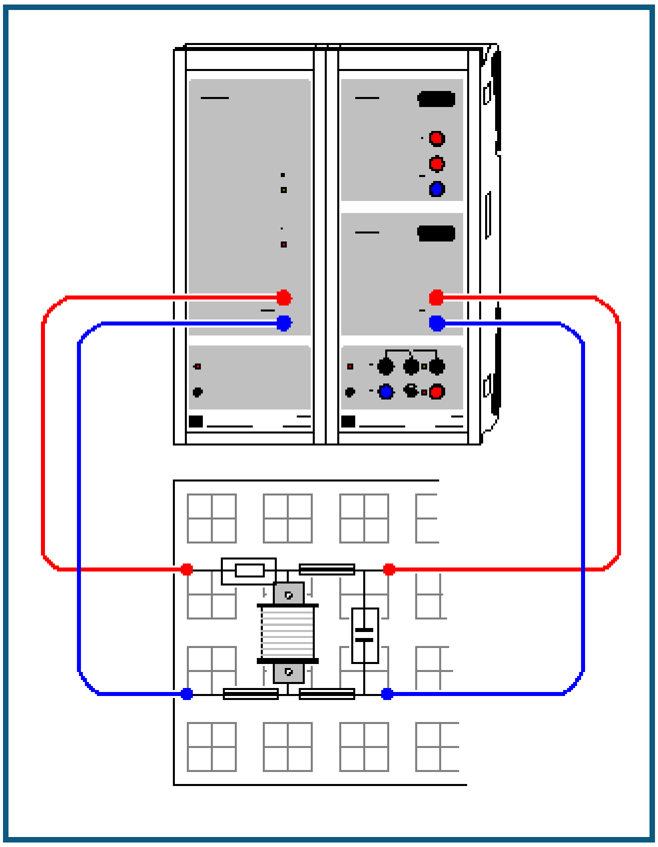
▨ Load settings
- Start the measurement with ⏱.
- Repeat the measurement with another frequency f (shift the pointer in the display instrument) or with other attenuation resistances as necessary.

## Modeling

The initial conditions for the charge Q and the current $I_C$ are both zero as there is no voltage and no current in the oscillator circuit before the measurement. The constants R (resistance), C (capacitance) and L (inductance) can be altered by dragging the pointer of the corresponding display instrument (or by clicking to the left or to the right of the pointer) until the model agrees with the measurement. The ohmic resistance of the coil (approx. 4 Ω) has to be taken into account when the attenuation resistance R is determined.

The Power-CASSY only switches the exciting frequency on when the measurement is started. Therefore the transient oscillation process of the oscillator circuit is seen. Depending on the attenuation and the frequency, you see that the oscillator circuit first oscillates at its natural frequency (resonance frequency) before it is forced to oscillate at the exciting frequency.

## RLC filter (low pass, high pass, band pass)



### Experiment description

A sinusoidal oscillation with frequency f and having a constant amplitude is applied to an electrical filter consisting of a resistor and a capacitor (RC), resistor and coil (RL) or a resistor and a parallel LC oscillator circuit (RLC). After a short settling time, the output of the filter also oscillates with the frequency f.

This experiment examines the RMS values of the output voltage U and the flowing current I, the impedances $Z_1 = 1/(1/i\varphi C) + i\varphi L)$ (LC only) and $Z = R + 1/(1/i\varphi C) + i\varphi L)$ (R with LC) and the phase relation θ between the current and the applied voltage as a function of the frequency f.

This experiment illustrates in a particularly clear fashion the function of a low pass (RC), high pass (RL) and band pass (RLC) filter, as well as impedances, phase shifts and the parallel resonance of the RLC filter. The loci illustrate the addition of complex resistances.

### Equipment list

| | | |
|---|---|---|
| 1 | Sensor-CASSY | 524 010 or 524 013 |
| 1 | Power-CASSY | 524 011 |
| 1 | CASSY Lab 2 | 524 220 |
| 1 | Plug-in board DIN A4 | 576 74 |
| 1 | Resistor 100 Ω STE 2/19 | 577 32 |
| 1 | STE coil, 500 turns | 590 83 |
| 1 | STE capacitor 4.7 κF, 5 % | 578 16 |
| 2 | Pairs of cables, 50 cm, red and blue | 501 45 |
| 1 | PC with Windows XP/Vista/7 | |

### Experiment setup (see drawing)

Connect the electrical filter to Power-CASSY and Sensor-CASSY as shown in the diagram. You can vary the type of filter (RC, RL or RLC) during the experiment by removing or plugging in the coil (L) or the capacitor (C).

### Carrying out the experiment

☐ Load settings
- Realize the RC filter by removing the coil.

- Start the measurement with ⏱. The frequency f is automatically increased in small steps. After a short setting time, the software measures and displays the respective RMS value of the output voltage U and the current I.

  The step size is variable and depends on the specifications of the number $n_0$, the starting frequency $f_0$ and the approximate value $f_1$ of the resonance frequency. Between the two frequencies $f_0$ and $f_1$, $n_0$ measuring values are recorded. Then the frequency f is further increased in a way that around $f=f_1$, i.e. the resonance frequency, values are recorded at a particularly high density. Thereby the measuring time required is considerably reduced as compared with equally spaced frequency steps. The specifications can be changed by shifting the pointer with the mouse or by changing the parameter value after clicking with the right mouse key.

  The measuring condition **delta t > 2/f+3** provides a settling time of 2/f+3 s after the frequency has been increased.

  The stop condition **f > 5000 or f > 5*f1** terminates the measurement at 5 kHz or 5 times the resonance frequency.
- Repeat the measurement with the RL filter and the RLC filter.

## Evaluation

The **Output Voltage** and **Input Current** displays (accessible with the mouse) show the curves of the output voltage and the current as function of the frequency. The RC filter attenuates the output voltage at high frequencies by about half (low pass) for each octave (doubling of frequency). The RL filter, on the other hand, attenuates the lower frequencies by about half (high pass) for each octave (half frequency). The RLC filter attenuates frequencies outside of the resonance frequency of the parallel LC oscillator corresponding to the individual filters. However, the output voltage shows a visible maximum in the resonance range (band pass). The resonance frequency is independent of R.

The two impedances $Z_1$ (LC only) and Z (R with LC) are also calculated and displayed. The resistance of the parallel LC oscillator reaches its maximum at its resonance frequency (in an ideal circuit this would be infinite). The flowing current is thus minimal, as is the voltage drop at the resistor. Consequently, the output voltage reaches its maximum where resonance occurs.

The **Phase** view shows the phase shift between the applied voltage and the flowing current.

The last two displays show the **Loci** for the complex resistance Z of the filter and the complex conductance Y. In the Z representation, the addition of complex resistances in series connection is nicely displayed. For a low pass we have $Z = R + 1/i\varphi C$ and for a high pass $Z = R + i\varphi L$. As only the frequency φ, that is the imaginary part of Z, is varied, the real ohmic part remains constant. Thus vertical lines are generated in the complex plane whose distance from the imaginary axis is equal to the ohmic resistance R. The coil in the example has an ohmic internal resistance of approximately 4 Ω. In the case of the high pass, the distance from the imaginary axis is therefore larger by approximately 4 Ω than in the case of the low pass.

## Remark

For an AC circuit we can write

$U = |U| * e^{i\varphi t}$ and $I = |I| * e^{i(\varphi t-\theta)}$

where the complex resistance Z = U/I no longer depends on t

$Z = |U|/|I| * e^{i\theta} = |Z| * e^{i\theta}$ (Z locus)

On the other hand we have

$Y = 1/Z = 1/|Z| * e^{-i\theta}$ (Y locus)

The Y locus corresponds to the complex inversion of the Z locus (r -> -r, θ -> -θ). This transformation turns the straight lines $Z = R + 1/i\varphi C$ and $Z = R + i\varphi L$ of the Z loci into semicircles in the Y representation (inversion with respect to the unit circle).

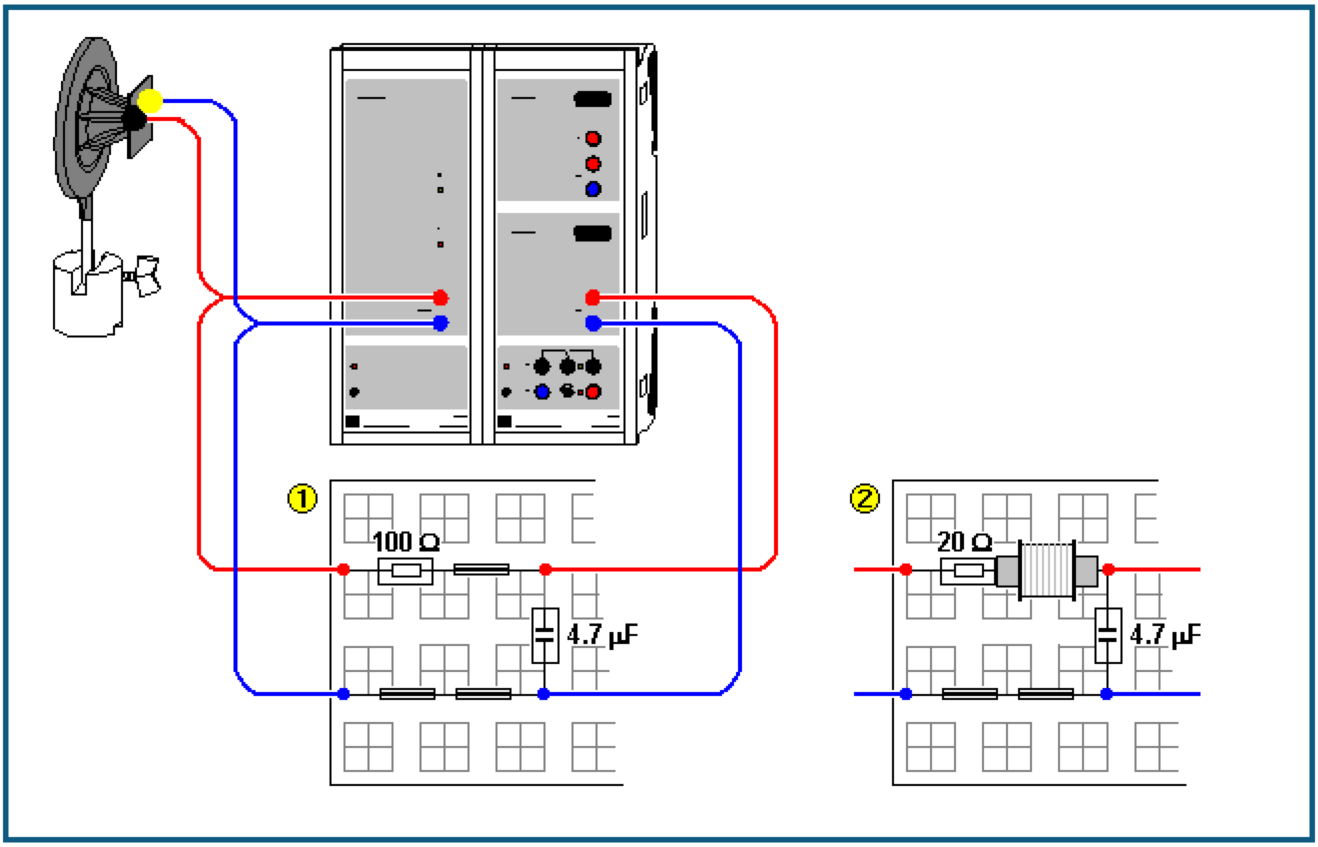
## Hints

You can show and hide all measuring instruments simultaneously with ⧉.

You can logarithmically scale the coordinate axes easily by clicking on the corresponding axis with the right mouse button.

The attenuations of 6 dB/octave (resp. 20 dB/decade) can be read off easily in a log-log display as the slope ±1.

## Low-pass filter (with modeling)



### Experiment description

In the first experiment, rectangular pulses with a constant amplitude are applied to a first-order low-pass filter ① consisting of a resistor and a capacitor (RC) or a second-order low-pass filter ② consisting of a resistor, a coil and a capacitor (RLC). The response of the filter to these pulses is investigated (step response) and compared with a model.

In the second experiment, an input signal of variable frequency (chirp) is applied to the low-pass filter. A Fourier transform is applied to both the input signal and the measured output signal, and the two frequency spectra are divided one by the other. The frequency-dependent amplitude change (amplitude response) obtained in this procedure is displayed and compared with a model.

For the first-order low-pass applies for the output voltage

$U_{RC}(t) = Q_{RC}(t) / C$

and the model equation is:

$Q_{RC}'(t) = I_{RC}(t) = (U(t) - U_{RC}(t)) / R$

For the second-order low-pass applies for the output voltage

$U_{RLC}(t) = Q_{RLC}(t) / C$

and the model equations are:

$Q_{RLC}'(t) = I_{RLC}(t)$
$I_{RLC}'(t) = (U(t) – U_{RLC}(t) – R \cdot I_{RLC}(t)) / L$

The constants R, L and C correspond to the resistor, the coil and the capacitor used.

### Equipment list

| | | |
|---|---|---|
| 1 | Sensor-CASSY | 524 010 or 524 013 |
| 1 | Power-CASSY | 524 011 |
| 1 | CASSY Lab 2 | 524 220 |
| 1 | Plug-in board DIN A4 | 576 74 |

| | | |
|---|---|---|
| 1 | STE resistor 20 Ω | 577 23 |
| 1 | Resistor 47 Ω STE 2/19 | 577 28 |
| 1 | Resistor 100 Ω STE 2/19 | 577 32 |
| 1 | STE coil, 500 turns | 590 83 |
| 1 | STE capacitor 4.7 κF, 5 % | 578 16 |
| 2 | Pairs of cables, 50 cm, red and blue | 501 45 |
| 1 | PC with Windows XP/Vista/7 | |

recommended:

| | | |
|---|---|---|
| 1 | Tweeter | 587 07 |
| 1 | Saddle base | 300 11 |
| 1 | Iron core, laminated | from 593 21 |
| 1 | Pair of cables, 50 cm, red and blue | 501 45 |

### Experiment setup (see drawing)

Connect the first-order or second-order low-pass filter to the Power-CASSY and the Sensor-CASSY as shown in the drawing. In order to increase the inductance L of the coil, you may use a laminated iron core. It is recommended to connect the tweeter to the output of the Power-CASSY for a better understanding of the measurement of the amplitude response.

### Carrying out the experiment

a) Step response

■ Load settings
- Realize the RC filter (first order) or RLC filter (second order).
- Start the measurement with ⏱.
- Repeat the measurement with another frequency f (shift the pointer in the display instrument) or with another order as necessary.

b) Amplitude response

■ Load settings
- Realize the RC filter (first order) or RLC filter (second order).
- Start the measurement with ⏱.
- Repeat the measurement with another order as necessary.

### Modeling

The constants R (resistance), C (capacitance) and L (inductance) can be altered by dragging the pointer of the corresponding display instrument (or by clicking to the left or to the right of the pointer) until the model agrees with the measurement. The ohmic resistance of the coil (approx. 4 Ω) has to be taken into account when the attenuation resistance R is determined.

a) Step response

The displays **Model RC** and **Model RLC** (select using the mouse) show the comparison of the measured filter response with the corresponding model. The Power-CASSY outputs the exciting frequency continuously. Therefore the transient oscillation process of the filter is not seen in the measured signal. The start time for the computation was chosen a period before zero, i.e. $t_0$=–1/f, in order that the transient oscillation process is also invisible in the model.

The additional displays **Frequency Spectrum RC** and **Frequency Spectrum RLC** make it possible to compare the attenuation of the input signal depending on the frequency and the order of the filter. This comparison is also possible by direct measurement of the amplitude response.

b) Amplitude response

The Power-CASSY excites the filter at a variable frequency (chirp). In this chirp the frequency is increased very quickly from 0 Hz to approx. 2500 Hz. In the **Amplitude Response**, the ratio of the amplitudes of the output signal and the input signal of the filter is displayed. The black curve is the measured curve, the red curve is the result of the first-order model, and the blue curve shows the second-order model.

During the measurement, the filter response must not overdrive the Sensor-CASSY (see **Standard** display). If necessary, repeat the measurement with a decreased amplitude A or an increased resistance R.

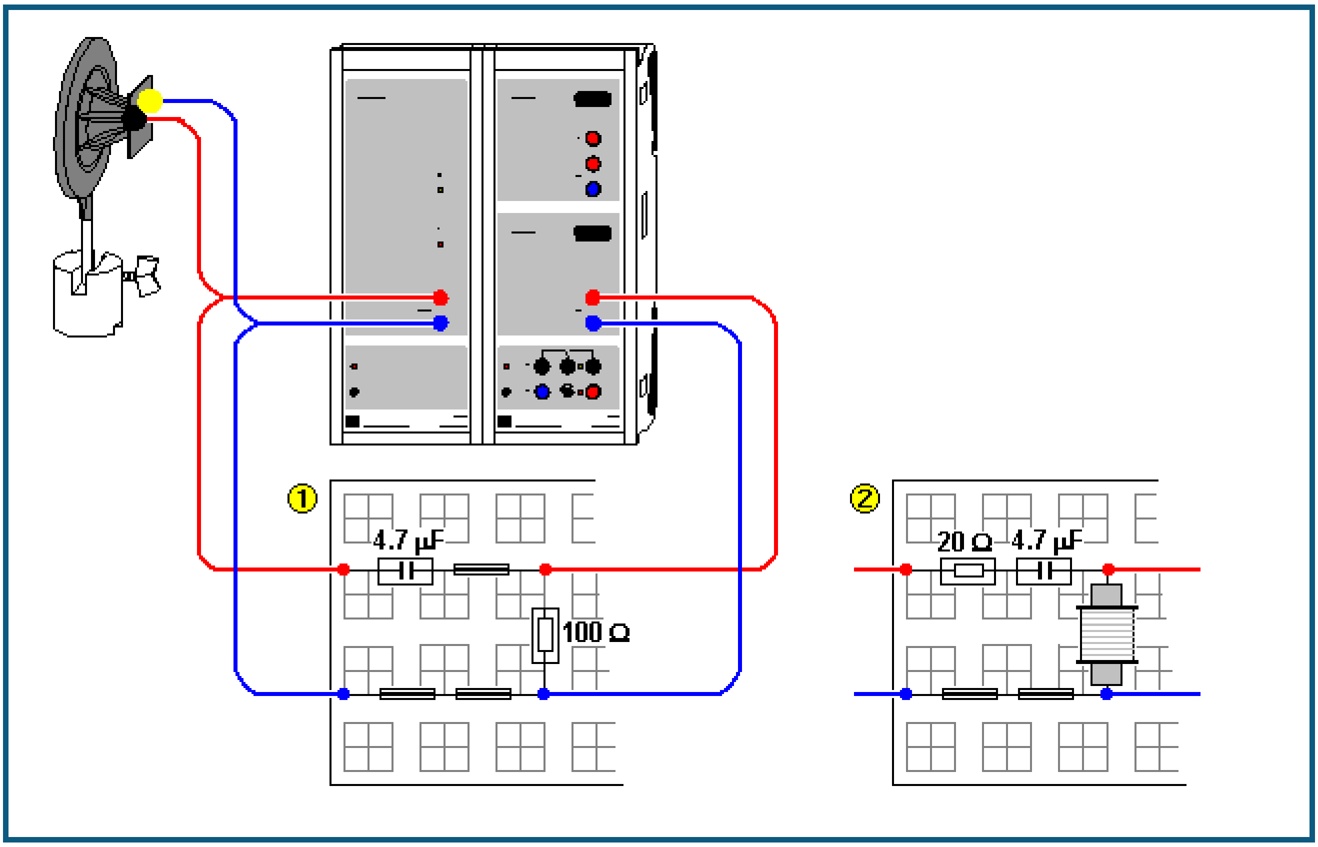
### Remark concerning the measurement of the amplitude response

When the basic frequency f of the chirp (f = 2.5 Hz in the example) is changed, the measuring interval has to be changed, too, so that the measuring time T corresponds to the chirp period again (T= 400 ms in the example).

Moreover, the range of the amplitudes $A_B$, $A_{RC}$ and $A_{RLC}$ has to be adjusted. In the example, the amplitude ratios are only defined if the amplitude of the FFT in the denominator is at least 1.5 % of the input amplitude A.

The computation time of the models is limited to 5 s. If this is not sufficient in the case of slow computers, the subsequent Fourier analysis is only computed for the incomplete solution. In this case, please increase the maximum computation time of the models.

## High-pass filter (with modeling)



### Experiment description

In the first experiment, rectangular pulses with a constant amplitude are applied to a first-order high-pass filter ① consisting of a resistor and a capacitor (RC) or a second-order high-pass filter ② consisting of a resistor, a coil and a capacitor (RLC). The response of the filter to these pulses is investigated (step response) and compared with a model.

In the second experiment, an input signal of variable frequency (chirp) is applied to the high-pass filter. A Fourier transform is applied to both the input signal and the measured output signal, and the two frequency spectra are divided one by the other. The frequency-dependent amplitude change (amplitude response) obtained in this procedure is displayed and compared with a model.

For the first-order high-pass applies for the output voltage

$U_{RC}(t) = U(t) – Q_{RC}(t) / C$

and the model equation is:

$Q_{RC}'(t) = I_{RC}(t) = U_{RC}(t) / R$

For the second-order high-pass applies for the output voltage

$U_{RLC}(t) = U(t) – R\cdot I_{RLC}(t) – Q_{RLC}(t)/C$

and the model equations are:

$Q_{RLC}'(t) = I_{RLC}(t)$
$I_{RLC}'(t) = U_{RLC}(t) / L$

The constants R, L and C correspond to the resistor, the coil and the capacitor used.

### Equipment list

| | | |
|---|---|---|
| 1 | Sensor-CASSY | 524 010 or 524 013 |
| 1 | Power-CASSY | 524 011 |
| 1 | CASSY Lab 2 | 524 220 |
| 1 | Plug-in board DIN A4 | 576 74 |

| | | |
|---|---|---|
| 1 | STE resistor 20 Ω | 577 23 |
| 1 | Resistor 47 Ω STE 2/19 | 577 28 |
| 1 | Resistor 100 Ω STE 2/19 | 577 32 |
| 1 | STE coil, 500 turns | 590 83 |
| 1 | STE capacitor 4.7 κF, 5 % | 578 16 |
| 2 | Pairs of cables, 50 cm, red and blue | 501 45 |
| 1 | PC with Windows XP/Vista/7 | |

recommended:

| | | |
|---|---|---|
| 1 | Tweeter | 587 07 |
| 1 | Saddle base | 300 11 |
| 1 | Iron core, laminated | from 593 21 |
| 1 | Pair of cables, 50 cm, red and blue | 501 45 |

### Experiment setup (see drawing)

Connect the first-order or second-order high-pass filter to the Power-CASSY and the Sensor-CASSY as shown in the drawing. In order to increase the inductance L of the coil, you may use a laminated iron core. It is recommended to connect the tweeter to the output of the Power-CASSY for a better understanding of the measurement of the amplitude response.

### Carrying out the experiment

a) Step response

■ Load settings
- Realize the RC filter (first order) or RLC filter (second order).
- Start the measurement with ⏱.
- Repeat the measurement with another frequency f (shift the pointer in the display instrument) or with another order as necessary.

b) Amplitude response

■ Load settings
- Realize the RC filter (first order) or RLC filter (second order).
- Start the measurement with ⏱.
- Repeat the measurement with another order as necessary.

### Modeling

The constants R (resistance), C (capacitance) and L (inductance) can be altered by dragging the pointer of the corresponding display instrument (or by clicking to the left or to the right of the pointer) until the model agrees with the measurement. The ohmic resistance of the coil (approx. 4 Ω) has to be taken into account when the attenuation resistance R is determined.

a) Step response

The displays **Model RC** and **Model RLC** (select using the mouse) show the comparison of the measured filter response with the corresponding model. The Power-CASSY outputs the exciting frequency continuously. Therefore the transient oscillation process of the filter is not seen in the measured signal. The start time for the computation was chosen a period before zero, i.e. $t_0$=–1/f, in order that the transient oscillation process is also invisible in the model.

The additional displays **Frequency Spectrum RC** and **Frequency Spectrum RLC** make it possible to compare the attenuation of the input signal depending on the frequency and the order of the filter. This comparison is also possible by direct measurement of the amplitude response.

b) Amplitude response

The Power-CASSY excites the filter at a variable frequency (chirp). In this chirp the frequency is decreased very quickly from approx. 2500 Hz to 0 Hz. In the Amplitude Response, the ratio of the amplitudes of the output signal and the input signal of the filter is displayed. The black curve is the measured curve, the red curve is the result of the first-order model, and the blue curve shows the second-order model.

During the measurement, the filter response must not overdrive the Sensor-CASSY (see Standard display). If necessary, repeat the measurement with a decreased amplitude A or an increased resistance R.

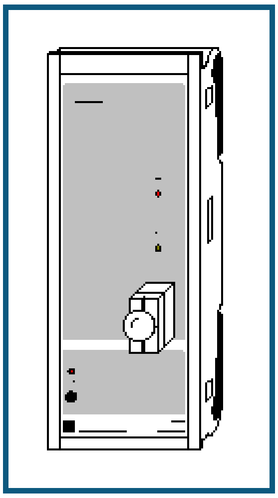
### Remark concerning the measurement of the amplitude response

When the basic frequency f of the chirp (f = 2.5 Hz in the example) is changed, the measuring interval has to be changed, too, so that the measuring time T corresponds to the chirp period again (T= 400 ms in the example).

Moreover, the range of the amplitudes $A_B$, $A_{RC}$ and $A_{RLC}$ has to be adjusted. In the example, the amplitude ratios are only defined if the amplitude of the FFT in the denominator is at least 1.5 % of the input amplitude A.

The computation time of the models is limited to 5 s. If this is not sufficient in the case of slow computers, the subsequent Fourier analysis is only computed for the incomplete solution. In this case, please increase the maximum computation time of the models.

## Characteristic of an incandescent lamp



### Experiment description

In an incandescent lamp the voltage and current are not proportional to one another. Their resistance depends greatly on the temperature. As an incandescent lamp heats up when electricity is supplied, different characteristics are obtained when the current is switched on and off. The characteristic also depends on the rate of increase dU/dt of the voltage.

### Equipment list

| | | |
|---|---|---|
| 1 | Power-CASSY | 524 011 |
| 1 | CASSY Lab 2 | 524 220 |
| 1 | Set of 10 lamps 12 V /3 W | 505 08 |
| 1 | STE Lamp holder E 10, top | 579 06 |
| 1 | PC with Windows XP/Vista/7 | |

### Experiment setup (see drawing)

You can attach the lamp directly to Power-CASSY.

### Carrying out the experiment

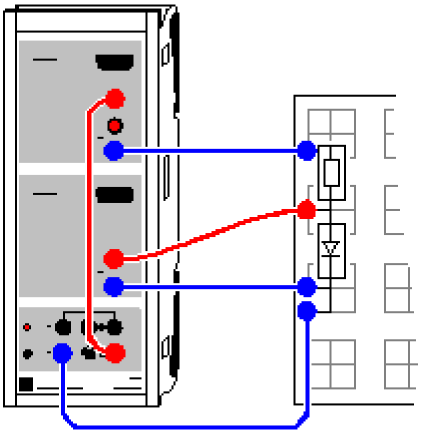
☐ Load settings

- Execute the measurement with ⏱ (the lamp is switched on and then off).
- If desired, vary the switching frequency of the lamp in Settings U1 and the measuring time in the Measuring Parameters (**Window → Show Measuring Parameters**) and repeat the experiment.

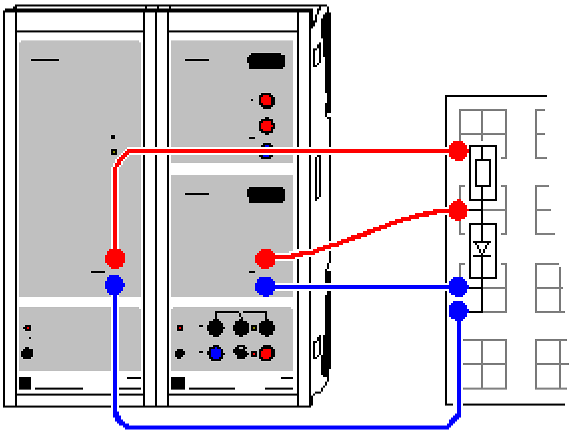
### Evaluation

In the characteristic, you can determine the inverse values of the cold and hot resistance of the incandescent lamp by fitting a straight line.

## Characteristic of a diode



Alternatively (with Power-CASSY):



### Experiment description

The semiconductor diodes are among the simplest semiconductor components. They consist of a semiconductor crystal in which an n-conducting zone meets a p-conducting zone. Recombination of the charge carriers, i.e. the electrons in the n-conducting and the holes in the p-conducting zones, creates a low-conductivity zone at the boundary layer. The conductivity is increased when electrons or holes are removed from the boundary layer by an external electric field. This direction of the electric field is called the reverse direction. Reversing the electric field drives the electrons and holes into the boundary layer, allowing current to flow more easily through the diode.

This experiment records and compares the current-voltage characteristics of various diodes (Si, Ge and light-emitting diodes).

### Equipment list

| | | |
|---|---|---|
| 1 | Sensor-CASSY | 524 010 or 524 013 |
| 1 | CASSY Lab 2 | 524 220 |
| 1 | Plug-in board DIN A4 | 576 74 |
| 1 | Resistor 100 Ω STE 2/19 | 577 32 |
| 1 | STE Si-diode 1N4007 | 578 51 |
| 1 | STE Ge-diode AA118 | 578 50 |
| 1 | STE Light emitting diode green | 578 57 |
| 1 | STE Light emitting diode yellow | 578 47 |
| 1 | STE Light emitting diode red | 578 48 |
| 1 | STE Light emitting diode infrared | 578 49 |

| | | |
|---|---|---|
| 1 | Connecting lead, 50 cm, blue | 500 422 |
| 2 | Pairs of cables, 50 cm, red and blue | 501 45 |
| 1 | PC with Windows XP/Vista/7 | |

### Alternatively (with Power-CASSY)

| | | |
|---|---|---|
| 1 | Sensor-CASSY | 524 010 or 524 013 |
| 1 | Power-CASSY | 524 011 |
| 1 | CASSY Lab 2 | 524 220 |
| 1 | Plug-in board DIN A4 | 576 74 |
| 1 | Resistor 100 Ω STE 2/19 | 577 32 |
| 1 | STE Si-diode 1N4007 | 578 51 |
| 1 | STE Ge-diode AA118 | 578 50 |
| 1 | STE Light emitting diode green | 578 57 |
| 1 | STE Light emitting diode yellow | 578 47 |
| 1 | STE Light emitting diode red | 578 48 |
| 1 | STE Light emitting diode infrared | 578 49 |
| 2 | Pairs of cables, 50 cm, red and blue | 501 45 |
| 1 | PC with Windows XP/Vista/7 | |

### Experiment setup (see drawing)

Connect the circuit to Sensor-CASSY inputs A (current) and B (voltage across the diode) as shown in the drawing. The diode is protected by a 100 Ω series resistor.

When using Power-CASSY place this to the left of Sensor-CASSY to supply the circuit and measure the current.

### Carrying out the experiment

■ Load settings

- Reverse the polarity of voltage source S (for negative characteristic segment) and set $U_{B1}$ to about –3 V.
- Start the measurement with ⏱.
- Slowly reduce the voltage to zero (turn to the left; the negative characteristic segment is recorded simultaneously).
- Restore the original polarity of voltage source S (for positive characteristic segment).
- Slowly increase the voltage (the positive characteristic segment is recorded simultaneously); be sure not to exceed the maximum current of the LED.
- Stop the measurement with ⏱.
- Repeat the measurement with a different diode; reverse the polarity of voltage source S and start the measurement with ⏱.

### Alternative (with Power-CASSY)

■ Load settings

- Record the characteristic of each diode with ⏱ (Power-CASSY sweeps the voltage range automatically).

### Evaluation

At negative voltages the current is zero regardless of the applied voltage (reverse direction). At positive voltages, a current appears starting at a conducting-state voltage U (conducting direction).

We can compare the conducting-state voltages U of various diodes. For the LEDs, we can use the equation

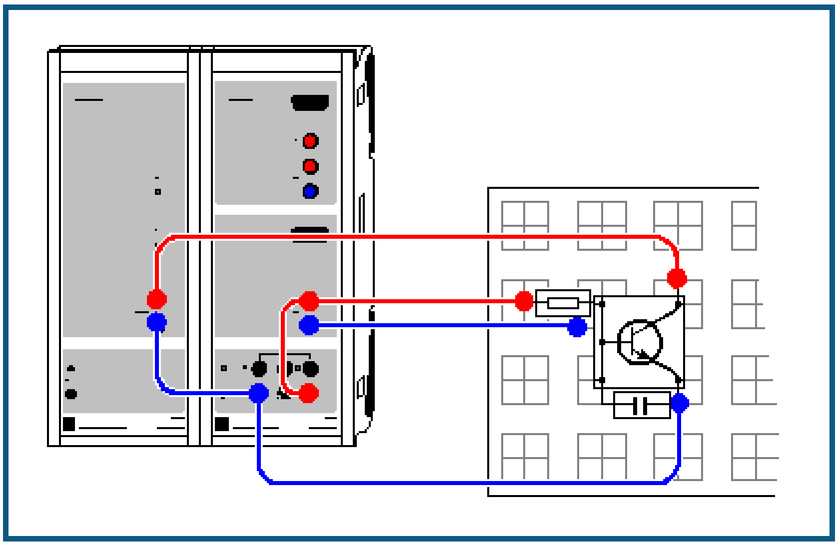
$e \cdot U = h \cdot c/\lambda$

to estimate roughly the wavelength $\lambda$ of the emitted light. In this example the conducting-state voltage of the red LED is approx. U = 1.4 V. From this we obtain $\lambda = hc/eU = 880$ nm.

### Remark

It is not possible to precisely determine the wavelength of light emitted by LEDs, as these emit a relatively broad frequency band that is usually filtered through a colored housing. Therefore the above wavelength determination is merely a rough estimate.

## Characteristic of a transistor



### Experiment description

Transistors are among the most important semiconductor components in electronic circuit technology. The electrodes of a bipolar transistor are called the emitter, the base and the collector. The transistor consists of a total of three n-conducting and p-conducting layers, in the order npn or pnp.

This experiment measures the two output characteristics of an npn transistor, i.e. the collector current $I_C$ as a function of the base current $I_B$ (at a constant collector-emitter voltage) and the collector current $I_C$ as a function of the collector-emitter voltage $U_{CE}$ (at different constant base currents $I_B$).

### Equipment list

| | | |
|---|---|---|
| 1 | Sensor-CASSY | 524 010 or 524 013 |
| 1 | Power-CASSY | 524 011 |
| 1 | CASSY Lab 2 | 524 220 |
| 1 | Plug-in board DIN A4 | 576 74 |
| 1 | STE transistor BD 137 | 578 67 |
| 1 | STE resistor 10 kΩ, 0.5 W | 577 56 |
| 1 | STE capacitor 1 µF | 578 15 |
| 1 | Pair of cables, 25 cm, red and blue | 501 44 |
| 2 | Pairs of cables, 50 cm, red and blue | 501 45 |
| 1 | PC with Windows XP/Vista/7 | |

### Experiment setup (see drawing)

Power-CASSY supplies the collector-emitter voltage $U_{CE}$ and simultaneously measures the collector current $I_C$ that is flowing. The cascaded Sensor-CASSY (mounted directly to the right of Power-CASSY) supplies an adjustable base current $I_B$ and simultaneously measures the voltage drop across a 10 kΩ resistor. The small 0.1 κF capacitor connected between the base and the emitter suppresses interference during measurement.

This experiment uses base currents up to about 1 mA and collector currents up to about 100 mA. Be sure to use suitable transistors (e.g. BD 137).

### Carrying out the experiment

a) Control characteristic of collector current $I_C$ as a function of base current $I_B$

▢ Load settings

- Power-CASSY maintains the collector-emitter voltage at a constant $U_{CE}$ = 2 V and measures the collector current $I_C$ continuously.
- Set the displayed base current $I_B$ at voltage source S of Sensor-CASSY to 0 mA.
- Start the measurement with ⏱.
- Slowly increase the base current until the characteristic is recorded.
- Stop the measurement with ⏱.

b) Characteristic of collector current $I_C$ as a function of collector-emitter voltage $U_{CE}$

■ Load settings

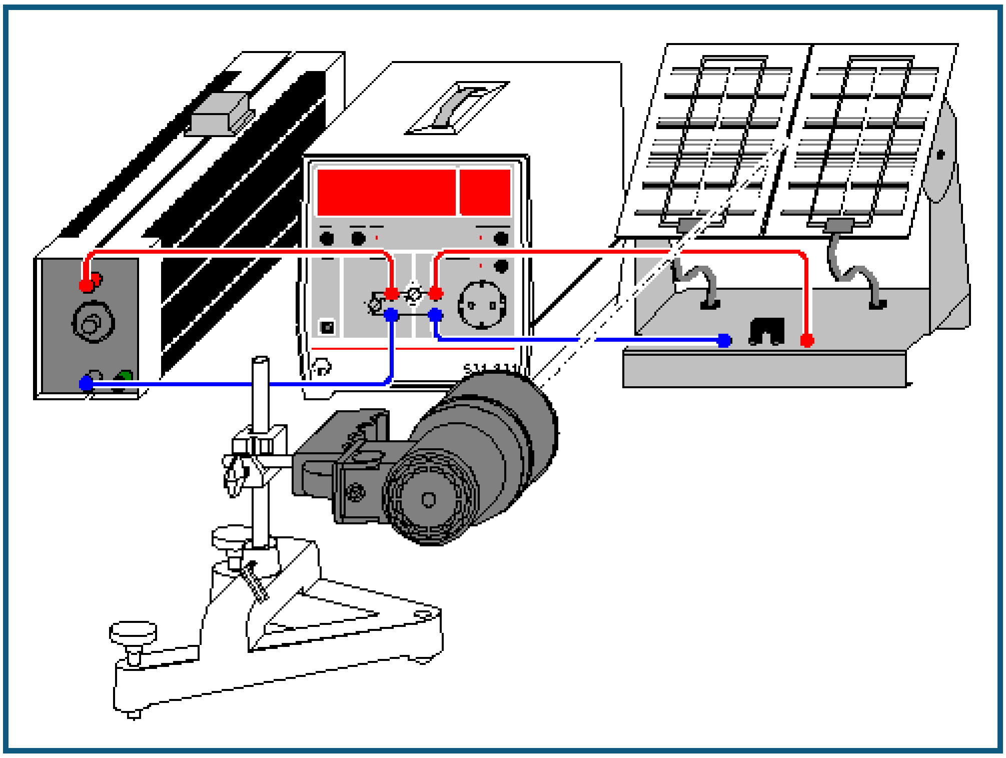
- Power-CASSY increases the collector-emitter voltage to $U_{CE}$ = 2 V during the measurement and measures the collector current $I_C$.
- Set the displayed base current $I_B$ at voltage source S of Sensor-CASSY to 0.1 mA.
- Start the measurement with ⏱ (the characteristic is recorded automatically).
- Increase the base current $I_B$ in steps of 0.1 mA and record additional characteristics with ⏱.

## Evaluation

The current gain can be determined easily from control characteristic a) by fitting a straight line. In the example, we obtain a current gain factor of $I_C/I_B$ = 149.6.

Characteristic b) also shows the current gain of a transistor in an impressive manner. Starting from a relatively low collector-emitter voltage $U_{CE}$, the output current $I_C$ remains virtually constant, depending only on the base current $I_B$.

## Power characteristic of a solar cell



### Experiment description

The power P of a solar cell is recorded for various illuminances as a function of a load resistance $R_1$. From the shapes of the curves, the optimal load resistances $R_{max}$ are determined at which the maximum power of the solar cell is reached in each case.

Moreover, at each illuminance (different angles of inclination α of the solar cell), the open-circuit voltage and the short-circuit current are measured and the internal resistances $R_0$ of the solar cell are calculated: $R_0=U_0/I_0$. The internal resistances $R_0$ are compared with $R_{max}$.

### Equipment list

| | | |
|---|---|---|
| 1 | Joule and wattmeter | 531 831 |
| 1 | Solar cell | 664 431 |
| 1 | Floodlight lamp, 1000 W | 450 70 |
| 1 | Rheostat 100 Ω | 537 34 |
| 1 | Steel tape measure | 311 77 |
| 1 | Stand base, V-shape, 28 cm | 300 01 |
| 1 | Stand rod, 100 mm | 300 40 |
| 1 | Leybold multiclamp | 301 01 |
| 2 | Pairs of cables, 100 cm | 501 46 |
| 1 | PC with Windows XP/Vista/7 | |

### Experiment setup (see drawing)

Set up the floodlight lamp at a distance of approx. 40 cm from the solar cell. First set up the solar cell perpendicularly to the incident light and connect it to the 4 mm sockets on the OUTPUT panel. Connect the load resistor to the 4 mm sockets on the INPUT panel.

### Remark

The power of the solar cell also varies with the temperature. To ensure that the temperature remains essentially constant during the measurement, the solar cell should be illuminated by the light source already 15 min before measured values are recorded.

## Carrying out the experiment

■ Load settings

a) Recording the characteristic

- Adjust the rheostat so that a resistance of 2 Ω is displayed in the display instrument Load Resistance $R_1$.
- Take the measured value into the table manually with ⏱.
- Increase the load resistance in steps of 2 Ω, and record further measured values.
- In order to vary the illuminance, incline the solar cell by an angle of 45° or 30°, respectively, relative to the incident light. Repeat the experiment for each angle.
- For each illuminance, determine the load resistance $R_{max}$ at which the maximum power of the solar cell is reached.

b) Measuring the open-circuit voltage and the short-circuit current

- Open the display instruments U, I, $U_0$, $I_0$ and $R_0$ by clicking on ⧉.
- Connect the solar cell to the 4 mm sockets of the joule and wattmeter marked with U.
- Using the mouse, take the value measured in the display instrument U to the display instrument Open-Circuit Voltage $U_0$ (drag & drop).
- Connect the solar cell to the socket of the joule and wattmeter marked with I.
- Using the mouse, take the value measured in the display instrument I to the display instrument Short-Circuit Current $I_0$ (drag & drop). Read the internal resistance $R_0$ of the solar cell.

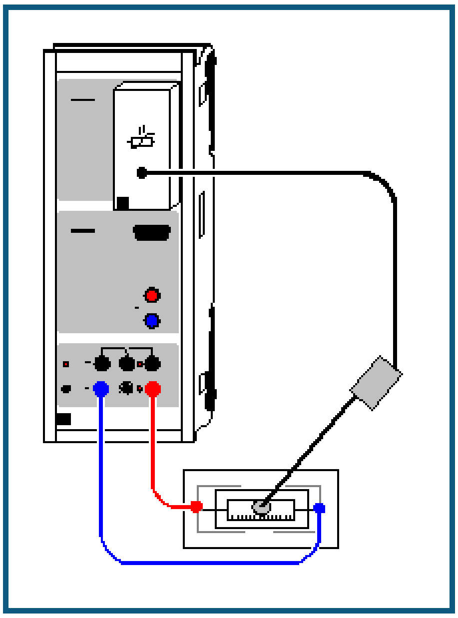
## Evaluation

The power supplied by a solar cell depends on the load resistance and on the illuminance.

The maximum power of the solar cell is reached if the load resistance is approximately equal to the internal resistance of the solar cell.

The maximum power of the solar cell is the larger, the larger the illuminance is (at constant temperature).

## Temperature control



### Experiment description

A temperature controller is an ideal application for demonstrating the function of a two-position controller and a PI controller. The inertia of the controlled temperature system leaves sufficient time for exact observation of the control algorithms.

In a two-position controller, the heating element is switched on when the temperature falls below threshold $\vartheta_1$, and switched off when the temperature exceeds a second threshold $\vartheta_2$.

Alternatively, the temperature can be controlled using PI control. A PI controller determines the system deviation w-x from the measured value $x = \vartheta_{A1}$ (temperature) and the reference variable w (set value of the temperature).

Together with the base load $y_0$, this gives us the manipulated variable $y = y_0 + K_P*(w-x) + K_I*\int(w-x)*dt$ for the PI controller. The proportional-action coefficient $K_P$ and the integral-action coefficient $K_I$ as control parameters can be optimized so that after a deviation (e.g. a change in the reference variable w) the system returns to a system deviation w-x of about 0 as soon as possible. The base load $y_0$ can be assumed as constant here.

If only a P-controller is used ($K_I = 0$), a residual system deviation w-x occurs which does not disappear until an I-component is applied.

### Equipment list

| | | |
|---|---|---|
| 1 | Sensor-CASSY | 524 010 or 524 013 |
| 1 | CASSY Lab 2 | 524 220 |
| | | |
| 1 | KTY box | 524 036 |
| 1 | KTY sensor | 529 036 |
| | or | |
| 1 | Temperature box | 524 045 |
| 1 | Temperature sensor NiCr-Ni | 666 193 |
| | or | |
| 1 | NiCr-Ni adapter S | 524 0673 |
| 1 | Temperature sensor NiCr-Ni, type K | 529 676 |
| | | |
| 1 | Socket board section | 576 71 |
| 1 | Heating element, 100 Ω, 2 W | 579 38 |
| 1 | Pair of cables, 100 cm, red and blue | 501 46 |
| 1 | PC with Windows XP/Vista/7 | |

### Experiment setup (see drawing)

The voltage source S supplies the heating element. The temperature of the heating element is measured using a KTY-sensor with the KTY-box at CASSY connector site A. For this purpose, fill a few drops of water in the heating element and immerse the KTY-sensor in the water.

### Carrying out the experiment

a) Two-position controller

■ Load settings

- Turn the potentiometer of the voltage source S all the way to the right.
- Replace switching thresholds $\vartheta_1$ and $\vartheta_2$ with individual values by moving the pointer of the display instrument with the mouse or changing the value of the parameter in the Settings $\vartheta$1 or $\vartheta$2 (right mouse button).
- If desired, you can record the temperature curve during control with ⏱, and stop recording with ⏱.

b) PI controller

■ Load settings

- Turn the potentiometer of the voltage source S all the way to the right.
- Set the reference variable w about 5 °C above the current temperature $\vartheta_{A1}$ by moving the pointer of the display instrument with the mouse or changing the value of the reference variable in the Settings w (right mouse button).
- Replace the proportional-action ($K_P$) and integral-action ($K_I$) coefficients using individual values of the parameter in the Settings KP or KI (right mouse button).
- Start (and stop) temperature control with ⏱.

### Evaluation

For the two-position controller, we can set horizontal lines to mark the two switching thresholds $\vartheta_1$ and $\vartheta_2$.

The quality of the PI controller depends significantly on the choice of the proportional-action coefficient $K_P$ and the integral-action coefficient $K_I$. The black line represents the reference variable w (set value). The red curve represents the controlled variable x (measured value) and should converge with the black curve quickly following a deviation. The blue curve represents the manipulated variable y and thus corresponds to the heating voltage.

### Empirically optimizing the PI temperature controller

The controlled temperature system is very slow. This is why the effects of changes in $K_P$ and $K_I$ can only be seen with a large delay. Empirical optimization will thus take a certain amount of time.

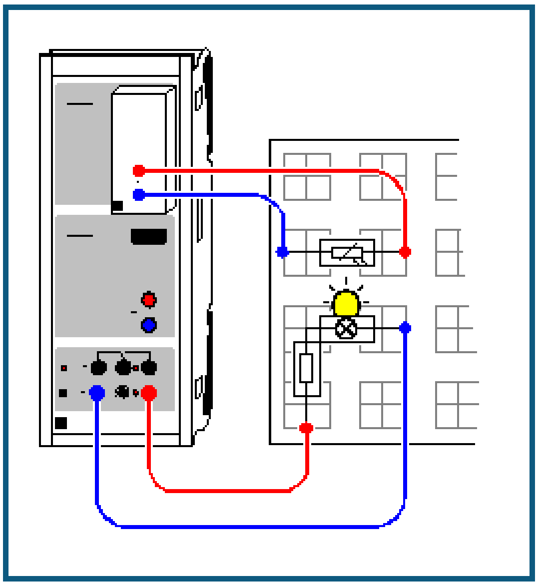
- Set $K_I$ to 0, and increase $K_P$ in moderate steps (e.g. by 1) until the control loop oscillates.
- Reduce $K_P$ again until the oscillations die out. A residual system deviation is created.
- Increase $K_I$ in moderate steps (e.g. by $K_P/200$) until the system oscillates again.
- Reduce $K_I$ again until the oscillations die out. Note that the controller becomes slower, the lower $K_I$ becomes.

In this example, we have used $K_P=5$ and $K_I=0.05$ /s.

### Automatically varying the reference variable

The reference variable w (set value) can be varied not only manually, but automatically as well. We can do this, for example, by entering the formula **30+sin(360*t/1000)** in the Settings w. This controls a sinusoidal temperature curve between 29 °C and 31 °C with a period of 1000 s.

## Brightness control



### Experiment description

This experiment realizes a brightness control for a light bulb using variable series resistors. A PI controller is used here. A PI controller determines the system deviation w-x from the measured value x = $R_{A1}$ (resistance of an LDR) and the reference variable w (set value of the LDR resistance).

Together with the base load $y_0$, this gives us the manipulated variable $y = y_0 + K_P*(w-x) + K_I*\int(w-x)*dt$ for the PI controller. The proportional-action coefficient $K_P$ and the integral-action coefficient $K_I$ as control parameters can be optimized so that after a deviation (e.g. an additional series resistor, a change in the reference variable w or the base load $y_0$) the system returns to a system deviation w-x of about 0 as soon as possible.

If only a P-controller is used ($K_I$ = 0), a residual system deviation w-x occurs which does not disappear until an I-component is applied.

### Equipment list

| | | |
|---|---|---|
| 1 | Sensor-CASSY | 524 010 or 524 013 |
| 1 | CASSY Lab 2 | 524 220 |
| 1 | Current source box | 524 031 |
| 1 | Plug-in board DIN A4 | 576 74 |
| 1 | Lamp socket E10, side | 579 05 |
| 1 | Set of 10 lamps 3.8 V/0.07 A | 505 10 |
| 1 | Toggle-switch, single-pole | 579 13 |
| 1 | Photoresistor LDR05 | 578 02 |
| 1 | STE resistor 10 Ω, 2 W | 577 20 |
| 1 | STE resistor 20 Ω, 2 W | 577 23 |
| 1 | STE resistor 47 Ω, 2 W | 577 28 |
| 1 | STE resistor 100 Ω, 2 W | 577 32 |
| 2 | Pairs of cables, 100 cm, red and blue | 501 46 |
| 1 | PC with Windows XP/Vista/7 | |

### Experiment setup (see drawing)

The voltage source S supplies the lamp via a 100 Ω protective resistor. The brightness of the lamp is measured using a light-dependent resistor together with the current source box at CASSY input A.

Additional series resistors can be switched on with the toggle switch to produce deviations. A closed toggle switch shorts the series resistor, and an open toggle switch leaves it in the circuit.

### Carrying out the experiment

☐ Load settings

- Turn the potentiometer of the voltage source S all the way to the right.

- The lamp lights up already, as a base load $y_0$ of 0.5 has been set. This means that PWM output S is operating at a duty factor of 50 %.
- Change the base load $y_0$ as you like, by setting the corresponding parameter value in the Settings y0 (right mouse button).
- Enter the measured resistance as the reference variable w by moving the pointer of the display instrument with the mouse or changing the value of the parameter in the Settings w (right mouse button).
- Start the control with ⏱ and stop it at the appropriate time with ⏱.
- During control, a deviation can be applied, e.g. by switching a series resistor or changing the reference variable or base load.
- You can optimize your controller by varying the proportional-action ($K_P$) and integral-action ($K_I$) coefficients; set the corresponding values in Settings KP or KI (right mouse button).

### Evaluation

The recorded curves clearly illustrate the quality of the controller. The black line represents the reference variable w (set value). The red curve represents the controlled variable x (measured value) and should converge with the black curve quickly following a deviation. The blue curve represents the manipulated variable y and thus corresponds to the lamp voltage.

### Empirically optimizing the PI brightness controller

Set negative values for $K_P$ and $K_I$, as the measured resistance value of the sensor box becomes less the greater the voltage at the voltage source S is.

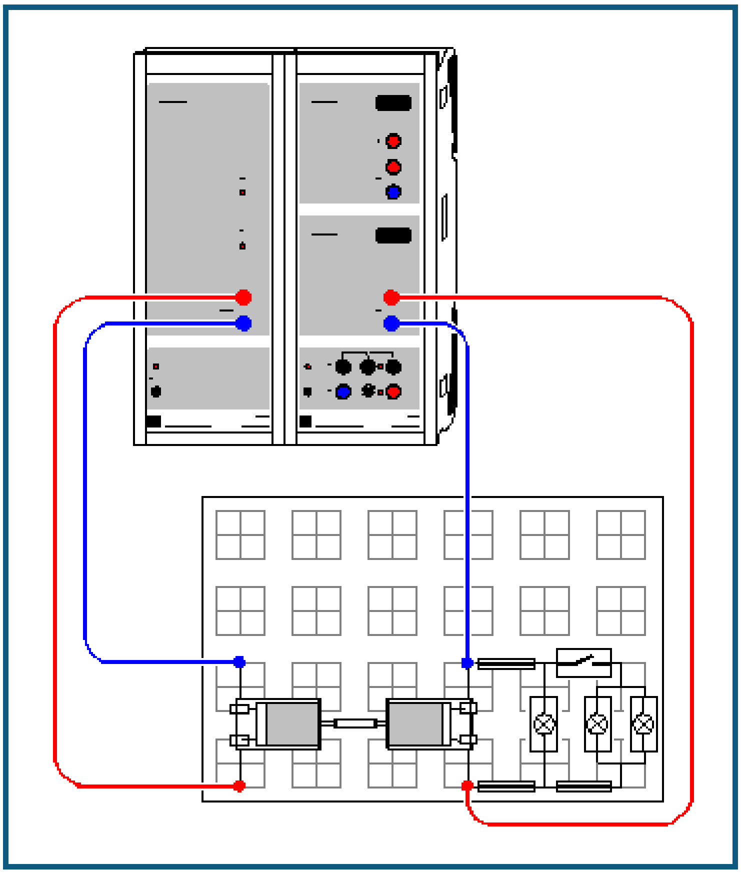
- Set $K_I$ to 0, and increase $K_P$ in moderate steps (e.g. by -0.1) until the control loop oscillates.
- Reduce $K_P$ again until the oscillations die out. A residual system deviation is created.
- Increase $K_I$ in moderate steps (e.g. by 10*$K_P$) until the system oscillates again.
- Reduce $K_I$ again until the oscillations die out. Note that the controller becomes slower, the lower $K_I$ becomes.

In this example, we have used $K_P$ = 0.5 and $K_I$ = 5 /s.

### Automatically varying the reference variable

The reference variable w (set value) can be varied not only manually, but automatically as well. We can do this, for example, by entering the formula **1+0.5*sin(360*t/20)** in the Settings w. This results in control of a sinusoidal resistance curve of the LDR between 0.5 kΩ and 1.5 kΩ with a period of 20 s.

## Voltage control



### Experiment description

This experiment realizes voltage control of a generator under a variable load. A PI controller is used here. A PI controller determines the system deviation w-x from the measured value x = $U_{B2}$ (voltage of the generator) and the reference variable w (set value of the generator).

Together with the base load $y_0$, this gives us the manipulated variable y = $y_0$ + $K_P$*(w-x) + $K_I$*∫(w-x)*dt for the PI controller. The proportional-action coefficient $K_P$ and the integral-action coefficient $K_I$ as control parameters can be optimized so that after a deviation (e.g. an additional load, a change in the reference variable w or the base load $y_0$) the system returns to a system deviation w-x of about 0 as soon as possible.

If only a P-controller is used ($K_I$ = 0), a residual system deviation w-x occurs which does not disappear until an I-component is applied.

### Equipment list

| | | |
|---|---|---|
| 1 | Sensor-CASSY | 524 010 or 524 013 |
| 1 | Power-CASSY | 524 011 |
| 1 | CASSY Lab 2 | 524 220 |
| 1 | Plug-in board DIN A4 | 576 74 |
| 2 | DC motors and tacho generators | 579 43 |
| 1 | Toggle-switch, single-pole | 579 13 |
| 3 | Lamp socket E10, top | 579 06 |
| 1 | Set of 10 lamps 3.8 V/0.07 A | 505 10 |
| 1 | Plastic tubing, 6 mm | 307 641 |
| 1 | Set of bridging plugs | 501 48 |
| 2 | Pairs of cables, 100 cm, red and blue | 501 46 |
| 1 | PC with Windows XP/Vista/7 | |

### Experiment setup (see drawing)

Power-CASSY supplies the motor (left), which drives the generator (right) via a section of plastic tubing approx. 25 mm long. The voltage of the generator is measured at input B of Sensor-CASSY. Make sure that the connections of either the motor or the generator are reversed, as the motor and the generator are linked in opposing directions.

The load on the generator is varied using three light bulbs, two of which can be switched on using a toggle switch.

### Carrying out the experiment

☐ Load settings

- The motor is already turning, as a base load $y_0$ of 6 V has been set.
- Change the base load $y_0$ as you like, by setting the corresponding parameter value in the Settings y0 (right mouse button).
- Check the measured voltage $U_{B2}$; this must be positive (reverse polarity if necessary).
- Enter the measured voltage as the reference variable w by moving the pointer of the display instrument with the mouse or changing the value of the parameter in the Settings w (right mouse button).
- Start the control with ⏱ and stop it at the appropriate time with ⏱.
- During control, a deviation can be applied, e.g. by varying the generator load or changing the reference variable or base load.
- You can optimize your controller by varying the proportional-action ($K_P$) and integral-action ($K_I$) coefficients; set the corresponding values in Settings KP or KI (right mouse button).

### Evaluation

The recorded curves clearly illustrate the quality of the controller. The black line represents the reference variable w (set value). The red curve represents the controlled variable x (measured value) and should converge with the black curve quickly following a deviation. The blue curve represents the manipulated variable y and thus corresponds to the motor voltage.

### Empirically optimizing the PI voltage controller

- Set $K_I$ to 0, and increase $K_P$ in moderate steps (e.g. by 0.1) until the control loop oscillates.
- Reduce $K_P$ again until the oscillations die out. A residual system deviation is created.
- Increase $K_I$ in moderate steps (e.g. by 10*$K_P$) until the system oscillates again.
- Reduce $K_I$ again until the oscillations die out. Note that the controller becomes slower, the lower $K_I$ becomes.

In this example, we have used $K_P$=0.5 and $K_I$=4 /s.

### Automatically varying the reference variable

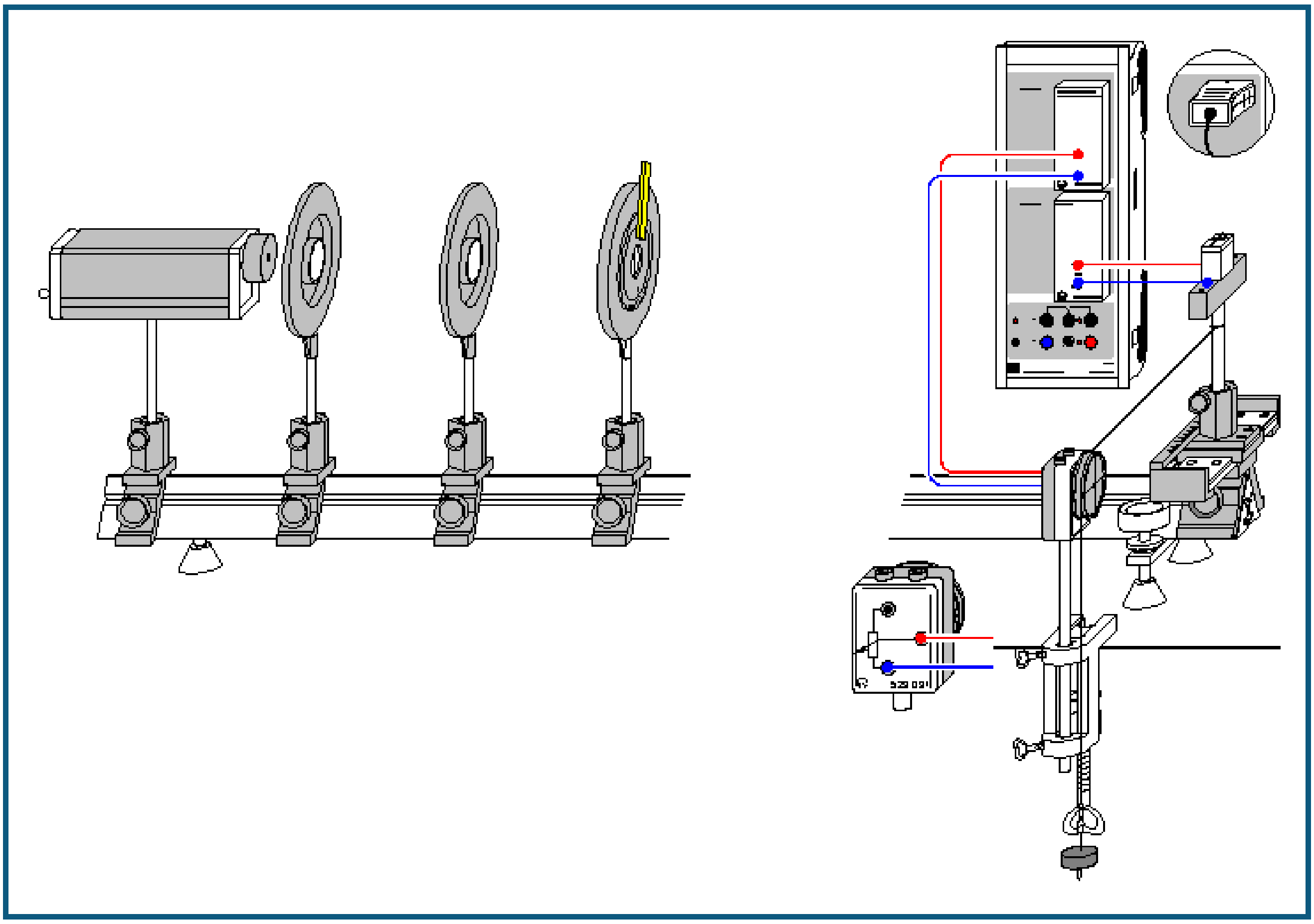
The reference variable w (set value) can be varied not only manually, but automatically as well. We can do this, for example, by entering the formula 4+sin(360*t/20) in the **Settings w**. This controls a sinusoidal voltage curve between 3 V and 5 V with a period of 20 s.

### Other control loops

This example can also be adapted to other control loops. As long as the controlled variable is a voltage, it is only necessary to modify the correcting range and the measuring range as well as the control parameters $K_P$ and $K_I$.

If the controlled quantity is provided by a sensor box, first of all the channel $U_{B2}$ has to be deleted by switching it off in the selection box in Settings UB2. Then, in Settings → CASSYs (**Window** → **Show CASSY Modules**), activate the sensor box with the mouse and again select **Averaged Values**. The unit and symbol of the reference variable w and the system deviation w-x must also be modified, as well as the calculation formula for system deviation (e.g. **w-RB2** instead of **w-UB2**). As in all CASSY experiments, you can change the settings by clicking on channel w or w-x with the right mouse button.

## Diffraction at a single slit



can also be carried out with Pocket-CASSY

**Be careful when experimenting with the He-Ne laser**

The He-Ne laser meets the requirements according to class 2 of EN 60825-1 "Safety of laser equipment". If the corresponding notes of the instruction sheet are observed, experimenting with the He-Ne laser is safe.

Never look into the direct or reflected laser beam.

No observer must feel dazzled.

### Experiment description

Diffraction phenomena always occur when the free propagation of light is changed by obstacles such as iris diaphragms or slits. The deviation from the rectilinear propagation of light observed in this case is called diffraction.

The voltage of a photocell is measured as a function of the diffraction angle. It is observed that the diffraction pattern moves more and more into the geometrical shadow area as the slit width decreases. The measuring values recorded are compared with the prediction of a model calculation for the diffraction intensity $U \propto (\sin(\pi b/\lambda \cdot \alpha)/(\pi b/\lambda \cdot \alpha))^2$, where the slit width b and the wavelength λ enter as parameters. For small diffraction angles α, α is easily determined from the distance L between the diffraction object and the photocell and the path of displacement s of the photocell as $\alpha \approx \tan \alpha = s/L$.

### Equipment list

| | | |
|---|---|---|
| 1 | Sensor-CASSY | 524 010 or 524 013 |
| 1 | CASSY Lab 2 | 524 220 |
| 1 | κV box | 524 040 |
| | | |
| 1 | Current source box | 524 031 |
| | with Displacement transducer and | 529 031 |
| | Pair of cables, 100 cm, red and blue | 501 46 |

| | | |
|---|---|---|
| | or | |
| 1 | Rotary motion sensor S | 524 082 |
| 1 | He-Ne laser, linearly polarized | 471 840 |
| 1 | Precision optical bench, 2 m | 460 33 |
| 4 | Riders, H=90 mm/B=60 mm | 460 374 |
| 1 | Sliding rider | 460 383 |
| 1 | Lens in frame, f = +5 mm | 460 01 |
| 1 | Lens in frame, f = +50 mm | 460 02 |
| 1 | Adjustable slit | 460 14 |
| 1 | Holder for plug-in elements | 460 21 |
| 1 | Photocell STE 2/19 | 578 62 |
| 1 | Bench clamp, simple | 301 07 |
| 1 | Fishing line, 10 m | from 309 48ET2 |
| 1 | Set of 12 weights, each 50 g | 342 61 |
| 1 | Pair of cables, 100 cm, red and blue | 501 46 |
| 1 | PC with Windows XP/Vista/7 | |

## Experiment setup (see drawing)

*Remark: the adjustment should be carried out in a slightly darkened room.*

- Using a rider, mount the He-Ne laser to the optical bench as shown in the drawing.
- Set up the photocell at a distance of approx. 1.90 m from the laser by means of the sliding rider and the holder for plug-in elements. The photocell should be located in the middle of the sliding rider. Stick two strips of dark paper on the photocell so that an entrance slit of approx. 1 mm is left.
- Direct the laser towards the photocell, and switch it on.
- Adjust the height of the laser so that the laser beam impinges on the centre of the photocell.
- Place the spherical lens with the focal length f = +5 mm in front of the laser at a distance of approx. 1 cm. The laser beam has to cover the photocell.
- Position the converging lens with the focal length f = +50 mm in front of the spherical lens at a distance of approx. 55 mm and displace it on the optical bench towards the spherical lens until the laser beam is sharply imaged on the photocell.
- Displace the converging lens on the optical bench somewhat further towards the spherical lens until the diameter of the laser beam on the photocell is approx. 6 mm. Now the laser beam should have a circular profile of constant diameter along the optical axis.
- Put the adjustable slit on the optical bench, and displace it until the distance L between the photocell and the slit diaphragm is 1.50 m.
- Fix the bench clamp with the displacement sensor to the table as shown in the drawing.
- The path of displacement $s_{A1}$ perpendicular to the optical axis is measured via the displacement sensor at the current supply box on input A of the Sensor-CASSY.
- In order to measure the voltage, the photocell is connected to input B of the Sensor-CASSY via the κV-box.

## Carrying out the experiment

■ Load settings
- Set the photocell to the position -6.0 cm opposite the displacement sensor.
- Turn the wheel of the displacement sensor to the stop so that the display of the path $s_{A1}$ is approximately -6.0 cm. If it turns out that the path measurement will lead to a wrong sign, connect the current supply box to the other arm of the displacement sensor.
- Tie a piece of fishing line to the holder for plug-in elements, wind it once around the wheel of the displacement sensor, and suspend a weight from it.
- Calibrate the zero of the path – for this place the photocell in the middle of the sliding rider (= zero of the scale or of the position of the principal intensity maxima, respectively).
- Enter the **target value** 0 cm in Settings sA1 **Correct**, and then select **Correct Offset**.
- Slide the photocell back to the position opposite the displacement sensor, and keep it there.
- If necessary, **Correct** the background brightness in the Settings UB1. For this enter the **target value** 0 mV, and then select **Correct Offset**.
- Start the measurement with ⏱ (the message **No Trigger Signal** appears).
- Displace the photocell very slowly by hand towards the displacement sensor. As soon as you pass the starting point at -5.5 cm, recording of measured values begins.
- Stop the measurement with ⏱.

## Evaluation

The intensity distribution of the diffraction pattern appears already during the measurement. The measured intensity distribution can now be compared with the result of the model calculation for small diffraction angles $\alpha \approx \tan \alpha = s_{A1}/L$ by performing a Free fit. Use the following formula:

A*(sin(180*B/0.633*(x-C)/150)/(180*B/0.633*(x-C)/150))^2

with

x: displacement $s_{A1}$ perpendicular to the optical axis
A: intensity $I_0$
B: slit width b in κm
C: correction of the position of the principal maximum
L: distance between the diaphragm and the photocell (here: L = 150 cm)
ı : wavelength of the He-Ne laser (here: ı = 0.633 κm)

In this fit, the wavelength ı = 0.633 κm of the He-Ne laser has been assumed to be known and the slit width b has been determined. The other way round, the wavelength ı of the laser can be determined if the slit width b is known. For this, the formula can be modified, e.g., in the following way:

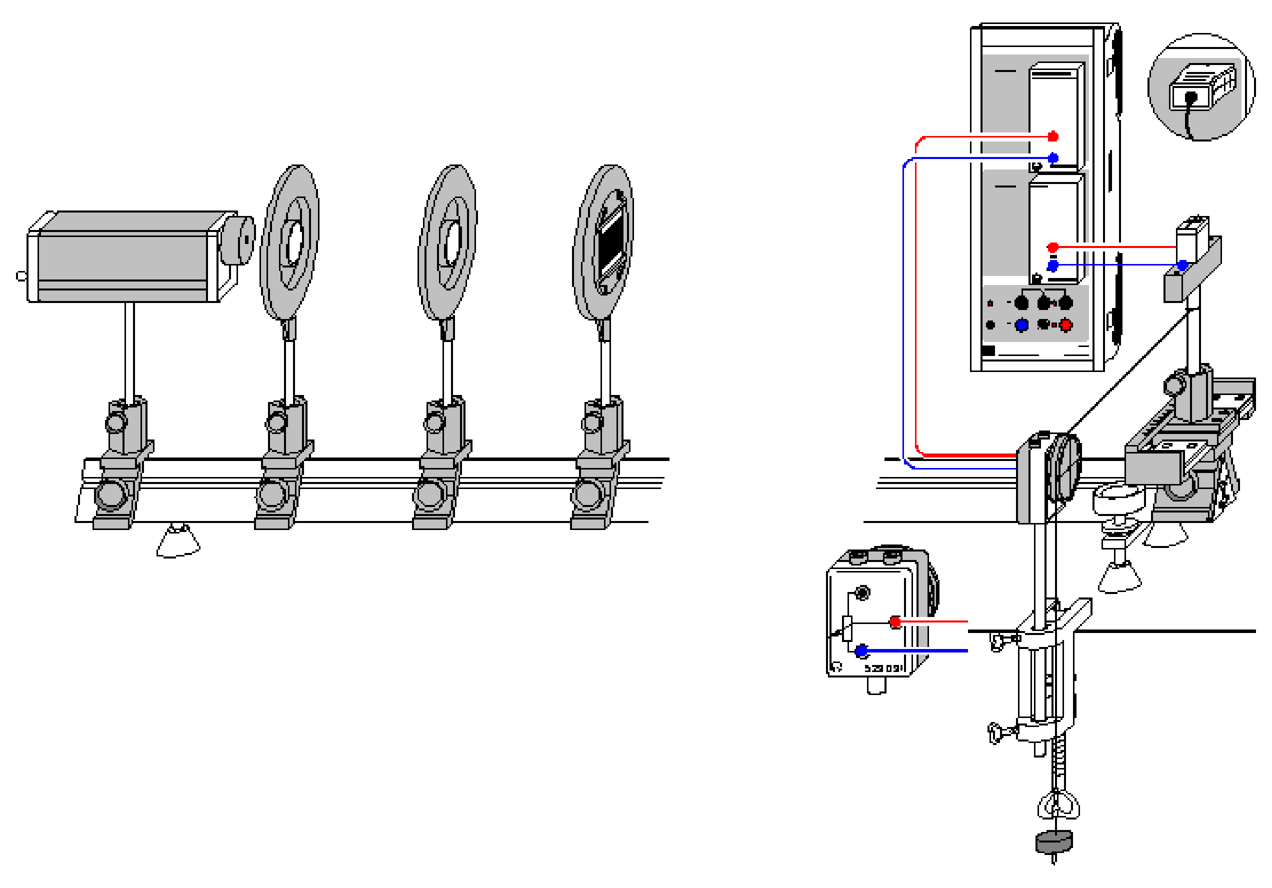
A*(sin(180*240/B*(x-C)/150)/(180*240/B*(x-C)/150))^2

For the Free fit, always a reasonable starting value for the slit width should be chosen, e.g., B=240 (κm) for b=0.24 mm.

## Remark

In this experiment on diffraction of light at a single slit, the intensity distribution is recorded manually. The measuring values can be recorded automatically with the aid of VideoCom (experiment P5.3.1.6).

## Diffraction at multiple slits



can also be carried out with Pocket-CASSY

**Be careful when experimenting with the He-Ne laser**

The He-Ne laser meets the requirements according to class 2 of EN 60825-1 "Safety of laser equipment". If the corresponding notes of the instruction sheet are observed, experimenting with the He-Ne laser is safe.

Never look into the direct or reflected laser beam.

No observer must feel dazzled.

### Experiment description

Diffraction phenomena always occur when the free propagation of light is changed by obstacles such as iris diaphragms or slits. The deviation from the rectilinear propagation of light observed in this case is called diffraction.

The voltage of a photocell is measured as a function of the diffraction angle. It is observed that the diffraction pattern moves more and more into the geometrical shadow area as the slit width decreases. The measuring values recorded are compared with the prediction of a model calculation for the diffraction intensity $U \propto (\sin(\pi b/\imath \cdot \alpha)/(\pi b/\imath \cdot \alpha))^2 * (\sin(N\pi d/\imath \cdot \alpha)/(\pi d/\imath \cdot \alpha))^2$, where the slit width b, the slit spacing d, the number of slits N, and the wavelength ı enter as parameters. For small diffraction angles α, α is easily determined from the distance L between the diffraction object and the photocell and the path of displacement s of the photocell as α≈ tan α = s/L.

### Equipment list

| | | |
|---|---|---|
| 1 | Sensor-CASSY | 524 010 or 524 013 |
| 1 | CASSY Lab 2 | 524 220 |
| 1 | κV box | 524 040 |
| | | |
| 1 | Current source box | 524 031 |
| | with Displacement transducer and | 529 031 |

| | | |
|---|---|---|
| | Pair of cables, 100 cm, red and blue | 501 46 |
| | or | |
| 1 | Rotary motion sensor S | 524 082 |
| | | |
| 1 | He-Ne laser, linearly polarized | 471 840 |
| 1 | Precision optical bench, 2 m | 460 33 |
| 4 | Riders, H=90 mm/B=60 mm | 460 374 |
| 1 | Sliding rider | 460 383 |
| 1 | Lens in frame, f = +5 mm | 460 01 |
| 1 | Lens in frame, f = +50 mm | 460 02 |
| 1 | Diaphragm with 3 double slits | 469 84 |
| 1 | Diaphragm with 4 double slits | 469 85 |
| 1 | Diaphragm with 5 multiple slits | 469 86 |
| 1 | Holder with spring clips | 460 22 |
| 1 | Photocell STE 2/19 | 578 62 |
| 1 | Holder for plug-in elements | 460 21 |
| 1 | Bench clamp, simple | 301 07 |
| 1 | Fishing line, 10 m | from 309 48ET2 |
| 1 | Set of 12 weights, each 50 g | 342 61 |
| 1 | Pair of cables, 100 cm, red and blue | 501 46 |
| 1 | PC with Windows XP/Vista/7 | |

### Experiment setup (see drawing)

*Remark: the adjustment should be carried out in a slightly darkened room.*

- Using a rider, mount the He-Ne laser to the optical bench as shown in the drawing.
- Set up the photocell at a distance of approx. 1.90 m from the laser by means of the sliding rider and the holder for plug-in elements. The photocell should be located in the middle of the sliding rider. Stick two strips of dark paper on the photocell so that an entrance slit of approx. 1 mm is left.
- Direct the laser towards the photocell, and switch it on.
- Adjust the height of the laser so that the laser beam impinges on the centre of the photocell.
- Place the spherical lens with the focal length f = +5 mm in front of the laser at a distance of approx. 1 cm. The laser beam has to cover the photocell.
- Position the converging lens with the focal length f = +50 mm in front of the spherical lens at a distance of approx. 55 mm and displace it on the optical bench towards the spherical lens until the laser beam is sharply imaged on the photocell.
- Displace the converging lens on the optical bench somewhat further towards the spherical lens until the diameter of the laser beam on the photocell is approx. 6 mm. Now the laser beam should have a circular profile of constant diameter along the optical axis.
- Put the holder with spring clips on the optical bench with the diaphragm being clamped, and displace it until the distance L between the photocell and the slit diaphragm is 1.50 m.
- Fix the bench clamp with the displacement sensor to the table as shown in the drawing.
- The path of displacement $s_{A1}$ perpendicular to the optical axis is measured via the displacement sensor at the current supply box on input A of the Sensor-CASSY.
- In order to measure the voltage, the photocell is connected to input B of the Sensor-CASSY via the κV-box.

### Carrying out the experiment

▨ Load settings

- Set the photocell to the position -6.0 cm opposite the displacement sensor.
- Turn the wheel of the displacement sensor to the stop so that the display of the path $s_{A1}$ is approximately -6.0 cm. If it turns out that the path measurement will lead to a wrong sign, connect the current supply box to the other arm of the displacement sensor.
- Tie a piece of fishing line to the holder for plug-in elements, wind it once around the wheel of the displacement sensor, and suspend a weight from it.
- Calibrate the zero of the path – for this place the photocell in the middle of the sliding rider (= zero of the scale or of the position of the principal intensity maxima, respectively).
- Enter the **target value** 0 cm in Settings sA1 **Correct**, and then select **Correct Offset**.
- Slide the photocell back to the position opposite the displacement sensor, and keep it there.
- If necessary, **Correct** the background brightness in the Settings UB1. For this enter the **target value** 0 mV, and then select **Correct Offset**.
- Start the measurement with ⏱ (the message **No Trigger Signal** appears).

- Displace the photocell very slowly by hand towards the displacement sensor. As soon as you pass the starting point at -5.5 cm, recording of measured values begins.
- Stop the measurement with ⏱.

## Evaluation

The intensity distribution of the diffraction pattern appears already during the measurement. The measured intensity distribution can now be compared with the result of the model calculation for small diffraction angles $\alpha \approx \tan \alpha = s_{A1}/L$ by performing a Free fit. Use the following formula:

A*(sin(180*B/0.633*(x-C)/150)/(180*B/0.633*(x-C)/150))^2 *
(sin(2*180*D/0.633*(x-C)/150)/sin(180*D/0.633*(x-C)/150))^2

with

x: displacement $s_{A1}$ perpendicular to the optical axis
A: intensity $I_0$
B: slit width b in κm
C: correction of the position of the principal maximum
D: slit spacing d in κm
N: number of slits (here double slit: N = 2)
L: distance between the diaphragm and the photocell (here: L = 150 cm)
ı : wavelength of the He-Ne laser (here: ı = 0.633 κm)

In this fit, the wavelength ı = 0.633 κm of the He-Ne laser has been assumed to be known and the slit width b and the slit spacing d have been determined. The other way round, the wavelength ı of the laser can be determined if the slit width b and the slit spacing d are known.

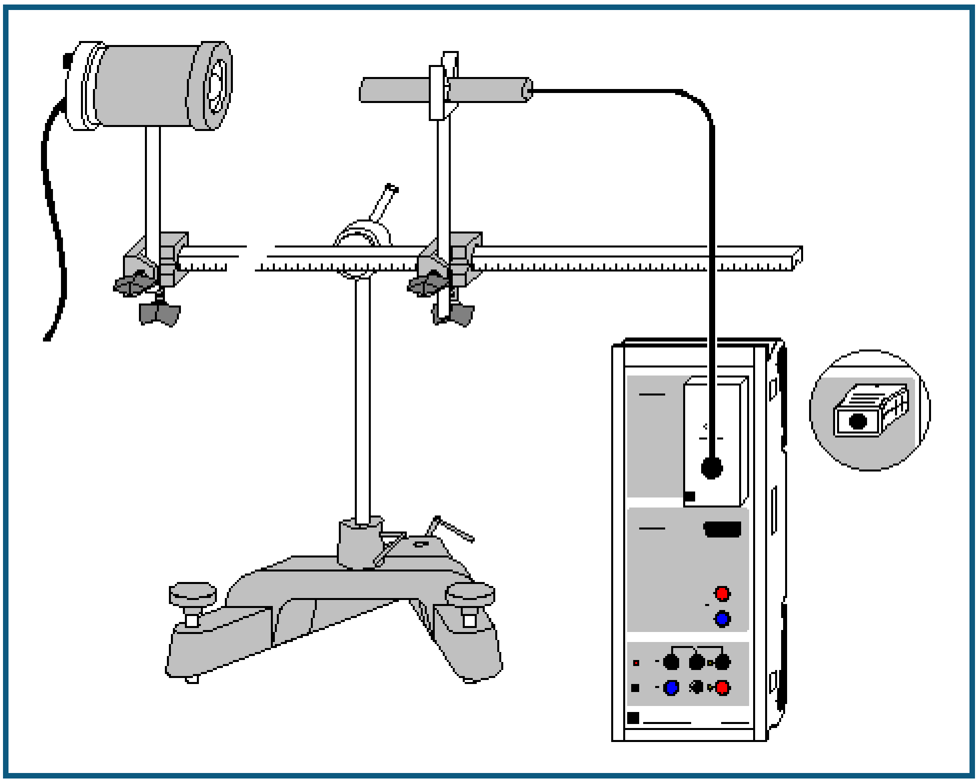
For the Free fit, always reasonable starting values for the slit width and the slit spacing should be chosen, e.g., B=200 (κm) for b=0.2 mm and D=250 (κm) for d=0.25 mm.

If the secondary maxima are not clearly seen for N > 2, the slit spacing d cannot be determined by the Free fit. In this case, the correct slit spacing d should be entered in κm as a starting value for the fit and then be kept constant (e.g. 250 for 0.25 mm).

## Remark

In this experiment on diffraction of light at multiple slits, the intensity distribution is recorded manually. The measuring values can be recorded automatically with the aid of VideoCom (experiment P5.3.1.7).

## Inverse square law for light



can also be carried out with Pocket-CASSY and Mobile-CASSY

### Experiment description

This experiment measures the illuminance E as a function of the distance d between an incandescent lamp filament and a lux sensor. It demonstrates that E is proportional to $1/d^2$.

### Equipment list

| | | |
|---|---|---|
| 1 | Sensor-CASSY | 524 010 or 524 013 |
| 1 | CASSY Lab 2 | 524 220 |
| 1 | Lux box or Lux adapter S | 524 051(1) |
| 1 | Lux sensor | 666 243 |
| 1 | Lamp, 6 V, 30 W | 450 51 |
| 1 | Lamp housing | 450 60 |
| 1 | Voltage source, 6 V, 30 W, e.g. | 521 210 |
| 1 | Small optical bench | 460 43 |
| 2 | Leybold multiclamps | 301 01 |
| 1 | Small clip plug | from 590 02ET2 |
| 1 | Perforated stand rod | 590 13 |
| 1 | Stand base, V-shape, 20 cm | 300 02 |
| 1 | PC with Windows XP/Vista/7 | |

### Experiment setup (see drawing)

Set up the lamp housing with lamp and the lux sensor on the optical bench. Attach the lux sensor to the perforated stand rod using the small clip plug. Slide the movable insert of the lamp housing all the way in.

### Carrying out the experiment

☐ Load settings

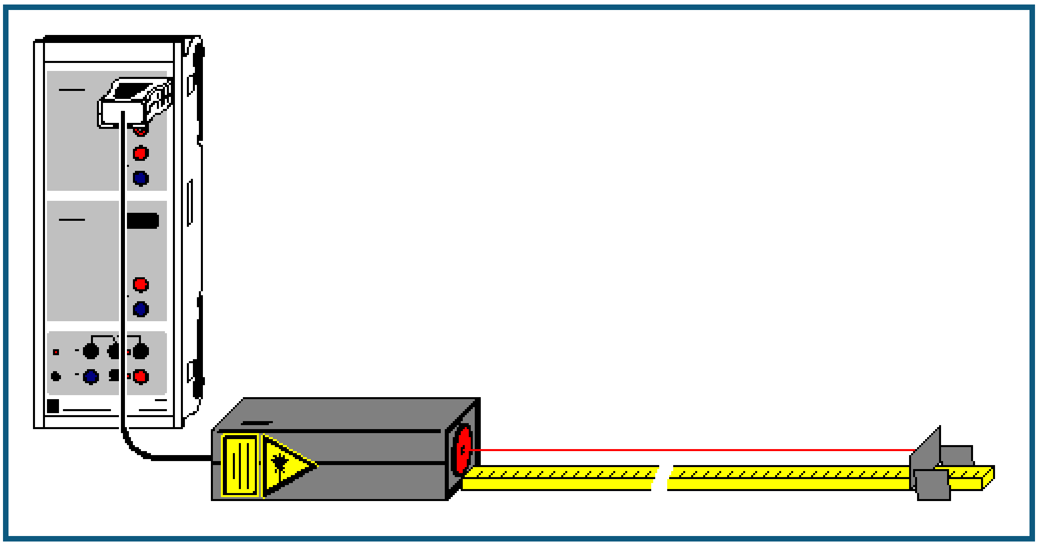
- Enter the correction factor F of your particular lux sensor (stamped on device) by opening Settings EA1, selecting **Correct,** entering the factor and clicking **Correct Factor**.
- Correct the background brightness with Settings EA1, **Correct**, **Correct Offset**.
- Switch on the lamp and set a distance of 10 cm between the lamp filament and the lux sensor.
- Enter this value in the table (click on the column d in the first table row and type in the value).

- Transfer the illuminance value to the table with ⏱.
- Increase the distance in steps, write the distances in the table and accept each new illuminance value with ⏱.

### Evaluation

The measurements are displayed in the diagram while the measurement is running. To confirm the inverse square law for light, you can fit a hyperbola $1/x^2$ to the diagram, or alternatively convert the x-axis to $1/x^2$ (click on the axis with the mouse) and fit a straight line.

## Velocity of light in air



can also be carried out with Pocket-CASSY and Mobile-CASSY

**Safety note**

Mind the safety notes in the instruction sheet of the laser motion sensor S.

### Experiment description

Modern distance meters use a periodically modulated laser beam for the measurement. They determine the phase shift between the emitted and the reflected modulated laser beam and, with the modulation frequency being known, obtain the time-of-flight t of the light on its path to and back from the reflector. Only afterwards do the distance meters calculate the distance with the aid of the known velocity of light.

In this experiment, the laser motion sensor S (laser S) is used as a time-of-flight meter because it is also capable of outputting the time-of-flight t directly. The proportionality between the distance and the time-of-flight of light is confirmed, and the velocity of light is calculated.

### Equipment list

| | | |
|---|---|---|
| 1 | Sensor-CASSY | 524 010 or 524 013 |
| 1 | CASSY Lab 2 | 524 220 |
| 1 | Laser motion sensor S | 524 073 |
| 1 | End buffer | from 337 116 |
| 1 | Wooden ruler | 311 03 |
| 1 | PC with Windows XP/Vista/7 | |

### Experiment setup (see drawing)

Lay the laser S on the table with its broad side down, and connect it to the input A of the CASSY. Stick a piece of retroreflecting foil enclosed with the laser S to the end buffer, and put the end buffer on the ruler at a distance of 30 cm from the laser so that the laser beam impinges perpendicularly on the centre of the foil.

Before the measurement, allow the laser S to warm up for approximately 5 minutes in order that the zero shift becomes as small as possible.

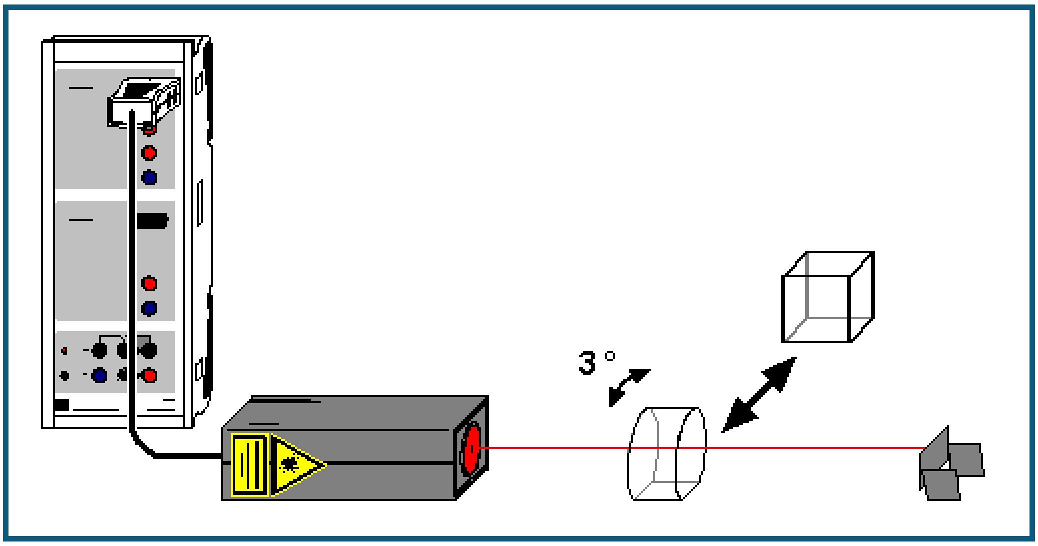
### Carrying out the experiment

☐ Load settings
- Define the zero of the time-of-flight (→ **0** ← in Settings ΓtA1).
- Enter the distance d=0 in the first column of the table (click on the first field of the table with the mouse).
- Record the first measuring point (d=0 m, Γt) with ⏱.
- Displace the end buffer away from the laser by 10 cm, and enter the distance 0.1 m in the first column of the table (click on the second field of the table with the mouse).
- Record the second measuring point (d=0.1 m, Γt) with ⏱.
- Repeat the measurement for greater distances up to approximately 50 cm.

## Evaluation

The optical path s of the laser beam is equal to twice the distance d. This is already taken into account in the s(t) diagram in the **Velocity of Light** display. The proportionality between s and t, i.e. s = c·t, is confirmed by the s(t) diagram. Fitting a straight line through the origin leads to the proportionality constant c = 0.3 m/ns = 300,000 km/s.

## Velocity of light in various materials



can also be carried out with Pocket-CASSY and Mobile-CASSY

**Safety note**

Mind the safety notes in the instruction sheet of the laser motion sensor S.

### Experiment description

Modern distance meters use a periodically modulated laser beam for the measurement. They determine the phase shift between the emitted and the reflected modulated laser beam and, with the modulation frequency being known, obtain the time-of-flight t of the light on its path to and back from the reflector. Only afterwards do the distance meters calculate the distance with the aid of the known velocity of light.

In this experiment, the laser motion sensor S (laser S) is used as a time-of-flight meter because it is also capable of outputting the time-of-flight t directly. Water and acrylic glass of thickness d are held into the path of the beam, and then the resulting increase of the time-of-flight $\Gamma t$ is measured. With the velocity of light c in air measured in the previous experiment, the velocity of light $c_M$ in matter can now be determined:

$c_M = 2d/(2d/c+\Gamma t) = 1/(1/c+\Gamma t/2d)$

Finally, the refractive index n is determined according to:

$n = c/c_M = c\cdot(1/c+\Gamma t/2d) = 1 + c/2d\cdot\Gamma t$

### Equipment list

| | | |
|---|---|---|
| 1 | Sensor-CASSY | 524 010 or 524 013 |
| 1 | CASSY Lab 2 | 524 220 |
| 1 | Laser motion sensor S | 524 073 |
| 1 | End buffer | from 337 116 |
| 1 | Plate glass cell, 50 mm × 50 mm × 50 mm | 477 03 |
| 1 | Acrylic glass block | 476 34 |
| 1 | PC with Windows XP/Vista/7 | |

### Experiment setup (see drawing)

Lay the laser S on the table with its broad side down, and connect it to the input A of the CASSY. Stick a piece of retroreflecting foil enclosed with the laser S to the end buffer, and put the end buffer on the ruler at a distance of approximately 50 cm from the laser so that the laser beam impinges perpendicularly on the centre of the foil.

Before the measurement, allow the laser S to warm up for approximately 5 minutes in order that the zero shift becomes as small as possible.

### Carrying out the experiment

▢ Load settings

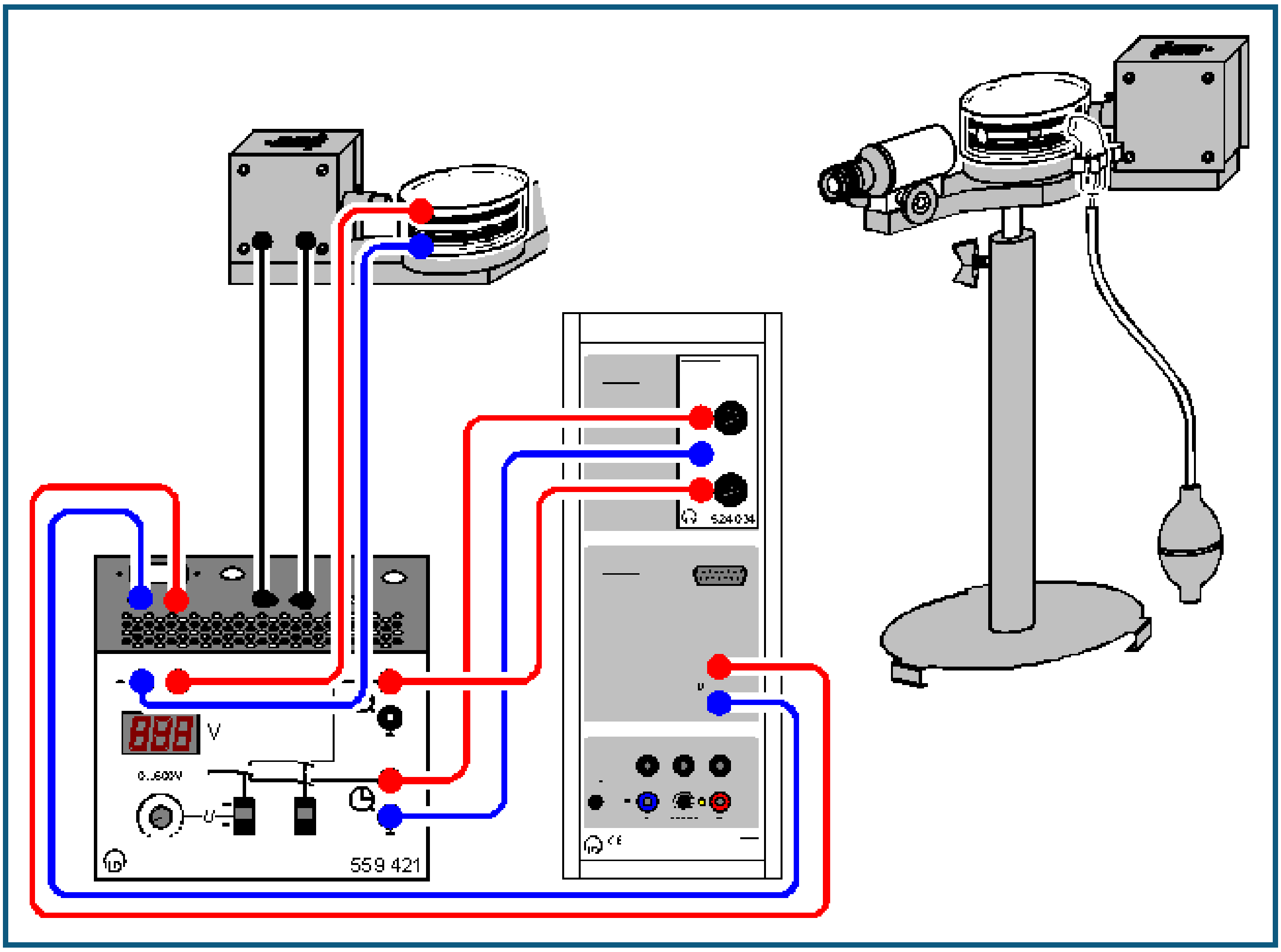
- Hold the empty and dry plate glass cell into the path of the beam such that the visible reflections of the laser beam from the glass surface are not reflected back to the laser (rotate the cell by approximately 3°). Otherwise the laser also sees these reflections and will not be able to determine the time-of-flight correctly. The increase of the length of the path resulting from this rotation is smaller than 1 % and can thus be neglected.
- Define the zero of the time-of-flight (→ **0** ← in Settings Γ tA1).
- Record the first "measuring point" (air) with ⏱.
- Fill the plate glass cell with water.
- Record the second measuring point (water) with ⏱.
- Remove the plate glass cell.
- Define the zero of the time-of-flight (→ **0** ← in Settings Γ tA1) anew.
- Hold the acrylic glass block into the path of the beam such that the visible reflections of the laser beam from the glass surface are not reflected back to the laser (rotate the acrylic glass block by approximately 3°).
- Record the third measuring point (acrylic glass) with ⏱.

### Evaluation

The two displays **Velocity of Light** and **Refractive Index** show the measuring results in the form of bar diagrams. The velocity of light in materials having a greater optical density decreases and the refractive index increases.

The literature values of the refractive indices of water and acrylic glass are n=1.33 and n=1.5.

## Millikan's experiment



can also be carried out with Pocket-CASSY

### Experiment description

In 1910, R. A. Millikan succeeded in demonstrating the quantized occurrence of smallest amounts of electrical charge using his famous oil droplet method. He observed charged oil droplets in a vertical electrical field of a plate capacitor with the plate distance d and determined the charge q of a floating droplet from its radius r and the electrical field E=U/d. In his experiment, he found that q only occurs as integral multiples of an elementary charge e, i.e. q = n·e.

### Theory

When an oil droplet with radius $r_0$ falls with the velocity $–v_1$, this droplet is subject to Stokes friction, which leads to the upward directed force $F_1 = 6\pi\cdot\varepsilon\cdot r_0\cdot v_1$ ($\varepsilon$ = viscosity of air). When the oil droplet rises with the velocity $v_2$ in an external electrical field E, the downward directed force due to Stokes friction is $F_2 = –6\pi\cdot\varepsilon\cdot r_0\cdot v_2$. The difference between these two forces is exactly the force $q_0\cdot E$ exerted by the applied electrical field E, i.e.

$q_0\cdot E = q_0\cdot U/d = F_1–F_2 = 6\pi\cdot\varepsilon\cdot r_0\cdot(v_1+v_2)$ or

$q_0 = 6\pi\cdot\varepsilon\cdot r_0\cdot d\cdot(v_1+v_2) / U$.

In order to determine the charge $q_0$, only the radius $r_0$ of the oil droplet under consideration is required, which, however, is easily obtained from the equilibrium of forces between its resultant gravitational force $F = –V\cdot\Gamma\rho\cdot g$ and the Stokes frictional force $F_1$ in the case of the falling droplet, where $\Gamma\rho$ is the difference between the densities of oil and air.

Thus we have:

$0 = F+F_1 = -4/3\ \pi \cdot r_0^3 \cdot \Gamma\rho \cdot g + 6\pi \cdot \varepsilon \cdot r_0 \cdot v_1$ or

$r_0 = \sqrt{(9\varepsilon v_1 / 2\Gamma\rho g)}$.

For a more precise determination of the charge q, it has to be taken into account that Stokes friction has to be corrected for very small radii r because these are of the order of magnitude of the mean free path of the air molecules. The corrected formula for the frictional force, which depends on the air pressure p, reads

$F = 6\pi\varepsilon rv\ /\ (1+b/rp)$

with b = 80 µm·hPa (constant).

With the abbreviation A = b/p, the corrected radius r is

$r = \sqrt{(r_0^2 + A^2/4)} - A/2$

and the corrected charge q is

$q = q_0\ /\ (1+A/r)^{1.5}$.

### Floating method

In this version of the experiment, the voltage U at the plate capacitor is adjusted such that a particular oil droplet floats, i.e. the rising velocity is $v_2$=0. The falling velocity $v_1$ is measured after switching off the voltage U at the capacitor. Because of $v_2$=0, the above formulas are slightly simplified.

However, $v_2$=0 cannot be adjusted very precisely for fundamental reasons. Therefore the floating method leads to larger measurement errors and broader scattering in the frequency distribution than in the case of the following method.

### Falling/rising method

In the second version, the two velocities $v_1$ and $v_2$ the voltage U are measured. This method makes possible more precise measured values than the floating method because the velocity $v_2$ is really measured.

### Equipment list

| | | |
|---|---|---|
| 1 | Sensor-CASSY | 524 010 or 524 013 |
| 1 | CASSY Lab 2 | 524 220 |
| 1 | Timer box | 524 034 |
| 1 | Millikan apparatus | 559 411 |
| 1 | Millikan supply unit | 559 421 |
| 1 | Connecting lead, 50 cm, red | 500 421 |
| 3 | Pairs of cables, 50 cm, red and blue | 501 45 |
| 1 | Pair of cables, 50 cm, black | 501 451 |
| 1 | PC with Windows XP/Vista/7 | |

### Experiment setup (see drawing)

Set up the Millikan apparatus as described in the instruction sheet, fill in oil, and set up the circuit as shown in the drawing. Connect the stopwatch output 1 to the input E and the stopwatch output 2 to the input F of the timer box. Connect the voltage output of the supply unit to the input B of the Sensor-CASSY.

Attention: the microscope creates an inverted image. Therefore all directions of motions are inverted. In the following, however, the real motion is described.

For a better demonstration of the oil droplets, it is recommended to record the image of the microscope by means of a video camera (e.g. VideoFlex from ken-a-vision). In this case, the camera can record upside down so that the visible direction of motion corresponds to the real direction of motion.

### Carrying out the experiment

a) Floating method

☐ Load settings

- Orient the eyepiece micrometer vertically and turn the lens holder of the eyepiece until you can clearly see the micrometer scale.
- First set the switches U and t in the down position.

- Switch the voltage at the capacitor on with the switch U and adjust it with the rotary potentiometer so (400-600 V) that a selected oil droplet rises with a velocity of approximately 1-2 scale graduation marks per second (i.e. it is seen falling when observed through the eyepiece). Then reduce the voltage until the oil droplet floats.
- Switch the voltage at the capacitor off with the switch U.
- As soon as the oil droplet is located at the height of a selected scale graduation mark, start the time measurement with the switch t.
- As soon as the oil droplet has fallen by another 20 scale graduation marks (corresponds to 1 mm), stop the time measurement with the switch t and switch the voltage at the capacitor on again with the switch U.
- Enter the measured values of the falling time $t_1$ and the voltage U in the table with ⏱. The calculated charge q is entered in the histogram automatically.
- Repeat the measurement for other oil droplets.

b) Falling/rising method

■ Load settings

- Orient the eyepiece micrometer vertically and turn the lens holder of the eyepiece until you can clearly see the micrometer scale.
- First set the switches U and t in the down position.
- Switch the voltage at the capacitor on with the switch U and adjust it with the rotary potentiometer so (400-600 V) that a selected oil droplet rises with a velocity of approximately 1-2 scale graduation marks per second (i.e. it is seen falling when observed through the eyepiece).
- Switch the voltage at the capacitor off with the switch U.
- As soon as the oil droplet is located at the height of a selected scale graduation mark, start the time measurement with the switch t.
- As soon as the oil droplet has fallen (i.e. risen as observed in the eyepiece) by another 20 scale graduation marks (corresponds to 1 mm), switch the voltage at the capacitor on again with the switch U. Thereby the time measurement $t_2$ is started automatically.
- As soon as the oil droplet is at the height of the first scale graduation mark again, stop the time measurement with the switch t.
- Enter the measured values of the falling time $t_1$, the rising time $t_2$ and the voltage U in the table with ⏱. The calculated charge q is entered in the histogram automatically.
- Repeat the measurement for other oil droplets.

## Evaluation

In the evaluation, mean values can be drawn the in measured frequency distribution and the relation q = n·e (with e =1.6022 · $10^{-19}$ C) can be confirmed.

## Remarks

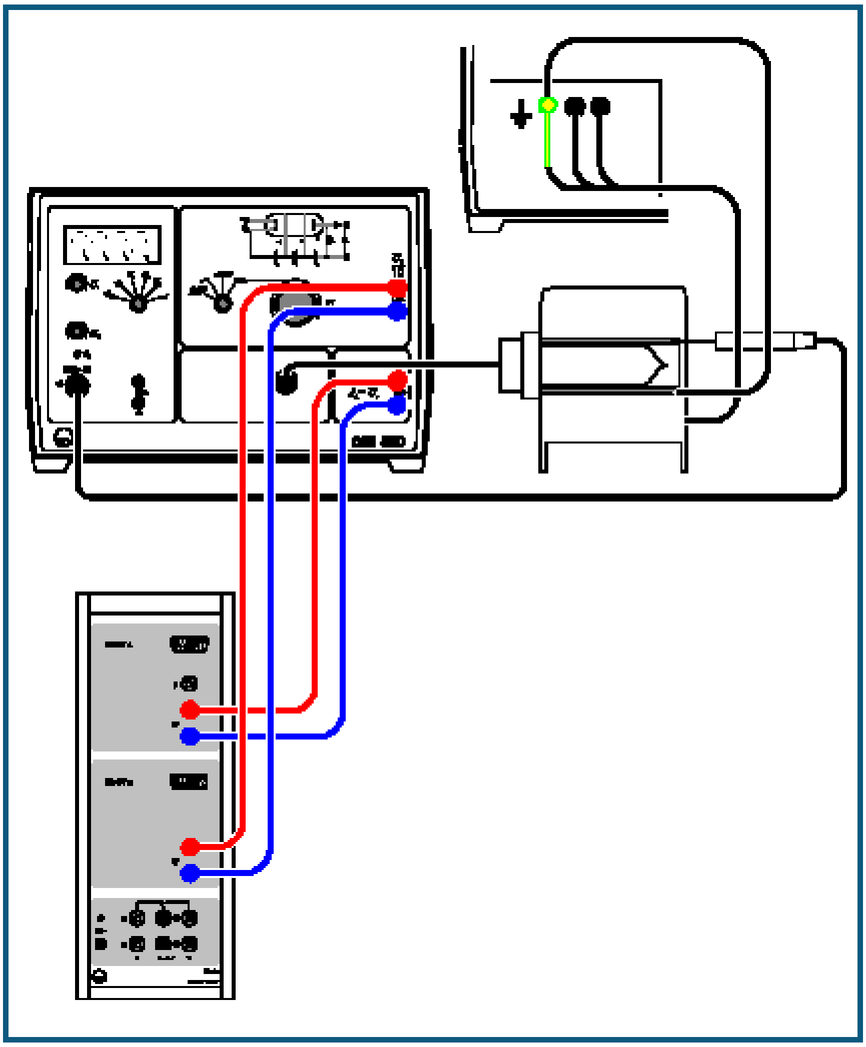
If oil droplets with a small charge are selected, statistical significance is achieved more quickly. Oil droplets carrying a small charge are identified by their small size and their slow motion in the electric field.

If there is not enough time during the lessons for observing about 20-30 oil droplets, the example with its measured values can be loaded instead of merely the settings. The new measured values then appear in the histogram as red bars thus confirming the results of the example drawn in black within the usual statistical uncertainty.

In order to measure negative charges q, the connections at the plate capacitor and at the input B of the CASSY have to be exchanged.

If the local air pressure differs considerably form 1013 hPa, the air pressure should be changed correspondingly in the formula defining the correction parameter A. However, the diplayed example values may then be wrong.

## Franck-Hertz experiment with mercury



can also be carried out with Pocket-CASSY

### Experiment description

In 1914, James Franck and Gustav Hertz reported an energy loss occurring in distinct "steps" for electrons passing through mercury vapour, and a corresponding emission at the ultraviolet line (ı = 254 nm) of mercury. Just a few months later, Niels Bohr recognized this as evidence confirming his model of the atom. The Franck-Hertz experiment is thus a classic experiment for confirming quantum theory.

In this experiment, the acceleration voltage $U_2$ is increased from 0 to 30 V while the driving potential $U_1$ and the braking voltage $U_3$ are held constant, and the corresponding collector current $I_A$ is measured. This current initially increases, much as in a conventional tetrode, but reaches a maximum when the kinetic energy of the electrons closely in front of grid $G_2$ is just sufficient to transfer the energy required to excite the mercury atoms ($E_{Hg}$ = 4.9 eV) through collisions. The collector current drops off dramatically, as after collision the electrons can no longer overcome the braking voltage $U_3$.

As the acceleration voltage $U_2$ increases, the electrons attain the energy level required for exciting the mercury atoms at ever greater distances from grid $G_2$. After collision, they are accelerated once more and, when the acceleration voltage is sufficient, again absorb so much energy from the electrical field that they can excite a mercury atom. The result is a second maximum, and at greater voltages $U_2$ further maxima of the collector current $I_A$.

### Equipment list

| | | |
|---|---|---|
| 1 | Sensor-CASSY | 524 010 or 524 013 |
| 1 | CASSY Lab 2 | 524 220 |
| 1 | Hg Franck-Hertz tube | 555 854 |

| | | |
|---|---|---|
| 1 | Socket for Hg Franck-Hertz tube | 555 864 |
| 1 | Electric oven, 230 V | 555 81 |
| 1 | Franck-Hertz supply unit | 555 880 |
| 1 | Temperature sensor NiCr-Ni | 666 193 |
| 2 | Pairs of cables, 100 cm, red and blue | 501 46 |
| 1 | PC with Windows XP/Vista/7 | |

### Experiment setup (see drawing)

- Make sure the Franck-Hertz supply unit is switched off.
- Connect the heating oven via the 4-mm safety sockets on the rear of the supply unit. In particular, ensure that the yellow and green plug is connected to the yellow and green safety socket (earth).
- Additionally, connect the copper lead of the copper sleeve with 4-mm plug to the green-yellow safety socket (to screen the Franck-Hertz tube from interference fields).
- Connect temperature sensor to the "NiCr-Ni" DIN socket and Franck-Hertz tube to the "Franck-Hertz tube" DIN socket of the supply unit.
- Insert the temperature sensor in the corresponding blind hole of the heating oven as far as it will go and slide the Franck-Hertz tube with copper sleeve into the oven.
  Note: If the thermal contact of the temperature sensor is poor, the measured oven temperature will be too low, resulting in overheating of the tube.
- Turn the operating-mode switch to RESET and switch on the supply unit (after a few seconds, the LED indicator for mercury (Hg) changes from green to red).
- Check the default setting $\vartheta_S$ = 180 °C and wait until the operating temperature is reached (LED indicator changes from red to green; the temperature $\vartheta$ first reaches a maximum, and then declines to the final value).

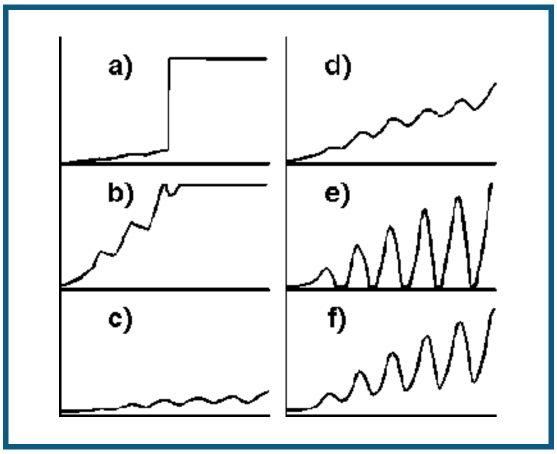
If the indicator in the display flashes:

- There is a mistake in the setup for temperature measurement (see the Instruction Sheet).
- Connect voltage input A for the Sensor-CASSY to output $U_A$ for the voltage proportional to the collector voltage and the voltage input B of Sensor-CASSY at output $U_2/10$ for the acceleration voltage.

### Carrying out the experiment

■ Load settings

- Set the driving potential $U_1$ = 1.5 V and the braking voltage $U_3$ = 1.5 V and record the Franck-Hertz curve in the "Ramp" operating mode. To do this, start the measurement by pressing ⏱ and immediately set the operating mode switch to "Ramp". The measurement is automatically stopped after 15 s, then return the operating mode switch to RESET.



1) Optimizing $\vartheta$

If the Franck-Hertz curve rises abruptly (a) and you can see a gas discharge in the Franck-Hertz tube through the insertion opening of the oven (blue glow):

- Immediately turn the operating-mode switch to RESET and wait until the setup reaches the operating temperature.
- If necessary, raise the set value $\vartheta_S$ using the screwdriver potentiometer (e.g. by 5 °C) and wait a few minutes until the system settles into the new thermal equilibrium.

2) Optimizing $U_1$

A higher driving potential $U_1$ results in a greater electron emission current.

If the Franck-Hertz curve rises too steeply, i.e. the overdrive limit of the current measuring amplifier is reached at values below $U_2$ = 30 V and the top of the Franck-Hertz curve is cut off (b):

- Reduce $U_1$ until the curve steepness corresponds to (d).

If the Franck-Hertz curve is too flat, i.e. the collector current $I_A$ remains below 5 nA in all areas (c):

- Increase $U_1$ until the curve steepness corresponds to (d).

If the Franck-Hertz curve is flat even after increasing $U_1$:

- Reduce the set value $\vartheta_S$ for the oven temperature using the screwdriver potentiometer.

3) Optimizing $U_3$

A greater braking voltage $U_3$ causes better-defined maxima and minima of the Franck-Hertz curve; at the same time, however, the total collector current is reduced.

If the maxima and minima of the Franck-Hertz curve are insufficiently defined (d):

- Alternately increase first the braking voltage $U_3$ and then the driving potential $U_1$ until you obtain the curve form shown in (f).

If the minima of the Franck-Hertz curve are cut off at the bottom (e):

- Alternately reduce first the braking voltage $U_3$ and then the driving potential $U_1$ until you obtain the curve form shown in (f).

The Hg Franck-Hertz tube in the experimental example was measured using the parameters $U_1$ = 2.58 V, $U_3$ = 1.95 V und $\vartheta_S$ = 180 °C.

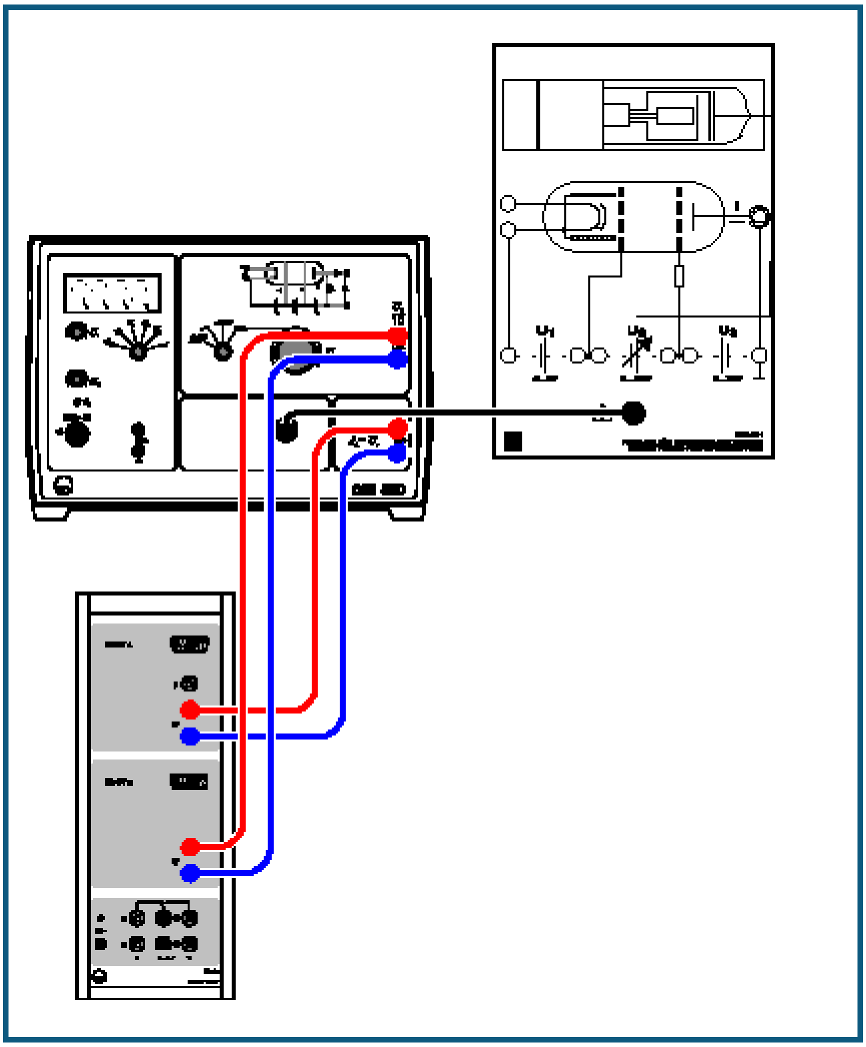
## Evaluation

The recorded curve is evaluated by drawing vertical lines or peak centers to find the distance between the subsequent maxima. In the experimental example, an average value of $U_2$ = 5.07 V is found. This corresponds to an energy transfer ΓE = 5.07 eV.

The value found in the literature for the transfer energy of the mercury atoms from the basic state 1S0 to the first 3P1 state is $E_{Hg}$ = 4.9 eV.

The position of the first maximum is determined through the contact voltage of the electrode materials used and the driving potential $U_1$. The larger distance between the maxima of higher order is caused by superposition of the Franck-Hertz curve by the characteristic tube line.

## Franck-Hertz experiment with neon

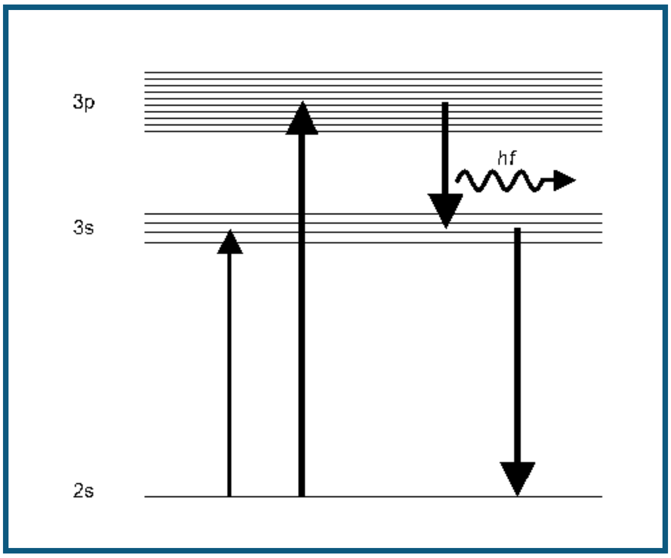


can also be carried out with Pocket-CASSY

### Experiment description

In 1914, James Franck and Gustav Hertz reported an energy loss occurring in distinct "steps" for electrons passing through mercury vapour, and a corresponding emission at the ultraviolet line (ı = 254 nm) of mercury. Just a few months later, Niels Bohr recognized this as evidence confirming his model of the atom. The Franck-Hertz experiment is thus a classic experiment for confirming quantum theory.

In this experiment, the energy loss of free electrons through inelastic scattering (excitation through impact) from neon atoms is investigated. Most probably the excitation occurs from the ground state to the ten 3p states, which are 18.4 eV and 19.0 eV above the ground state. The four slightly lower 3s states at 16.6 eV to 16.9 eV are less likely to be excited. The de-excitation of the 3p states to the ground state by emission of photons is only possible with a detour via the 3s states. The light emitted during this process within the visible range between red and green and can therefore be observed without any equipment.



An evacuated glass tube is filled with neon at room temperature to a gas pressure of about 10 hPa. The glass tube contains a system of four electrodes. Electrons are emitted by the hot cathode and form a charge cloud. These electrons are attracted by the driving potential $U_1$ between the cathode and the grid-shaped control electrode $G_1$ and then accelerated by the acceleration voltage $U_2$ in the direction of grid $G_2$. Between $G_2$ and the collector electrode, a braking voltage $U_3$ is applied. Only electrons with sufficient kinetic energy can reach the collector and contribute to the collector current.

In this experiment, the acceleration voltage $U_2$ is increased from 0 to 80 V while the driving potential $U_1$ and the braking voltage $U_3$ are held constant, and the corresponding collector current $I_A$ is measured. This current initially increases, much as in a conventional tetrode, but reaches a maximum when the kinetic energy of the electrons closely in front of grid $G_2$ is just sufficient to transfer the energy required to excite the neon atoms through collisions. The collector current drops off dramatically, as after collision the electrons can no longer overcome the braking voltage $U_3$.

As the acceleration voltage $U_2$ increases, the electrons attain the energy level required for exciting the neon atoms at ever greater distances from grid $G_2$. After collision, they are accelerated once more and, when the acceleration voltage is sufficient, again absorb so much energy from the electrical field that they can excite a neon atom. The result is a second maximum, and at greater voltages $U_2$ further maxima of the collector current $I_A$.

### Equipment list

| | | |
|---|---|---|
| 1 | Sensor-CASSY | 524 010 or 524 013 |
| 1 | CASSY Lab 2 | 524 220 |
| 1 | Ne Franck-Hertz tube | 555 870 |
| 1 | Holder with socket | 555 871 |
| 1 | Connecting cable for Ne-FH | 555 872 |
| 1 | Franck-Hertz supply unit | 555 880 |
| 2 | Pairs of cables, 100 cm, red and blue | 501 46 |
| 1 | PC with Windows XP/Vista/7 | |

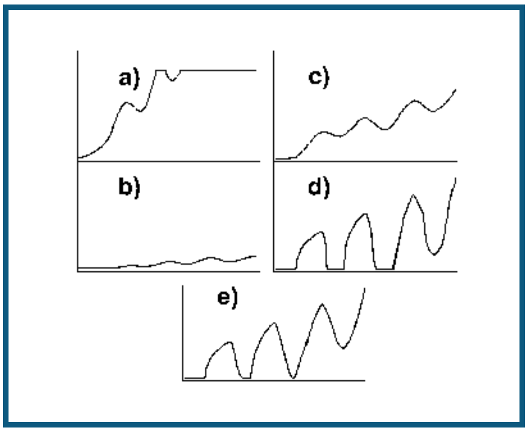
### Experiment setup (see drawing)

- Clamp the Ne Franck-Hertz tube in the socket on the holder and connect by means of a connection cable to the socket "Franck-Hertz tube" of the Franck-Hertz supply unit.
- Set the operating-mode switch on the Franck-Hertz supply unit to RESET.
- Connect voltage input A for the Sensor-CASSY to output $U_A$ for the voltage proportional to the collector voltage and the voltage input B of Sensor-CASSY at output $U_2/10$ for the acceleration voltage.

### Carrying out the experiment

■ Load settings

- Set the driving potential $U_1$ = 1.5 V and the braking voltage $U_3$ = 5 V and record the Franck-Hertz curve in the "Ramp" operating mode. To do this, start the measurement by pressing ⏱ and immediately set the operating mode switch to "Ramp". The measurement is automatically stopped after 40 s, then return the operating mode switch to RESET.



1) Optimizing $U_1$

A higher driving potential $U_1$ results in a greater electron emission current.

If the Franck-Hertz curve rises too steeply, i.e. the overdrive limit of the current measuring amplifier is reached at values below $U_2$ = 80 V and the top of the Franck-Hertz curve is cut off (a):

- Reduce $U_1$ until the curve steepness corresponds to (c).

If the Franck-Hertz curve is too flat, i.e. the collector current $I_A$ remains below 5 nA in all areas (b):

- Increase $U_1$ until the curve steepness corresponds to (c).
- If necessary, optimize the cathode heating as described in the Instruction Sheet for the Franck-Hertz supply unit.

2) Optimizing $U_3$

A greater braking voltage $U_3$ causes better-defined maxima and minima of the Franck-Hertz curve; at the same time, however, the total collector current is reduced.

If the maxima and minima of the Franck-Hertz curve are insufficiently defined (c):

- Alternately increase first the braking voltage $U_3$ and then the driving potential $U_1$ until you obtain the curve form shown in (e).

If the minima of the Franck-Hertz curve are cut off at the bottom (d):

- Alternately reduce first the braking voltage $U_3$ and then the driving potential $U_1$ until you obtain the curve form shown in (e).

The Ne Franck-Hertz tube in the experimental example was measured using the parameters $U_1$ = 1.5 V and $U_3$ = 7.9 V.

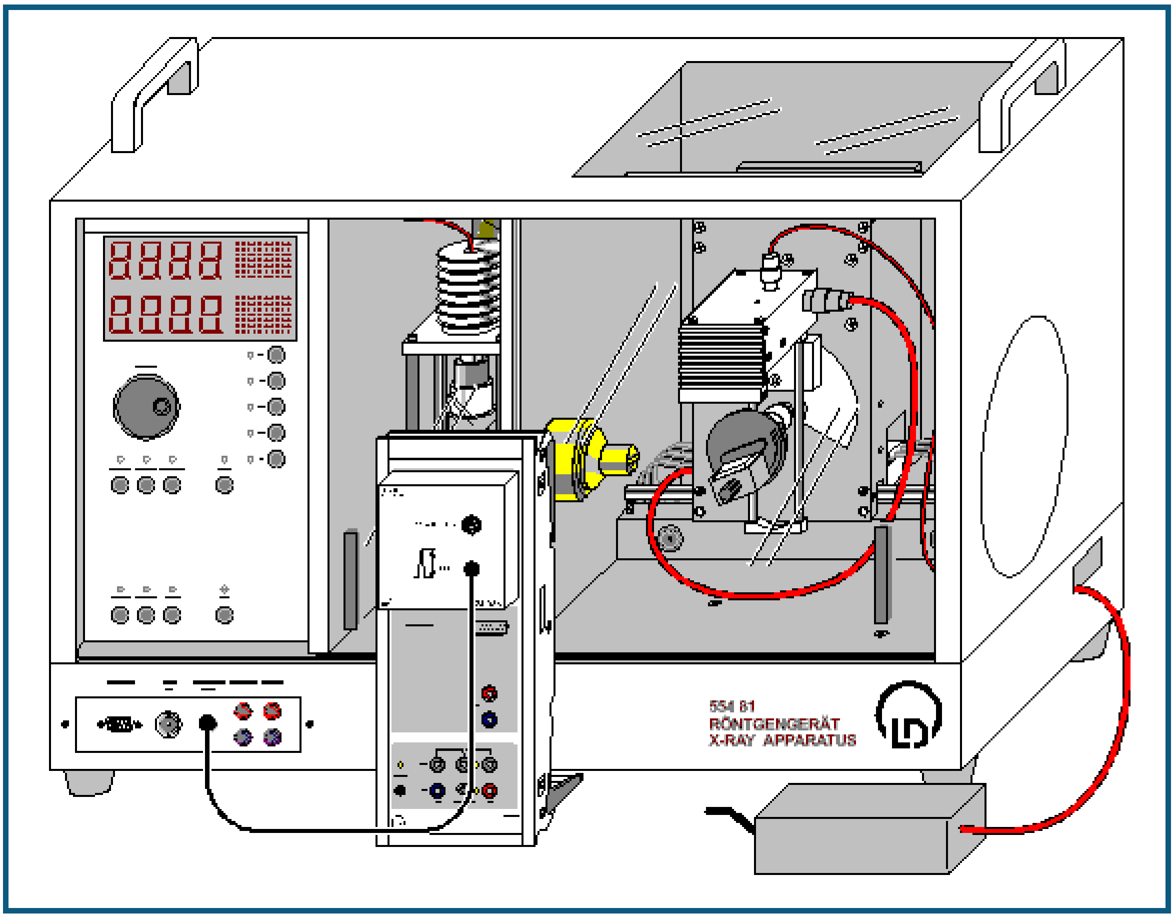
### Evaluation

The recorded curve is evaluated by drawing vertical lines (by eye) to find the distance between the subsequent maxima. In the experimental example, an average value of $U_2$ = 18.2 V is found. This value is much closer to the excitation energies for the 3p-levels of neon (18.4-19.0 eV) than to the energies of the 3s-levels (16.6–16.9 eV). Thus, the probability of excitation to the latter due to inelastic electron collision is significantly less.

The substructure in the measured curve shows that the excitation of the 3s-levels cannot be ignored altogether. Note that for double and multiple collisions, each combination of excitation of a 3s-level and a 3p-level occurs.

In the Ne Franck-Hertz tube, luminous zones can be observed which depend on the acceleration voltage. They directly correlate with the minima of the Franck-Hertz curve.

# Moseley's law (K-line x-ray fluorescence)



can also be carried out with Pocket-CASSY

## Safety notes

The X-ray apparatus fulfils all regulations on the design of an X-ray apparatus and fully protected device for instructional use and is type approved for school use in Germany (BfS 05/07 V/Sch RöV or NW 807 / 97 Rö).

The built-in protective and shielding fixtures reduce the dose rate outside the X-ray apparatus to less than 1 µSv/h, which is of the order of magnitude of the natural background radiation.

- Before putting the X-ray apparatus into operation, inspect it for damage and check whether the voltage is switched off when the sliding doors are opened (See instruction sheet of the X-ray apparatus).
- Protect the X-ray apparatus against access by unauthorized persons.

Avoid overheating of the anode in the X-ray tube.

- When switching the X-ray apparatus on, check whether the ventilator in the tube chamber starts rotating.

The goniometer is positioned solely by means of electric stepper motors.

- Do not block the target arm and the sensor arm of the goniometer and do not use force to move them.

When handling heavy metals or allergen substances from the target set, observe their operating instructions.

## Experiment description

X-ray fluorescence occurs when electrons are knocked out of the inner shells of an atom through x-ray radiation. The atom ionized in this way then has a vacancy (electron hole) in a lower shell which previously had been full. These electron holes can be filled with electrons from other, less strongly bound shells of the atom: e.g. the K-shell can be closed by the transition of an electron from the L-shell. Such a transition is connected with the emission of a photon. This radiation has only particular discrete photon energies corresponding to the energy difference of the levels involved, and it is characteristic for every chemical element.

The designations of the characteristic x-ray lines are a combination of the symbol for the electron shell (K, L, M etc.) and a Greek letter (α, β, γ, etc.). The electron shell being referred to is the one which was ionized before the electron transition. For example, the designation $K_\alpha$-line describes the transition from the L-shell into the K-shell, $K_\beta$-line refers to the transition from the M-shell to the K-shell. The $L_\alpha$- and $L_\beta$-lines refer to the transitions from the M-shell and the N-shell to the L-shell.

For the energies E of the characteristic lines Moseley discovered in 1913 the following law

$$\sqrt{\frac{E}{Ry}} = (Z-\sigma)\sqrt{\frac{1}{n_1^2}-\frac{1}{n_2^2}}$$

with the atomic number Z, the screening constant ζ, the constant $Ry = m_e e^4/8\varepsilon_0^2 h^2$ = 13.6 eV and the main quantum numbers $n_1$ and $n_2$ for the electron shells involved ($n_1 < n_2$).

In the experiment, the energies of the $K_\alpha$ and $K_\beta$-lines for Ti, Fe, Ni, Cu, Zn, Zr, Mo and Ag are determined, Moseley's law is confirmed and the screening constants $\zeta_\alpha$ and $\zeta_\beta$ are determined.

## Equipment list

| | | |
|---|---|---|
| 1 | Sensor-CASSY | 524 010 or 524 013 |
| 1 | CASSY Lab 2 | 524 220 |
| 1 | MCA box | 524 058 |
| 1 | X-ray apparatus with x-ray tube Mo | 554 801 or 554 811 |
| 1 | Target set for K-line fluorescence | 554 844 |
| 1 | X-ray energy detector | 559 938 |
| 1 | HF cable, 1 m | 501 02 |
| 1 | PC with Windows XP/Vista/7 | |

## Experiment setup (see drawing)

- Guide the connection cable for the table-top power supply through the empty channel of the x-ray apparatus and connect it to the mini-DIN socket of the x-ray energy detector.
- Secure the sensor holder with the mounted x-ray energy detector in the goniometer sensor arm
- Connect the signal output of the x-ray energy detector to the BNC socket SIGNAL IN of the x-ray apparatus by means of the BNC cable included
- Feed enough connection cable through to make complete movement of the sensor arm possible
- Press the SENSOR button and set the sensor angle with the rotary adjuster ADJUST manually to 90°
- Set the distances between the slit aperture of the collimator and the axis of rotation as well as between the axis of rotation and the window of the x-ray energy detector both to 5 to 6 cm
- Press the TARGET button and adjust the target angle manually using the rotary button ADJUST to 45°.
- Connect Sensor-CASSY to the computer and connect the MCA box
- Connect the SIGNAL OUT output in the connection panel of the x-ray apparatus to the MCA box by means of the BNC cable.

## Carrying out the experiment

■ Load settings

- Connect the table-top power supply to the mains (after approx. 2 min the LED will glow green and the x-ray energy detector will be ready for use)
- Place the titanium (Ti) target from the target set for K-lines fluorescence onto the target table
- Set the tube high voltage U = 35 kV, emission current I = 1.00 mA and switch the high voltage on
- Start the spectrum recording with ⏱
- Then record the spectra for the other targets (Fe, Ni, Cu, Zn, Zr, Mo and Ag) in the target set for K-lines fluorescence

## Energy calibration

The energy calibration of the spectra is made using the $K_\alpha$-lines of iron (Fe) and molybdenum (Mo).

- Open in the Settings EA (right mouse button) the Energy calibration, select **Global for all spectra of this input** and enter on the right-hand side the energies of the Fe $K_\alpha$-line (6.40 keV) and of the Mo $K_\alpha$-line (17.48 keV).
- In the context menu of the diagram select Calculate peak center, mark the Fe $K_\alpha$-line (2nd spectrum) and enter the result in the left-hand side of the Energy calibration (e.g. with drag & drop from the status line)
- Then determine the center of the Mo $K_\alpha$-line (7th spectrum) and also enter the result on the left-hand side
- Switch the display to energy (e.g. with Drag & Drop of $E_A$ into the diagram)

## Evaluation

As the atomic number Z increases the energy of the characteristic lines also increases and so does the separation between the α- and the β-component in the K spectral series. For a quantitative analysis, the energies of the individual lines can be determined:

- Select spectrum in the diagram
- In the context menu choose Set Marker → Vertical line and mark approximately the positions of the $K_\alpha$ and $K_\beta$-line with two vertical lines.
- In the context menu of the diagram select Fit Function → Gaussians of equal width and mark the area of the desired peak (also mark sufficient background!)
- Read the determined peak positions from the status line and enter them together with the atomic numbers Z of Ti (Z=22), Fe (Z=26), Ni (Z=28), Cu (Z=29), Zn (Z=30), Zr (Z=40), Mo (Z=42) and Ag (Z=47) into the **Energy** diagram (click with mouse) (e.g. by drag & drop from the status line)

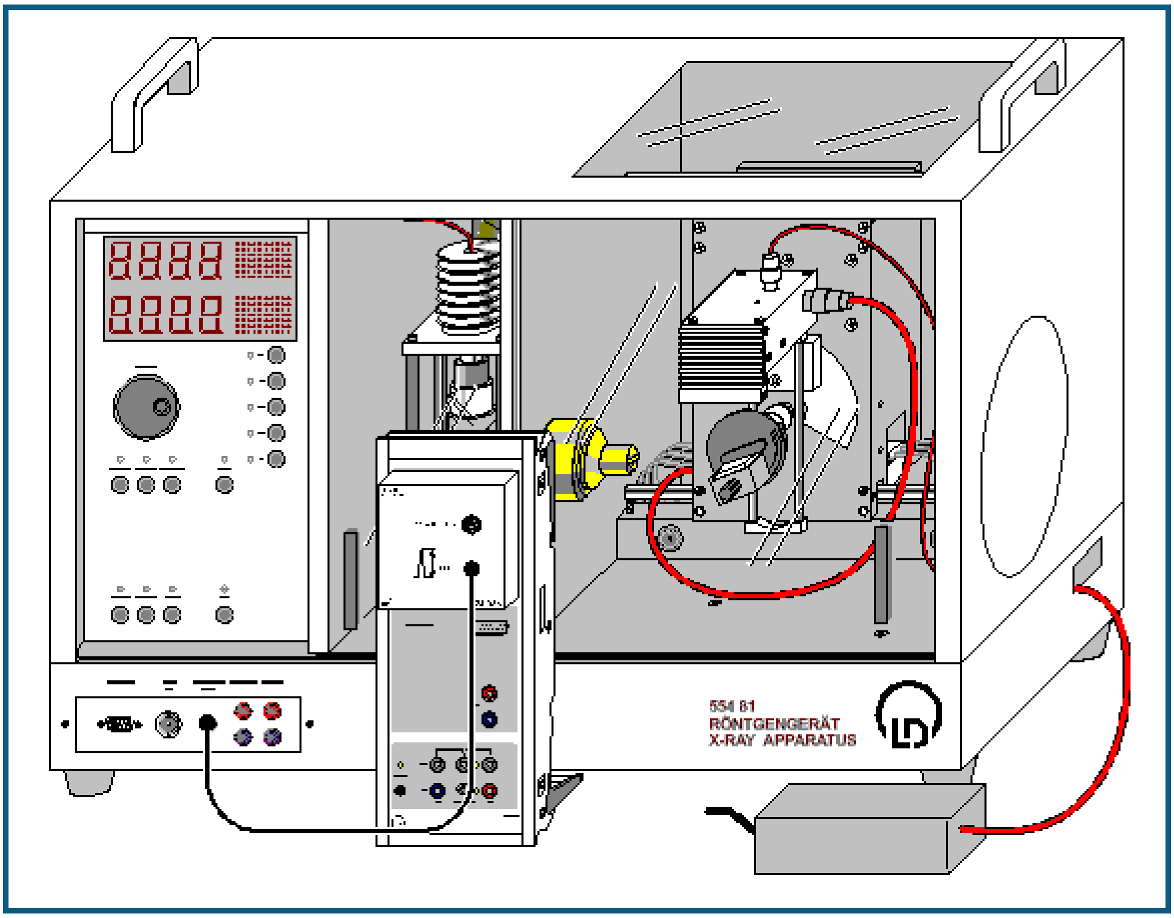
For each line, the expression √E/Ry is automatically calculated and plotted in the **Moseley** diagram as a function of the atomic number Z. The same applies to the screening constants $\zeta_\alpha$ and $\zeta_\beta$ and the **Screening** diagram.

In the **Moseley** diagram, by a free fit with the formula (x-1)*sqr(3/4), the theoretical line for the $K_\alpha$-line can be entered, which corresponds well to the measured values.

The **Screening** diagram shows for the $K_\alpha$-line that the deviation from the theoretically expected $\zeta_\alpha=1$ grows with increasing atomic number Z. This is explained by the fact that the influence of the external electrons increases as the number of electrons increases.

The screening constants $\zeta_\beta$ for the $K_\beta$-lines have a value $\zeta_\beta\approx2$ which indicates, as expected, a stronger effective screening of the nucleus charge for the electron transitions from the higher level $n_2=3$.

## Moseley's law (L-line x-ray fluorescence)



can also be carried out with Pocket-CASSY

### Safety notes

The X-ray apparatus fulfils all regulations on the design of an X-ray apparatus and fully protected device for instructional use and is type approved for school use in Germany (BfS 05/07 V/Sch RöV or NW 807 / 97 Rö).

The built-in protective and shielding fixtures reduce the dose rate outside the X-ray apparatus to less than 1 µSv/h, which is of the order of magnitude of the natural background radiation.

- Before putting the X-ray apparatus into operation, inspect it for damage and check whether the voltage is switched off when the sliding doors are opened (See instruction sheet of the X-ray apparatus).
- Protect the X-ray apparatus against access by unauthorized persons.

Avoid overheating of the anode in the X-ray tube.

- When switching the X-ray apparatus on, check whether the ventilator in the tube chamber starts rotating.

The goniometer is positioned solely by means of electric stepper motors.

- Do not block the target arm and the sensor arm of the goniometer and do not use force to move them.

When handling heavy metals or allergen substances from the target set, observe their operating instructions.

### Experiment description

X-ray fluorescence occurs when electrons are knocked out of the inner shells of an atom through x-ray radiation. The atom ionized in this way then has a vacancy (electron hole) in a lower shell which previously had been full. These electron holes can be filled with electrons from other, less strongly bound shells of the atom: e.g. the K-shell can be closed by the transition of an electron from the L-shell. Such a transition is connected with the emission of a photon. This radiation has only particular discrete photon energies corresponding to the energy difference of the levels involved, and it is characteristic for every chemical element.

The designations of the characteristic x-ray lines are a combination of the symbol for the electron shell (K, L, M etc.) and a Greek letter (α, β, γ, etc.). The electron shell being referred to is the one which was ionized before the electron transition. For example, the designation $K_\alpha$-line describes the transition from the L-shell into the K-shell, $K_\beta$-line refers to the transition from the M-shell to the K-shell. The $L_\alpha$- and $L_\beta$-lines refer to the transitions from the M-shell and the N-shell to the L-shell.

For the energies E of the characteristic lines Moseley discovered in 1913 the following law

$$\sqrt{\frac{E}{Ry}} = (Z-\sigma)\sqrt{\frac{1}{n_1^{2}}-\frac{1}{n_2^{2}}}$$

with the atomic number Z, the screening constant $\zeta$, the constant $Ry = m_e e^4/8\varepsilon_0^2 h^2$ = 13.6 eV and the main quantum numbers $n_1$ and $n_2$ for the electron shells involved ($n_1 < n_2$).

In the experiment the energies of the $L_\alpha$ and $L_\beta$-lines for Ag, In, Sn, W, Au and Pb are determined, Moseley's law is confirmed and the screening constants $\zeta_\alpha$ and $\zeta_\beta$ are determined. The fine structure of the lines, e.g. $L_{\alpha1}$ and $L_{\alpha2}$, cannot be resolved in this experiment. Therefore they appear in the spectrum as a single ($L_\alpha$) line.

## Equipment list

| | | |
|---|---|---|
| 1 | Sensor-CASSY | 524 010 or 524 013 |
| 1 | CASSY Lab 2 | 524 220 |
| 1 | MCA box | 524 058 |
| 1 | X-ray apparatus with x-ray tube Mo | 554 801 or 554 811 |
| 1 | Target set for L-line fluorescence | 554 846 |
| 1 | X-ray energy detector | 559 938 |
| 1 | HF cable, 1 m | 501 02 |
| 1 | PC with Windows XP/Vista/7 | |

## Experiment setup (see drawing)

- Guide the connection cable for the table-top power supply through the empty channel of the x-ray apparatus and connect it to the mini-DIN socket of the x-ray energy detector.
- Secure the sensor holder with the mounted x-ray energy detector in the goniometer sensor arm
- Connect the signal output of the x-ray energy detector to the BNC socket SIGNAL IN of the x-ray apparatus by means of the BNC cable included
- Feed enough connection cable through to make complete movement of the sensor arm possible
- Press the SENSOR button and set the sensor angle with the rotary adjuster ADJUST manually to 90°
- Set the distances between the slit aperture of the collimator and the axis of rotation as well as between the axis of rotation and the window of the x-ray energy detector both to 5 to 6 cm
- Press the TARGET button and adjust the target angle manually using the rotary button ADJUST to 45°.
- Connect Sensor-CASSY to the computer and connect the MCA box
- Connect the SIGNAL OUT output in the connection panel of the x-ray apparatus to the MCA box by means of the BNC cable.

## Carrying out the experiment

■ Load settings

- Connect the table-top power supply to the mains (after approx. 2 min the LED will glow green and the x-ray energy detector will be ready for use)
- Place the first target (Ag) from the target set for L-lines fluorescence onto the target table
- Set the tube high voltage U = 35 kV, emission current I = 1.00 mA and switch the high voltage on
- Start the spectrum recording with ⏱
- Then record spectra for the other targets (In, Sn, W, Au and Pb) in the target set for L-lines fluorescence.

## Energy calibration

The energy calibration of the spectra is made using the $L_\alpha$-line of tungsten (W) and the $K_\alpha$-line of silver (Ag).

- Open in the Settings EA (right mouse button) the Energy calibration, select **Global for all spectra of this input** and enter on the right-hand side the energies of the W $L_\alpha$-line (8.40 keV) and of the Ag $K_\alpha$-line (22.17 keV).
- In the context menu of the diagram select Calculate peak center, mark the W $L_\alpha$-line (largest peak in the 4th spectrum) and enter the result in the left-hand side of the Energy calibration (e.g. with drag & drop from the status line)
- Then determine the center of the Ag $K_\alpha$ line (1st spectrum) and also enter it on the left-hand side
- Switch the display to energy (e.g. with Drag & Drop of $E_A$ into the diagram)

## Evaluation

As the atomic number Z increases, the energy of the characteristic lines also increases and so does the separation between the α- and the β-components in the L spectral series. For the heavier elements, in addition to the $L_\alpha$ and $L_\beta$-components, the relatively small $L_l$ and $L_\gamma$-components can also be demonstrated with the x-ray energy detector. For a quantitative analysis, the energies of the individual lines can be determined:

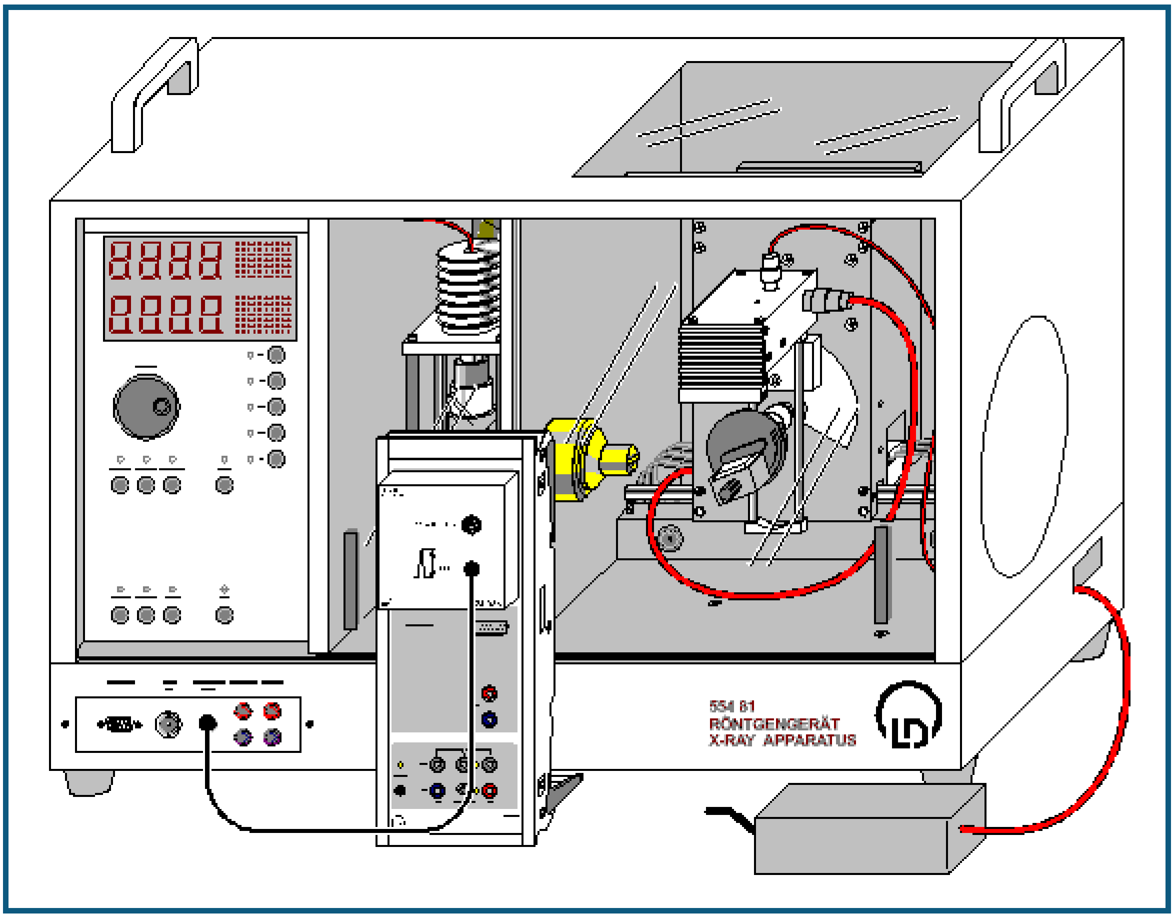
- Select spectrum in the diagram
- In the context menu choose Set Marker → Vertical line and mark approximately the positions of the $L_\alpha$ and $L_\beta$-line with two vertical lines. Because for the elements silver, indium and tin the $L_\alpha$-line and $L_\beta$-line are not resolved, they will be treated in the evaluation as a single line.
- In the context menu of the diagram select Fit Function → Gaussians of equal width and mark the area of the desired peak (also mark sufficient background!)
- Read the determined peak positions from the status line and enter them together with the atomic numbers Z of Ag (Z=47), In (Z=49), Sn (Z=50), W (Z=74), Au (Z=79) and Pb (Z=82) into the **Energy** diagram (click with mouse) (e.g. by drag & drop from the status line)

For each line, the expression $\sqrt{E/Ry}$ is automatically calculated and plotted in the **Moseley** diagram as a function of the atomic number Z. The same applies to the screening constants $\zeta_\alpha$ and $\zeta_\beta$ and the **Screening** diagram.

In the **Moseley** diagram, by means of a Best-fit straight line for $L_\alpha$ and $L_\beta$, the linear relationship in Moseley's law can be confirmed.

In the **Screening** diagram, the very different dependence of the atomic screening constants for the $L_\alpha$-lines and $L_\beta$-lines of the atomic number Z indicates the differences in structure of the sublevels in the M-shell and the L-shell. It is remarkable that the atomic screening constant for the $L_\alpha$-lines has a value of ≈ 7. This means that the screening is provided by the seven electrons remaining in the L-shell after ionization. This again indicates that the p-orbitals and s-orbitals (L-shell or K-shell respectively) have such a form that the two electrons in the K-shell are ineffective at screening the $L_\alpha$-transition.

## Energy dispersive Bragg reflection into different orders of diffraction



can also be carried out with Pocket-CASSY

### Safety notes

The X-ray apparatus fulfils all regulations on the design of an X-ray apparatus and fully protected device for instructional use and is type approved for school use in Germany (BfS 05/07 V/Sch RöV or NW 807 / 97 Rö).

The built-in protective and shielding fixtures reduce the dose rate outside the X-ray apparatus to less than 1 µSv/h, which is of the order of magnitude of the natural background radiation.

- Before putting the X-ray apparatus into operation, inspect it for damage and check whether the voltage is switched off when the sliding doors are opened (See instruction sheet of the X-ray apparatus).
- Protect the X-ray apparatus against access by unauthorized persons.

Avoid overheating of the anode in the X-ray tube.

- When switching the X-ray apparatus on, check whether the ventilator in the tube chamber starts rotating.

The goniometer is positioned solely by means of electric stepper motors.

- Do not block the target arm and the sensor arm of the goniometer and do not use force to move them.

### Experiment description

According to a model first described by W.H. and W.L. Bragg in 1913, the regular arrangement of atoms in a crystal can be interpreted in such a way that they are arranged on parallel lattice planes.

If parallel x-rays hit the crystal these are elastically scattered by each of the atoms. If two conditions apply, the waves scattered at the individual atoms will interfere constructively.

These conditions are:

Incident angle $\alpha_1$ = diffracted angle $\alpha_2$ = $\alpha$

and

$n \cdot \lambda = 2 \cdot d \cdot \sin \alpha$ (Bragg's condition)

with d the distance between the lattice planes and order of diffraction n being an integer number. The angle α applies relative to the lattice planes.

When recording the spectrum by means of an energy resolving detector, not the wavelengths, but the energies are recorded. For this case, Bragg's condition can be rewritten with $E = h\lambda = hc/\lambda$ as follows:

$E_n = nhc / 2d\sin\alpha$

or

$E_n/n = hc / 2d\sin\alpha \approx 620\ \text{pm} \cdot \text{keV} / d\sin\alpha$

Here $E_n$ is the energy of the x-ray radiation reflected in the order of diffraction n. It is apparent that with a fixed angle α the lowest energy $E_1$ occurs in the first order of diffraction. The ratio of the radiation energy in the order of diffraction n with the radiation energy in the first order $E_n/E_1$ corresponds to the order of diffraction. The ratio $E_n/n$ is constant for every set of lattice planes.

### Equipment list

| | | |
|---|---|---|
| 1 | Sensor-CASSY | 524 010 or 524 013 |
| 1 | CASSY Lab 2 | 524 220 |
| 1 | MCA box | 524 058 |
| 1 | X-ray apparatus with goniometer | 554 801 or 554 811 |
| 1 | X-ray tube Cu | 554 862 or 554 85 |
| 1 | X-ray energy detector | 559 938 |
| 1 | HF cable, 1 m | 501 02 |
| 1 | PC with Windows XP/Vista/7 | |

### Experiment setup (see drawing)

- If necessary exchange the Mo x-ray tube for the Cu x-ray tube (see operating instructions for the x-ray apparatus)
- Guide the connection cable for the table-top power supply through the empty channel of the x-ray apparatus and connect it to the mini-DIN socket of the x-ray energy detector.
- Secure the sensor holder with the mounted x-ray energy detector in the goniometer sensor arm
- Connect the signal output of the x-ray energy detector to the BNC socket SIGNAL IN of the x-ray apparatus by means of the BNC cable included
- Feed enough connection cable through to make complete movement of the sensor arm possible
- Connect Sensor-CASSY to the computer and connect the MCA box
- Connect the SIGNAL OUT output in the connection panel of the x-ray apparatus to the MCA box by means of the BNC cable.
- Set the distances between the slit aperture of the collimator and the axis of rotation as well as between the axis of rotation and the window of the x-ray energy detector both to 5 to 6 cm
- Lay the NaCl crystal from the scope of delivery of the X-ray apparatus on the target stage and clamp it gently.
- Press the COUPLED pushbutton, and, using the ADJUST knob, adjust a target angle of 4.5° manually.

### Remark

For the experiment, the Cu x-ray tube is inserted, because, due to its thinner window, the radiation provided covers a wider energy range: approx. 5 to 35 keV at the high voltage 35 kV. The crystal angles are selected in such a way that the bremsstrahlung and not the characteristic lines are reflected by the crystal. Otherwise the much larger intensity in the characteristic line can considerably falsify the intensity ratio of various orders of diffraction.

### Carrying out the experiment

☐ Load settings

- Connect the table-top power supply to the mains (after approx. 2 min the LED will glow green and the x-ray energy detector will be ready for use)
- Set the tube high voltage U = 35 kV, emission current I = 1.00 mA and switch the high voltage on
- Record the calibration spectrum (start the spectrum recording with ⏱)
- Set the emission current to I = 0.40 mA
- Record the spectra for the target angles 5°, 10°, 15° and 20°

## Energy calibration

The X-rays to be measured produce additional fluorescence X-rays in the housing of the Si-PIN photodiode of the X-ray energy detector, which are also registered. In the primary spectrum therefore, in addition to the peaks of the reflected radiation, the gold (Au) and the silver (Ag) lines are also to be expected. With the help of these lines the energy calibration of the spectra can be carried out.

Through the scatter of the Cu $K_\alpha$-line of the primary spectrum of the x-ray tube, on the left-hand side a peak occurs at E=8.1 keV. The subsequent smaller peaks at E=9.7 keV, 11.4 keV and 22.2 keV have been caused by the fluorescence of the housing (Au $L_\alpha$, $L_\beta$ and Ag $K_\alpha$) and the large peak on the right-hand side is the reflected radiation (Bragg's condition).

- Select spectrum $N_1$ (4.5°)
- Open in the Settings EA (right mouse button) the Energy calibration, select **Global for all spectra of this input** and enter on the right-hand side the energies of the Au $L_\alpha$-line (9.71 keV) and of the Ag $K_\alpha$-line (22.16 keV).
- In the context menu of the diagram select Calculate peak center, mark the Au $L_\alpha$-line and enter the result in the left-hand side of the Energy calibration (e.g. with drag & drop from the status line)
- Then determine the centre for the Ag $K_\alpha$-line and also enter it on the left-hand side.
- Switch the display to energy (e.g. with Drag & Drop of $E_A$ into the diagram)

## Remark

In order to excite the silver K-lines in the housing material, the energy of the reflected radiation must exceed the K-edge of silver (25.52 keV). For this reason the energy calibration is carried out on the spectrum for α=4.5°.

## Evaluation

For confirmation that the remaining peaks associated with the various orders of diffraction belong to the same set of lattice planes, the ratios of the peak energies must be analysed.

For the determination of the peak energies as a function of the scatter angle

- Select energy spectrum (5°, 10°, 15° and 20°).
- In the context menu of the diagram select Calculate peak centre and mark the desired peak
- Read the determined peak positions from the status line and enter as $E_n$=1, $E_n$=2, $E_n$=3 or $E_n$=4 together with the angle α into the **Energy** diagram (click with mouse) (e.g. by drag & drop from the status line)

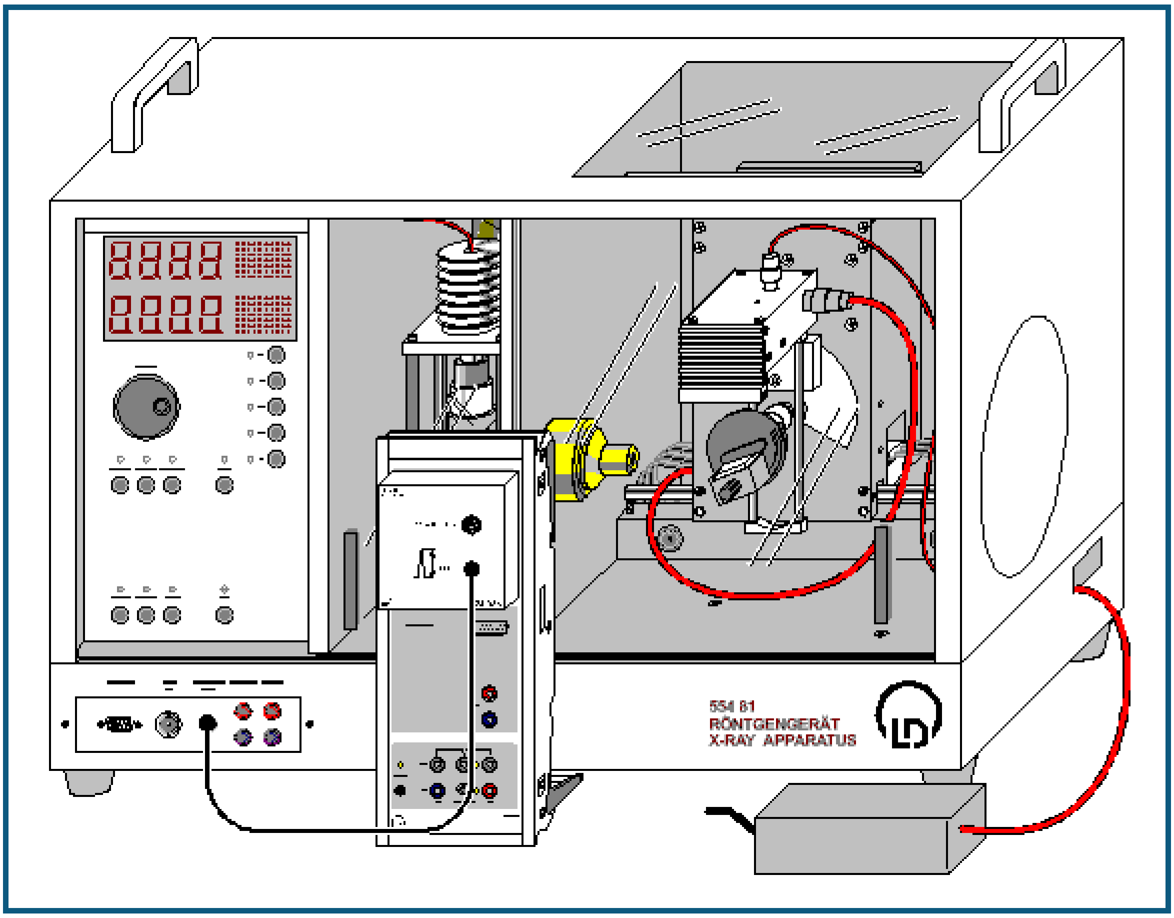
In the **Order** diagram a table is formed in which the ratios $E_n/E_1$ of the radiation energy in the order of diffraction n with the first order radiation energy are given. They have approximately integer values which confirms the assumption that they belong to different orders of diffraction from the same set of lattice planes.

In the **Lattice plane spacing** diagram the lattice plane spacing d was calculated for each crystal angle from the determined values $E_n/n$. It becomes apparent that the diffraction for all angles was observed from the same set of lattice planes with a spacing of d ≈ 280 pm. By comparing with the data given in the literature for NaCl (grid constant 564 pm) it becomes apparent that this is the diffraction from the (200) lattice planes (d = 282 pm).

## Additional information

For a Bragg spectrum recorded using a Geiger-Müller counter as the detector, the photons which are reflected in the various orders of diffraction are counted together. A spectrum recorded in this way is therefore a combination of several components which cannot easily be separated. In the 20° spectrum it is particularly clear how incorrect the statement about the intensity of radiation would be if only the first order of diffraction were taken into account and the existence of higher orders of diffraction were ignored.

## Compton effect on X-rays



can also be carried out with Pocket-CASSY

### Safety notes

The X-ray apparatus fulfils all regulations on the design of an X-ray apparatus and fully protected device for instructional use and is type approved for school use in Germany (BfS 05/07 V/Sch RöV or NW 807 / 97 Rö).

The built-in protective and shielding fixtures reduce the dose rate outside the X-ray apparatus to less than 1 µSv/h, which is of the order of magnitude of the natural background radiation.

- Before putting the X-ray apparatus into operation, inspect it for damage and check whether the voltage is switched off when the sliding doors are opened (See instruction sheet of the X-ray apparatus).
- Protect the X-ray apparatus against access by unauthorized persons.

Avoid overheating of the anode in the X-ray tube.

- When switching the X-ray apparatus on, check whether the ventilator in the tube chamber starts rotating.

The goniometer is positioned solely by means of electric stepper motors.

- Do not block the target arm and the sensor arm of the goniometer and do not use force to move them.

### Experiment description

When X-rays pass through matter, part of them is scattered. According to classical physics, the frequency of the radiation should not be changed by the scattering process. However, in 1923 the American physicist A.H. Compton observed that the frequency was reduced in some of the scattered X-rays.

In order to explain this phenomenon, the entire scattering process has to be treated in terms of quantum physics, and the X-rays have to be considered, for example, according to the particle aspect. Moreover, it is assumed that the scattering electron are free, which is a good approximation for the outer atomic electron shells at energies in the range of X-rays. Thus, in a scattering process, a photon with the frequency $\lambda_1$, i.e. with the energy $E_1 = h\cdot\lambda_1$, hits a free electron at rest with the rest mass $m_0$. The photon is scattered by the angle $\vartheta$.

Assuming energy and momentum conservation, Compton calculated the energy $E_2$ of the scattered radiation and obtained

$$E_2 = E_1 \Big/ \left( 1 + \frac{E_1}{m_0 c^2} \left( 1 - \cos \vartheta \right) \right).$$

In the experiment, Compton's investigations are repeated on a scattering body made of acrylic glass. The results are compared with the above equation. The spectrum is recorded by means of the X-ray energy detector.

### Equipment list

| | | |
|---|---|---|
| 1 | Sensor-CASSY | 524 010 or 524 013 |
| 1 | CASSY Lab 2 | 524 220 |
| 1 | MCA box | 524 058 |
| 1 | X-ray apparatus with x-ray tube Mo | 554 801 or 554 811 |
| 1 | Compton accessory X-ray II | 554 8371 or 554 837 |
| 1 | X-ray energy detector | 559 938 |
| 1 | HF cable, 1 m | 501 02 |
| 1 | PC with Windows XP/Vista/7 | |

### Experiment setup (see drawing)

- Put the Zr filter (from the scope of delivery of the X-ray apparatus) onto the beam entrance side of the circular collimator (from the scope of delivery of the Compton accessory X-ray II)
- Mount the circular collimator in the collimator mount of the X-ray apparatus
- Guide the connection cable for the table-top power supply through the empty channel of the x-ray apparatus and connect it to the mini-DIN socket of the x-ray energy detector.
- Secure the sensor holder with the mounted x-ray energy detector in the goniometer sensor arm
- Connect the signal output of the x-ray energy detector to the BNC socket SIGNAL IN of the x-ray apparatus by means of the BNC cable included
- Feed enough connection cable through to make complete movement of the sensor arm possible
- Press the SENSOR key and, using the ADJUST knob, adjust a sensor angle of 150° manually. If necessary, push the goniometer to the right
- Adjust the distance between the X-ray energy detector and the axis of rotation so that the detector housing just does not cover the X-ray beam at this sensor angle
- Then push the goniometer to the left so that the detector housing just does not touch the circular collimator (approx. 8 cm distance between the circular collimator and the axis of rotation)
- Connect Sensor-CASSY to the computer and connect the MCA box
- Connect the SIGNAL OUT output in the connection panel of the x-ray apparatus to the MCA box by means of the BNC cable.

### Experiment preparation

☐ Load settings
- Connect the table-top power supply to the mains (after approx. 2 min the LED will glow green and the x-ray energy detector will be ready for use)

For an accurate measurement of the small energy shifts, it has to be taken into account that the calibration of the X-ray energy detector undergoes a slight shift at high counting rates. Therefore it is sensible to restrict the counting rates to 200 /s.

Estimating the counting rate in the scattering arrangement:

- Put the acrylic glass scattering body on the target stage, and clamp it
- Press the TARGET pushbutton, and, using the ADJUST knob, adjust the target angle manually to 20°
- Set the tube high voltage U = 35 kV, emission current I = 1.00 mA and switch the high voltage on
- Start the spectrum recording with ⏱
- Vary the sensor angle slowly between 150° and 30° each time reading the total counting rate above on the right in the CASSY Lab window
- Reduce the emission current if the total counting rate clearly exceeds 200 /s

Adjusting the counting rate of the primary beam:

- Remove the target holder with the target stage, and take the sensor into the 0° position
- Put the absorption screen onto the circular collimator, and align it carefully (the screws should point upwards and downwards, respectively)
- Reduce the emission current to 0.1 mA, and switch the high voltage on

- Start the spectrum recording with ⏱
- In steps of 0.1° look for the sensor angle at which the total counting rate is only slightly greater than the counting rates measured in the scattering arrangement (if necessary, change the emission current slightly)

If no or only a small counting rate is measured:

- Check the alignment of the absorption screen (with the screws pointing upwards and downwards, you may try to turn the screen by 180°)

### Carrying out the experiment

The X-rays to be measured produce additional fluorescence X-rays in the housing of the Si-PIN photodiode of the X-ray energy detector, which are also registered. Therefore the Au $L_\alpha$ and the Au $L_\beta$ lines are to be expected in the primary spectrum apart from the Mo $K_\alpha$- and the Mo $K_\beta$ lines. With the help of these lines the energy calibration of the spectra can be carried out.

▨ Load settings

- Record the primary spectrum (0° position) with ⏱
- Open in the Settings EA (right mouse button) the Energy calibration, select **Global for all spectra of this input** and enter on the right-hand side the energies of the Au $L_\alpha$-line (9.72 keV) and of the Mo $K_\alpha$-line (17.48 keV).
- In the context menu of the diagram select Calculate peak center, mark the Au $L_\alpha$-line (small peak on the left had side of the Au $L_\beta$ line, which is also small) and enter the result in the left-hand side of the Energy calibration (e.g. with drag & drop from the status line)
- Then determine the peak center of the Mo $K_\alpha$-line (high peak) and also enter the result on the left-hand side
- Switch the display to energy (e.g. with Drag & Drop of $E_A$ into the diagram)
- Remove the absorption screen
- Mount the target holder with the target stage on the goniometer
- Put the acrylic glass scattering body on the target stage, and clamp it
- Adjust the emission current I = 1.00 mA (or the emission current determined previously for estimating the counting rate), and switch the high voltage on
- Adjust a target angle of 20° and a sensor angle of 30°
- Record a new spectrum (30° position) with ⏱
- Then record further spectra at constant target angle for the sensor angles 60°, 90°, 120° and 150°

### Evaluation

The energy of the scattered radiation decreases with increasing scattering angle. The intensity of the scattered radiation takes its minimum at $\vartheta = 90°$.

For further evaluation, you can zoom in on the region around the scattered peak and select Calculate Peak Center for each energy-shifted peak. Starting from a scattering angle of $\vartheta = 90°$, the energy resolution of the detector is sufficient for separating the unshifted peak (elastic scattering from strongly bound electrons) and the shifted peak (inelastic scattering from quasi-free electrons). For the determination of the peak center, only the region of the energy-shifted peak should be marked.

For each peak center, the energy is entered in the **Evaluation** display together with the corresponding scattering angle. The energy can be taken from the status line into the table using the mouse (drag & drop). The angle has to be entered manually in the table.

For a comparison of the measured energies with the energies calculated from energy and momentum conservation, a free fit of the equation

17.48/(1+17.48*(1-cos(x))/A)

can be selected in the **Evaluation** display with the starting value A = 511 (=constant).

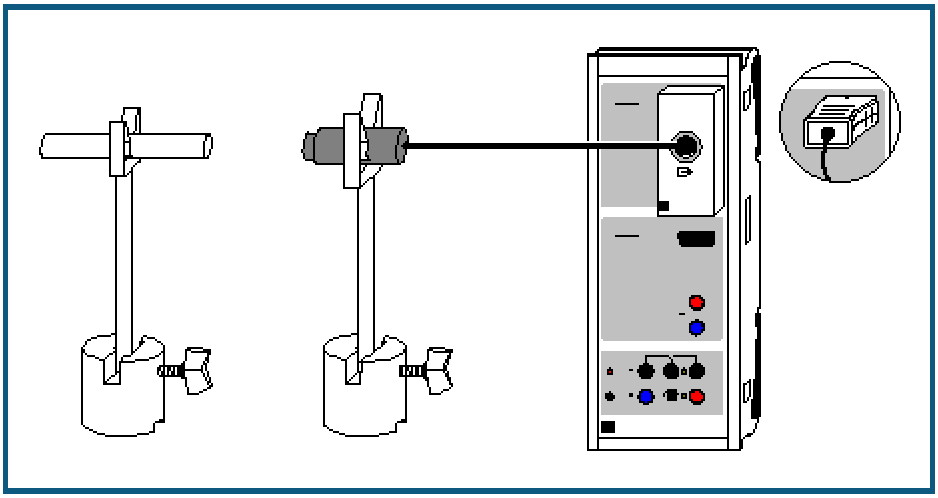
The result corresponds to the theoretical curve with the parameters $E_1 = 17.48$ keV and $m_0 \cdot c^2 = 511$ keV, which is in good agreement with the measured values.

When X-rays pass through matter, part of them is scattered and experiences an energy shift (Compton effect). The energy shift can be calculated by describing the scattering process as a collision between an X-ray photon and a free electron at rest and by postulating the conservation of energy and momentum in this process.

### Remark

Alternatively, the comparison between measurement and theory can be carried out as a free fit with the free fit parameter A (the rest mass of the collision partner of the X-ray photon). As a result a value for the parameter A is obtained, which agrees with the "rest mass" of an electron ($m_0 \cdot c^2 = 511$ keV) to a good approximation.

## Poisson distribution



can also be carried out with Pocket-CASSY

### Experiment description

The number x of decay events of a radioactive preparation over a time interval Γt is not constant. A large number of individual measurements can be represented as a frequency distribution H(x) scattered around the mean value κ. By comparing this frequency distribution with the Poisson distribution, we can confirm that x shows a Poisson distribution around the mean value κ.

### Equipment list

| | | |
|---|---|---|
| 1 | Sensor-CASSY | 524 010 or 524 013 |
| 1 | CASSY Lab 2 | 524 220 |
| 1 | GM box | 524 033 |
| | with End-window counter | 559 01 |
| | or | |
| 1 | GM counter tube S | 524 0331 |
| 1 | Set of radioactive preparations | 559 83 |
| 1 | Large clip plug | 591 21 |
| 1 | Small clip plug | 590 02 |
| 2 | Connection rods | 532 16 |
| 2 | Saddle bases | 300 11 |
| 1 | PC with Windows XP/Vista/7 | |

### Experiment setup (see drawing)

The end-window counter is connected to the GM box at input A of Sensor-CASSY. Handle the counter tube and the preparation with care.

### Carrying out the experiment

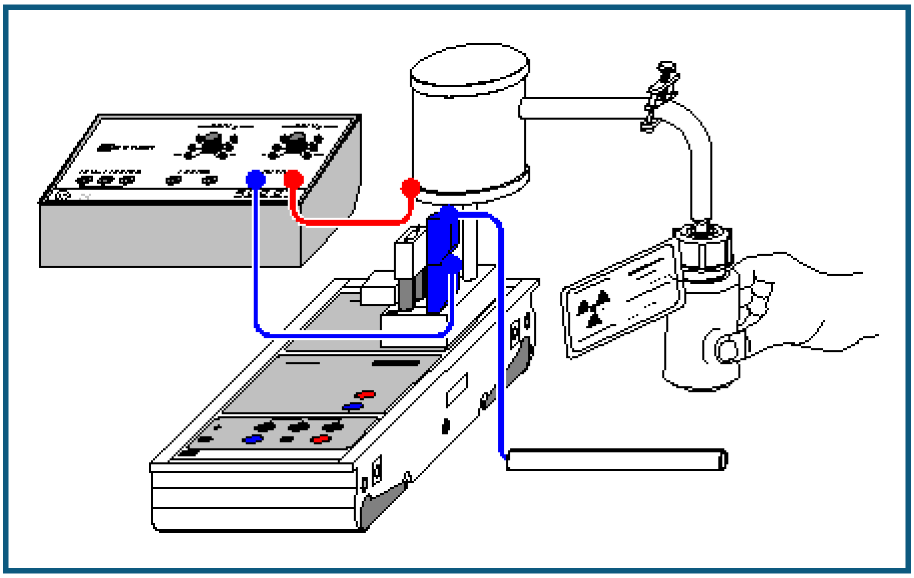
☐ Load settings

- If necessary, modify the gate time Γt (Settings RA1).
- Preset the measurement if necessary. Enter the number of measurements as the stop condition of the Measuring Parameters (**Window → Show Measuring Parameters**, e.g. **n > 1000** for 1000 individual measurements).
- Start the measurement series with ⏱, and stop it again with ⏱ after recording the series.

### Evaluation

In the evaluation, you can compare the measured frequency distribution with a Poisson distribution. For higher mean values κ the Poisson distribution develops into a Gaussian distribution.

## Half-life of radon



can also be carried out with Pocket-CASSY and Mobile-CASSY

### Experiment description

From the fact that all radioactive nuclei of an isotope decay with the same probability, it follows that over the time interval dt, the number N of radioactive nuclei will decrease by

$dN = - \imath \cdot N \cdot dt$

($\imath$ : decay constant). Thus, for the number N, the law of radioactive decay applies:

$N(t) = N(t=0) \cdot e^{-\imath \cdot t}$.

Among other things, this law states that after the half-life

$t½ = \ln 2 / \imath$

the number of radioactive nuclei will be reduced by half.

To determine the half-life of radon 220 (Rn-220), a plastic bottle with thorium salt is sealed in an ionization chamber, and the inert gas radon, which is formed in the course of the decay sequence of natural thorium, is pumped into the chamber by squeezing the bottle. This gas contains the isotope Rn-220, which has a half-life of about 55 s. The half-lives of other radon isotopes differ greatly from this value, and can thus be ignored in these experiments.

This experiment measures the curve over time of the ionization current proportional to the radioactivity of the gas. Here, the electrometer box in high-ohm configuration serves as a highly sensitive ammeter.

### Equipment list

| | | |
|---|---|---|
| 1 | Sensor-CASSY | 524 010 or 524 013 |
| 1 | CASSY Lab 2 | 524 220 |
| 1 | Electrometer box | 524 054 |
| 1 | Ionization chamber | 546 25 |
| 1 | Thorium source | 546 36 (no longer available) |
| 1 | Power supply 450 V DC | 522 27 |
| 1 | STE resistor 10 GΩ | 577 03 |
| 1 | STE capacitor 100 pF | 578 22 |
| 2 | Clamping plugs | 590 011 |
| 1 | Coupling plugs | from 340 89ET5 |
| 2 | Connection rods | 532 16 |
| 1 | Set of bridging plugs | 501 48 |
| 1 | Connecting lead, 50 cm, blue | 500 422 |
| 1 | Pair of cables, 100 cm, red and blue | 501 46 |
| 1 | PC with Windows XP/Vista/7 | |

### Experiment setup (see drawing)

Set up the experiment directly on the electrometer box at Sensor-CASSY input A. Plug in the ionization chamber at the top right socket of the box using the coupling plug and the connection rod; jumper the two top left sockets with a bridging plug, and connect the 10 GΩ measuring resistor and the 100 pF smoothing capacitor to the bottom left sockets (use clamping plugs to attach these two components).

The remaining ground socket of the electrometer box is used to ground the experimenter (who holds a grounded connection rod during the experiment) to minimize external influences on this sensitive measurement.

### Carrying out the experiment

■ Load settings
- If necessary, correct the offset of the electrometer box - ground the connection rod of the ionization chamber, select **Correct** in Settings UA1, enter the first target value 0 V and click **Correct Offset**.
- Apply a voltage of 450 V between the ground of the electrometer box and the cylinder of the ionization chamber.
- Squeeze the thorium source several times to charge the ionization chamber with radon 220.
- After a short settling pause, start the measurement with ⏱ (the measurement stops automatically after 180 s).

### Evaluation

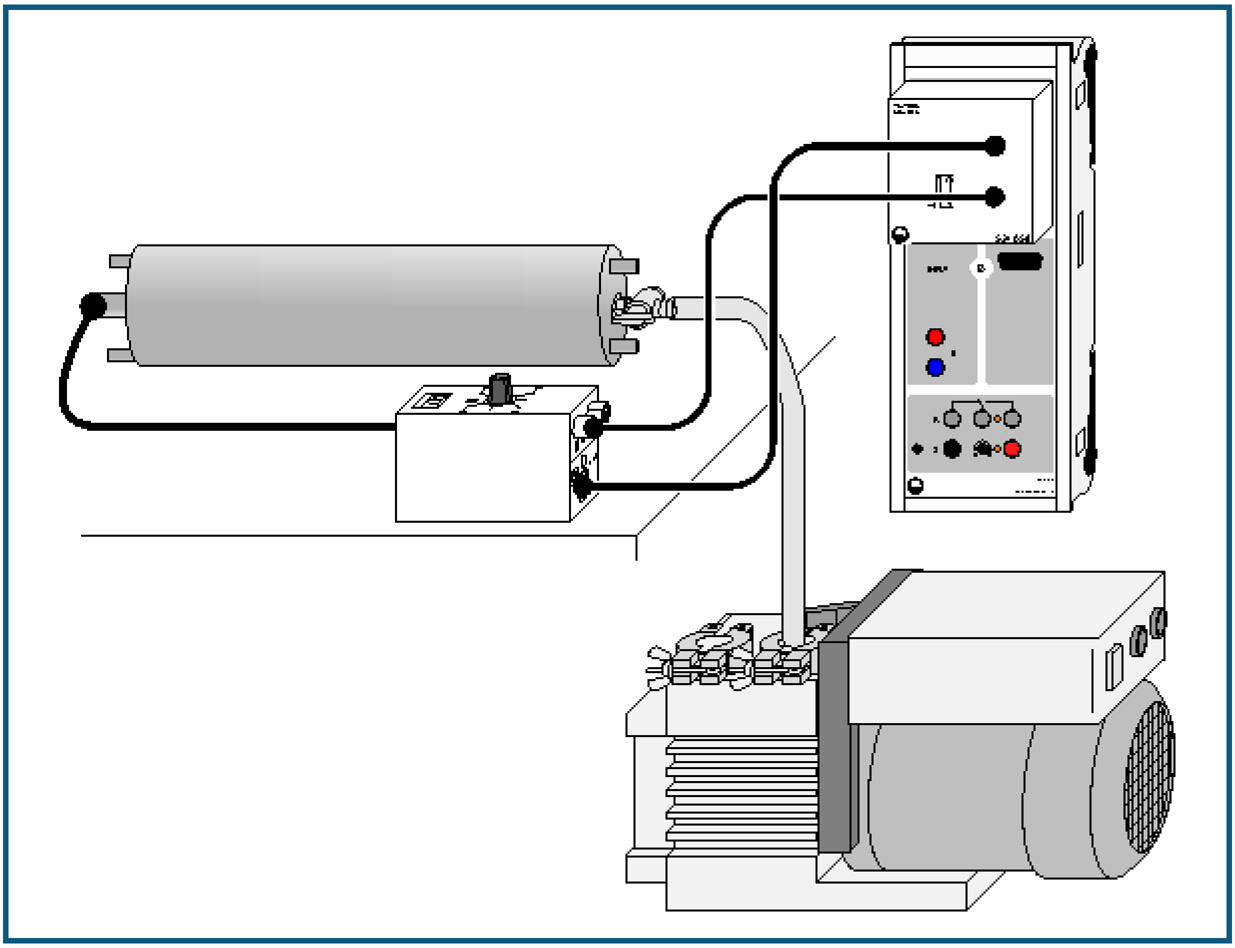
You can determine the half-life in one of several ways. You can graphically illustrate and read off the half-life by marking your diagram with horizontal and vertical lines.

Fitting an exponential function to the I(t) curve gives us the inverse of the decay constant ı as parameter B of this operation. The half-life is thus t½ = ln2·B = 0.693·B.

Parameter A of a best-fit straight line of the logarithmic display (press the right mouse button over the y-axis to select logarithmic display) gives us a half-life of t½ = –log2/A = –0.301/A.

This example gives us the literature value t½ = 55.6 s.

## α spectroscopy of radioactive samples (Am-241)



✓ can also be carried out with Pocket-CASSY

**Safety note**

When handling radioactive preparations, in addition to the radiation protection regulations, state-specific requirements and the regulations of the educational authorities are also to be observed, e.g. in the Federal Republic of Germany at the very least the radiation protection regulations (StrlSchV - Strahlenschutzverordnung) and the directives on safety during school lessons. This applies even in cases where the preparation used in this experiment in itself does not require the nomination of a trained radiation officer.

Since the used preparations produce ionizing radiation, the following safety rules must nevertheless be kept to:

- Prevent access to the preparations by **unauthorized persons**.
- Before using the reparations make sure that they are **intact**.
- For the purpose of **shielding**, keep the preparations in their safety container.
- To ensure **minimum exposure time** and **minimum activity**, take the preparations out of the safety container only as long as is necessary for carrying out the experiment.
- To ensure **maximum distance**, hold the preparations only at the upper end of the metal holder.

### Experiment description

The α spectrum of the Am-241 preparation is recorded, and an energy calibration is carried out with known lines.

### Equipment list

| | | |
|---|---|---|
| 1 | Sensor-CASSY | 524 010 or 524 013 |
| 1 | CASSY Lab 2 | 524 220 |
| 1 | MCA box | 524 058 |
| 1 | Am-241 preparation | 559 825 |
| 1 | Alpha spectroscopy chamber | 559 565 |
| 1 | Semiconductor detector | 559 921 |

| | | |
|---|---|---|
| 1 | Discriminator preamplifier | 559 931 |
| 1 | Multicore cable, 6-pole, 1.5 m | 501 16 |
| 1 | HF cable, 1 m | 501 02 |
| 1 | HF cable, 0.25 m | 501 01 |
| 1 | Rotary-vane vacuum pump | 378 73 |
| 1 | T-piece DN 16 KF | 378 005 |
| 1 | Centering ring DN 10/16 KF | from 378 040ET2 |
| 1 | Air inlet valve DN 10 KF | 378 771 |
| 1 | Set of centering rings DN 16 KF | 378 045ET2 |
| 2 | Clamping rings DN 10/16 KF | 378 050 |
| 1 | Small flange DN 16 KF with hose nozzle | 378 031 |
| 1 | Vacuum tubing, 8/18 mm dia. | 667 186 |
| 1 | PC with Windows XP/Vista/7 | |

additionally recommended:

| | | |
|---|---|---|
| 1 | Two-channel oscilloscope 400 | 575 212 |

### Experiment setup (see drawing)

The preparation and the detector are placed in the alpha spectroscopy chamber. The detector is connected to the discriminator-preamplifier via the short BNC cable. The discriminator-preamplifier is connected to the MCA box. The pump is connected to the alpha spectroscopy chamber.

### Carrying out the experiment

■ Load settings
- Evacuate the alpha spectroscopy chamber.
- Start the measurement with ⏱.
- Vary the gain of the MCA box until the spectrum covers all available channels. This typically occurs at gains around -3.
- After every change of the gain the measured spectrum should be deleted with 🗋 to avoid mixing of different spectra. The measurement goes on then, and the measuring time is restarted.
- When the set measuring time is over, the measurement is stopped.

### Evaluation

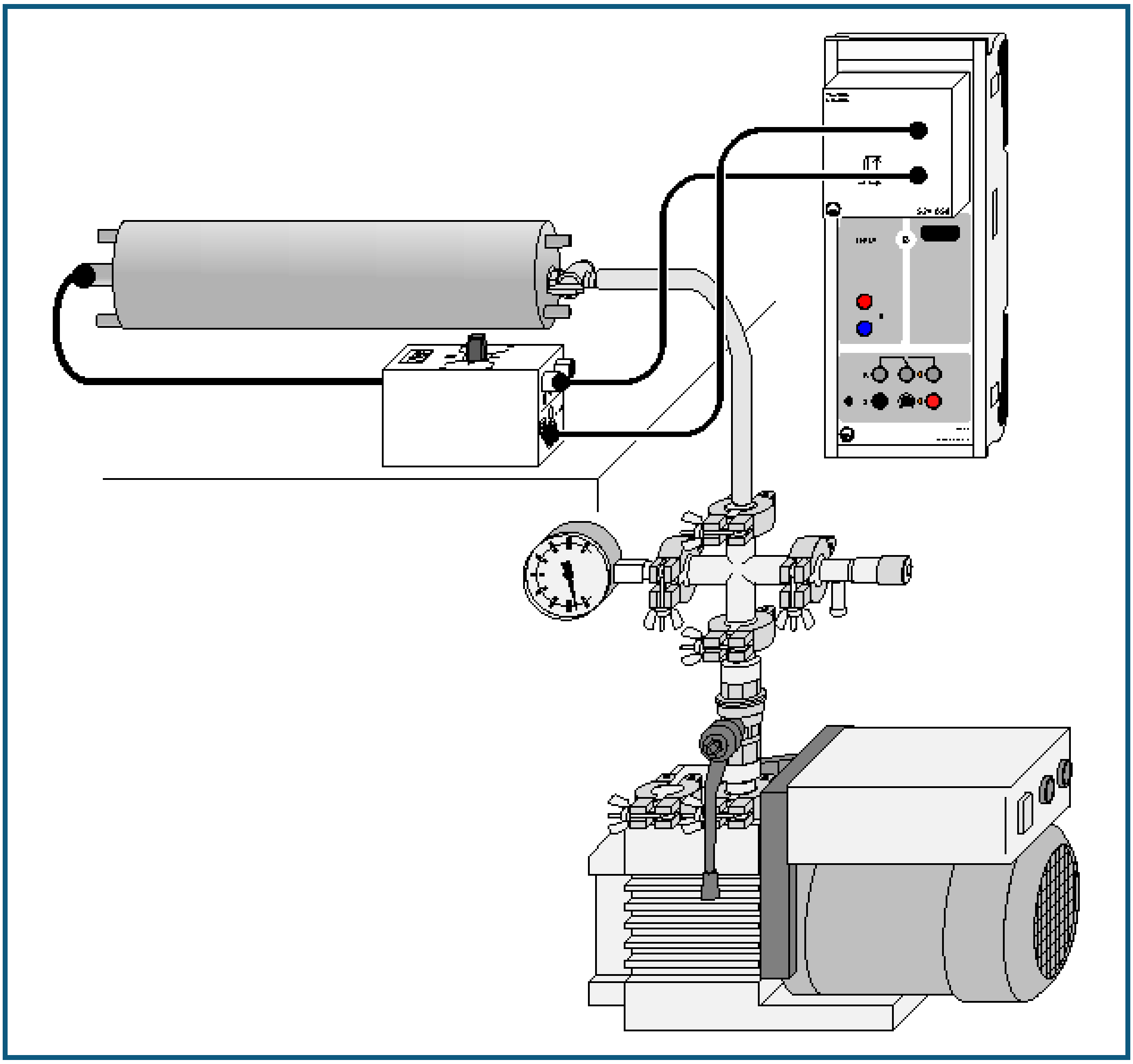
The isotope Am-241 decays into Np-237 by emitting an α particle. As several excited states of neptunium are available, α particles of different energies are emitted in this decay. In 100 decays, 84 α particles with an energy of 5486 keV are emitted and 13 with an energy of 5443 keV. The energy difference between the two decay events is small but it can be resolved in the measurement if an open preparation without covering (e.g. 559 825) and the discriminator preamplifier (559 931) are used. A covered preparation such as 559 821 blurs the α-energies excessively when they pass through the covering.

After the measurement the spectrum is not yet calibrated. An energy calibration has to be carried out in order to display it as an energy spectrum. When using open americium (559 825), a single-point calibration can be carried out making use of one of the americium spectrum lines. In the case of covered preparations, it is appropriate to use two lines in the Ra-226 (559 435) spectrum for the calibration. An energy calibration using only a covered americium (559 821) preparation is not sensible.

### Remark

Due to the cover of the preparations (e.g. 559 821), there is a strong offset in energy. The measured spectrum starts only at an energy of 1-2 MeV. Particles with lower energy are stopped before reaching the detector.

## Determining the energy loss of α radiation in air (Am-241)



can also be carried out with Pocket-CASSY

**Safety note**

When handling radioactive preparations, in addition to the radiation protection regulations, state-specific requirements and the regulations of the educational authorities are also to be observed, e.g. in the Federal Republic of Germany at the very least the radiation protection regulations (StrlSchV - Strahlenschutzverordnung) and the directives on safety during school lessons. This applies even in cases where the preparation used in this experiment in itself does not require the nomination of a trained radiation officer.

Since the used preparations produce ionizing radiation, the following safety rules must nevertheless be kept to:

- Prevent access to the preparations by **unauthorized persons**.
- Before using the reparations make sure that they are **intact**.
- For the purpose of **shielding**, keep the preparations in their safety container.
- To ensure **minimum exposure time** and **minimum activity**, take the preparations out of the safety container only as long as is necessary for carrying out the experiment.
- To ensure **maximum distance**, hold the preparations only at the upper end of the metal holder.

### Experiment description

The energy loss of the α radiation from the Am-241 sample is measured in the spectroscopy chamber in dependence on the air pressure. From this the energy loss at normal pressure is calculated as a function of the distance. The range of the α radiation in air is obtained.

### Equipment list

| | | |
|---|---|---|
| 1 | Sensor-CASSY | 524 010 or 524 013 |
| 1 | CASSY Lab 2 | 524 220 |
| 1 | MCA box | 524 058 |
| 1 | Am-241 preparation | 559 825 |
| 1 | Alpha spectroscopy chamber | 559 565 |
| 1 | Semiconductor detector | 559 921 |
| 1 | Discriminator preamplifier | 559 931 |
| 1 | Multicore cable, 6-pole, 1.5 m | 501 16 |
| 1 | HF cable, 1 m | 501 02 |
| 1 | HF cable, 0.25 m | 501 01 |
| 1 | Rotary-vane vacuum pump | 378 73 |
| 1 | Small flange DN 16 KF | 378 031 |
| 1 | Vacuum tubing, 8/18 mm dia. | 307 68 |
| 1 | Cross DN 16 KF | 378 015 |
| 1 | Variable leak valve DN 16 KF | 378 776 |
| 1 | Pointer manometer | 378 510 |
| 2 | Sets of centering rings DN 16 KF | 378 045ET2 |
| 4 | Clamping rings DN 10/16 KF | 378 050 |
| 1 | PC with Windows XP/Vista/7 | |

### Experiment setup (see drawing)

The preparation and the detector are placed in the spectroscopy chamber. The detector is connected to the discriminator-preamplifier via the short BNC cable. The discriminator-preamplifier is connected to the MCA box. The pump and the vacuum meter are connected to the spectroscopy chamber.

### Carrying out the experiment

☐ Load settings

- After inserting the preparation and the detector, cautiously evacuate the spectroscopy chamber.
- When the vacuum is established, record the spectrum with ⏱ varying the gain until the Am-241 line is approximately in the middle of the spectrum. This typically occurs at gains around -3.
- Calibrate the energy
- Open the variable leak valve until the pressure in the vacuum chamber is approx. 100 mbar. Record another spectrum.
- Increase the pressure in the vacuum chamber in steps of about 100 mbar. Record an α spectrum at each pressure.

### Evaluation

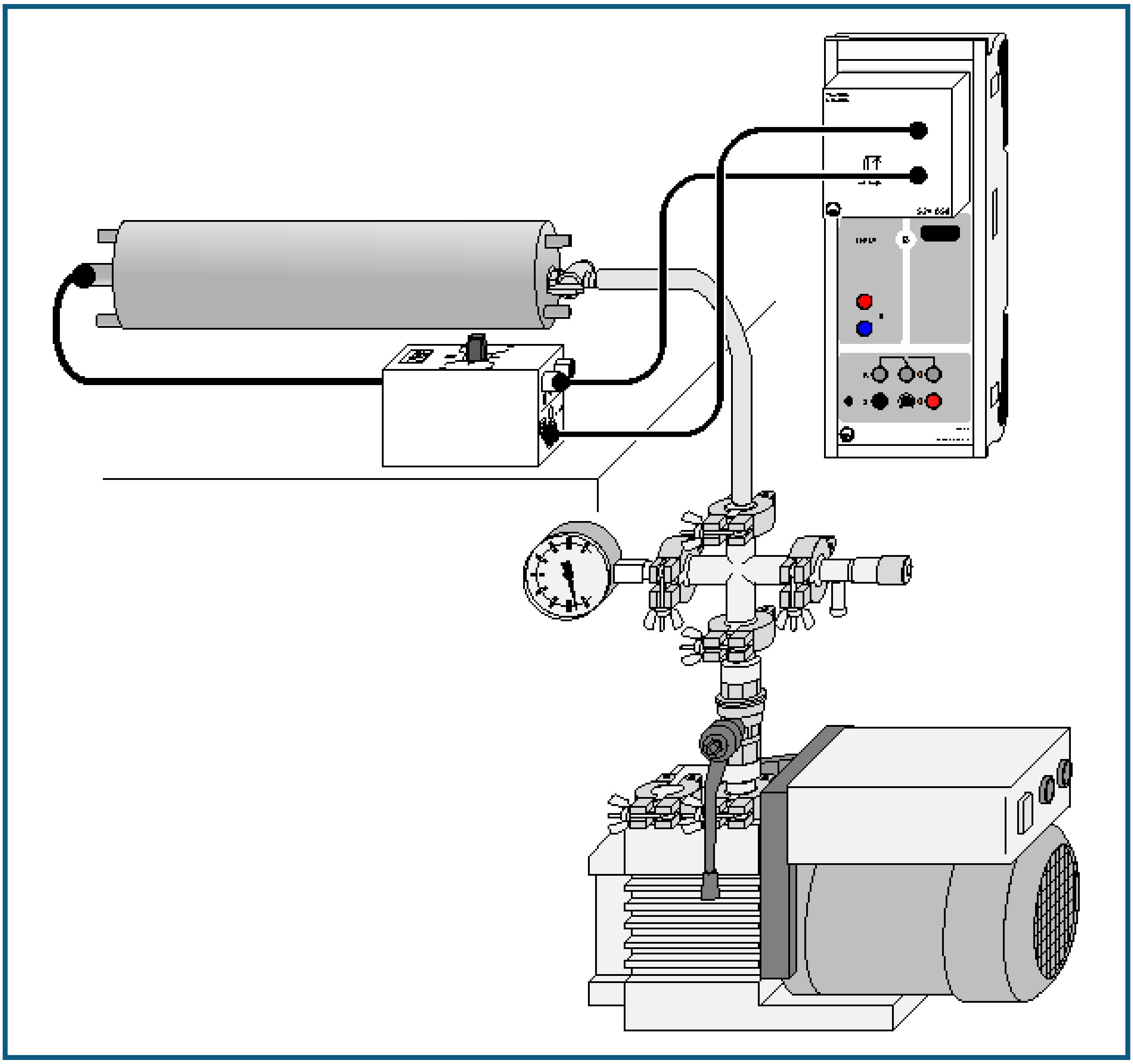
The energy of the α line is determined from the individual spectra. The air pressure is converted into an effective path in air at normal pressure. From the representation of the energy as a function of the effective path in air the range of the α radiation in air is read.

### Remarks

The range in air can, of course, also be measured directly without using the spectroscopy chamber. It can be determined by varying the distance. In this case, however, the setup requires some improvisation with respect to fixing the preparation. The detector can be attached to the discriminator-preamplifier directly. In this case, it provides stronger pulses as in the spectroscopy chamber as the load of the capacitance of the BNC cable is missing.

Due to the cover of the preparations (e.g. 559 821), there is a strong offset in energy. The measured spectrum starts only at an energy of 1-2 MeV. Particles with lower energy are stopped before reaching the detector.

# Determining the energy loss of α radiation in air (Ra-226)



can also be carried out with Pocket-CASSY

## Safety note

When handling radioactive preparations, in addition to the radiation protection regulations, state-specific requirements and the regulations of the educational authorities are also to be observed, e.g. in the Federal Republic of Germany at the very least the radiation protection regulations (StrlSchV - Strahlenschutzverordnung) and the directives on safety during school lessons. This applies even in cases where the preparation used in this experiment in itself does not require the nomination of a trained radiation officer.

Since the used preparations produce ionizing radiation, the following safety rules must nevertheless be kept to:

- Prevent access to the preparations by **unauthorized persons**.
- Before using the reparations make sure that they are **intact**.
- For the purpose of **shielding**, keep the preparations in their safety container.
- To ensure **minimum exposure time** and **minimum activity**, take the preparations out of the safety container only as long as is necessary for carrying out the experiment.
- To ensure **maximum distance**, hold the preparations only at the upper end of the metal holder.

### Experiment description

The energy loss of the α radiation from the Ra-226 sample is measured in the spectroscopy chamber in dependence on the air pressure. From this the energy loss at normal pressure is calculated as a function of the distance. The range of the α radiation in air for different energies is obtained.

### Equipment list

| | | |
|---|---|---|
| 1 | Sensor-CASSY | 524 010 or 524 013 |
| 1 | CASSY Lab 2 | 524 220 |
| 1 | MCA box | 524 058 |
| 1 | Ra-226 preparation | 559 435 |
| 1 | Alpha spectroscopy chamber | 559 565 |
| 1 | Semiconductor detector | 559 921 |
| 1 | Discriminator preamplifier | 559 931 |
| 1 | Multicore cable, 6-pole, 1.5 m | 501 16 |
| 1 | HF cable, 1 m | 501 02 |
| 1 | HF cable, 0.25 m | 501 01 |
| 1 | Rotary-vane vacuum pump | 378 73 |
| 1 | Small flange DN 16 KF | 378 031 |
| 1 | Vacuum tubing, 8/18 mm dia. | 307 68 |
| 1 | Cross DN 16 KF | 378 015 |
| 1 | Variable leak valve DN 16 KF | 378 776 |
| 1 | Pointer manometer | 378 510 |
| 2 | Sets of centering rings DN 16 KF | 378 045ET2 |
| 4 | Clamping rings DN 10/16 KF | 378 050 |
| 1 | PC with Windows XP/Vista/7 | |

### Experiment setup (see drawing)

The preparation and the detector are placed in the spectroscopy chamber. The detector is connected to the discriminator-preamplifier via the short BNC cable. The discriminator-preamplifier is connected to the MCA box. The pump and the vacuum meter are connected to the spectroscopy chamber.

### Carrying out the experiment

■ Load settings

- After inserting the preparation and the detector, cautiously evacuate the spectroscopy chamber.
- When the vacuum is established, record the spectrum with ⏱ varying the gain until the Ra-226 lines are approximately in the middle of the spectrum. This typically occurs at gains around -3.
- Calibrate the energy
- Open the variable leak valve until the pressure in the vacuum chamber is approx. 100 mbar. Record another spectrum.
- Increase the pressure in the vacuum chamber in steps of about 100 mbar. Record an α spectrum at each pressure.

### Evaluation

The energies of the α lines are determined from the individual spectra. The air pressure is converted into an effective path in air at normal pressure. From the representation of the energies as a function of the effective path in air the energy-dependent range of the α radiation in air is read.

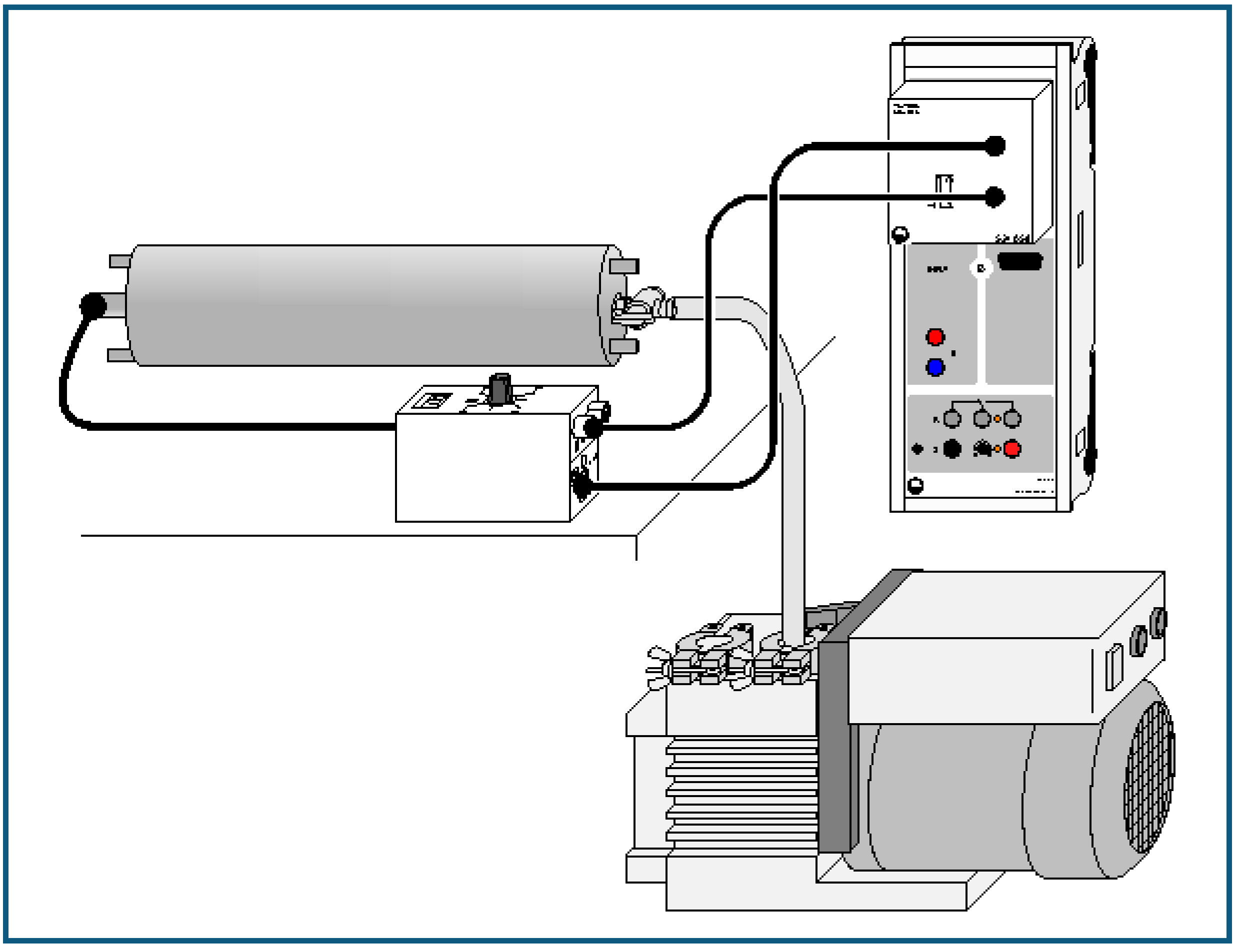
### Remarks

The range in air can, of course, also be measured directly without using the spectroscopy chamber. It can be determined by varying the distance. In this case, however, the setup requires some improvisation with respect to fixing the preparation. The detector can be attached to the discriminator-preamplifier directly. In this case, it provides stronger pulses as in the spectroscopy chamber as the load of the capacitance of the BNC cable is missing.

In measurements with the semiconductor detector, a relatively high background level arises due to the β radiation. The counting rate in the lower 100 channels is therefore rather high. The line itself is hard to see then because of the automatic scaling of the spectrum. Here a zoom should be used in the diagram. Because of the internal architecture of the MCA box working at gains from -2 to -4.6 is recommendable in this case.

Due to the cover of the preparations (e.g. 559 821), there is a strong offset in energy. The measured spectrum starts only at an energy of 1-2 MeV. Particles with lower energy are stopped before reaching the detector.

## Determining the energy loss of α radiation in aluminum and in gold



✓ can also be carried out with Pocket-CASSY

**Safety note**

When handling radioactive preparations, in addition to the radiation protection regulations, state-specific requirements and the regulations of the educational authorities are also to be observed, e.g. in the Federal Republic of Germany at the very least the radiation protection regulations (StrlSchV - Strahlenschutzverordnung) and the directives on safety during school lessons. This applies even in cases where the preparation used in this experiment in itself does not require the nomination of a trained radiation officer.

Since the used preparations produce ionizing radiation, the following safety rules must nevertheless be kept to:

- Prevent access to the preparations by **unauthorized persons**.
- Before using the reparations make sure that they are **intact**.
- For the purpose of **shielding**, keep the preparations in their safety container.
- To ensure **minimum exposure time** and **minimum activity**, take the preparations out of the safety container only as long as is necessary for carrying out the experiment.
- To ensure **maximum distance**, hold the preparations only at the upper end of the metal holder.

### Experiment description

The energy loss of α radiation in an aluminum or gold foil is determined as a function of the α energy.

### Equipment list

| | | |
|---|---|---|
| 1 | Sensor-CASSY | 524 010 or 524 013 |
| 1 | CASSY Lab 2 | 524 220 |
| 1 | MCA box | 524 058 |
| 1 | Am-241 preparation | 559 825 |
| 1 | Ra-226 preparation | 559 435 |
| 1 | Alpha spectroscopy chamber | 559 565 |

| | | |
|---|---|---|
| 1 | Gold and aluminum foil in holder | 559 521 |
| 1 | Semiconductor detector | 559 921 |
| 1 | Discriminator preamplifier | 559 931 |
| 1 | Multicore cable, 6-pole, 1.5 m | 501 16 |
| 1 | HF cable, 1 m | 501 02 |
| 1 | HF cable, 0.25 m | 501 01 |
| 1 | Rotary-vane vacuum pump | 378 73 |
| 1 | T-piece DN 16 KF | 378 005 |
| 1 | Centering ring DN 10/16 KF | from 378 040ET2 |
| 1 | Air inlet valve DN 10 KF | 378 771 |
| 1 | Set of centering rings DN 16 KF | 378 045ET2 |
| 2 | Clamping rings DN 10/16 KF | 378 050 |
| 1 | Small flange DN 16 KF with hose nozzle | 378 031 |
| 1 | Vacuum tubing, 8/18 mm dia. | 667 186 |
| 1 | PC with Windows XP/Vista/7 | |

### Experiment setup (see drawing)

The preparation and the corresponding film on the detector are mounted in the spectroscopy chamber. The detector is connected to the discriminator-preamplifier via the short BNC cable. The discriminator-preamplifier is connected to the MCA box. The pump is connected to the spectroscopy chamber.

### Carrying out the experiment

▨ Load settings
- Mount the Ra-226 preparation in the spectroscopy chamber
- Evacuate the chamber
- Record the spectrum with ⏱, and set the gain so that the spectrum is well displayed
- Use the outer lines of the spectrum for the energy calibration. When doing this, take account of the covering (literature value minus 1100 keV)
- Aerate the chamber, place the gold film (2 κm thick) onto the detector, and carefully evacuate the chamber
- Record the spectrum with the gold film
- Aerate the chamber. Be careful when doing this otherwise the gold foil can be destroyed by the pressure difference or swirling dust particles.
- Mount the aluminum film (8 κm thick), carefully evacuate the chamber, record spectrum
- Carefully aerate the chamber, mount the Am-241 preparation and repeat the measurement for the gold and the aluminum film without changing the energy calibration

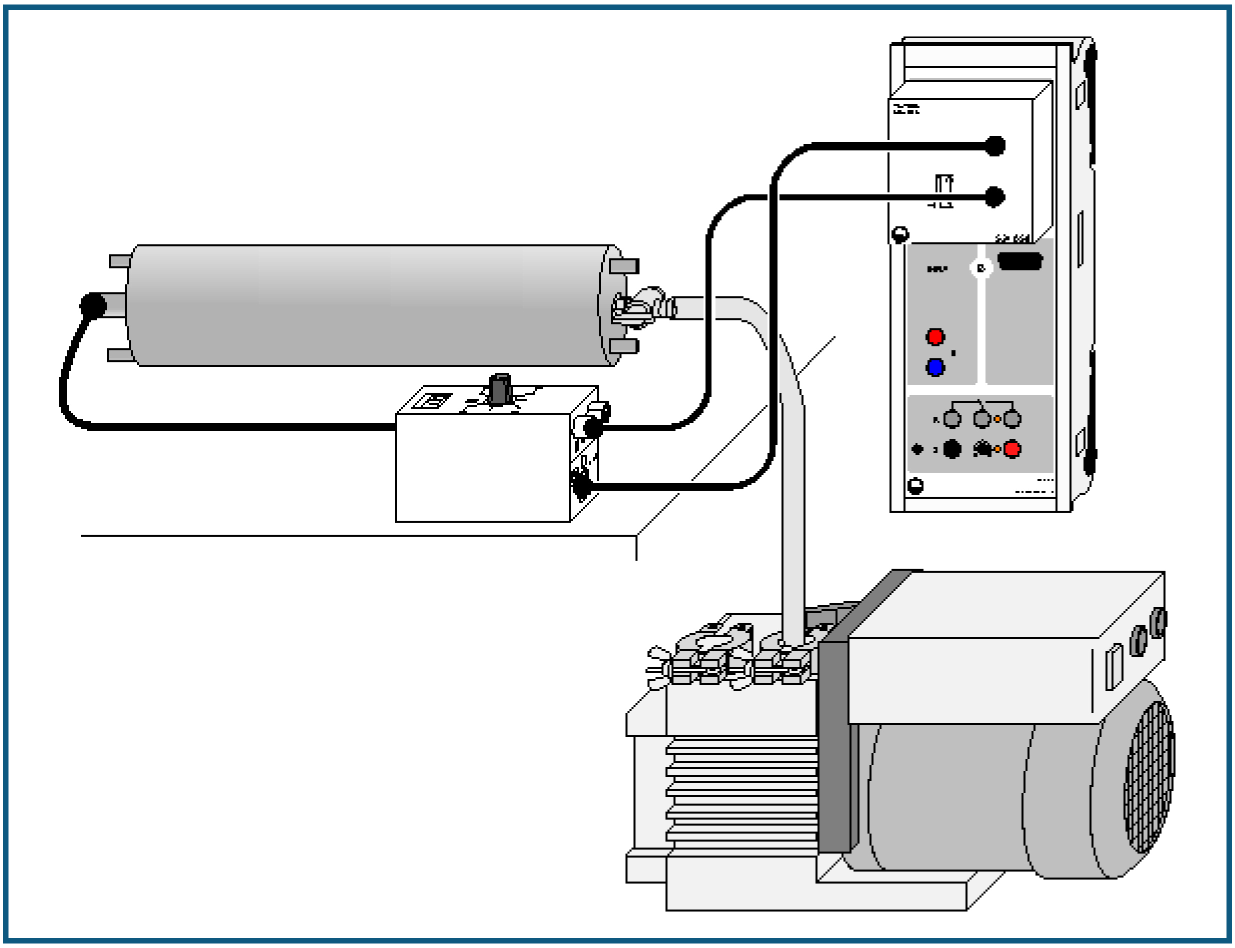
### Evaluation

From each of the spectra the energy of the lines is determined. The energy loss per path length in aluminum and gold is plotted as a function of the energy and compared with the results from the Bethe-Bloch formula.

### Remark

Due to the cover of the preparations, there is a strong offset in energy when the energy calibration is made with values taken from the literature. The measured spectrum starts only at an energy of 1-2 MeV. Particles with lower energy are stopped before reaching the detector.

## Determining the age of a Ra-226 sample



can also be carried out with Pocket-CASSY

**Safety note**

When handling radioactive preparations, in addition to the radiation protection regulations, state-specific requirements and the regulations of the educational authorities are also to be observed, e.g. in the Federal Republic of Germany at the very least the radiation protection regulations (StrlSchV - Strahlenschutzverordnung) and the directives on safety during school lessons. This applies even in cases where the preparation used in this experiment in itself does not require the nomination of a trained radiation officer.

Since the used preparations produce ionizing radiation, the following safety rules must nevertheless be kept to:

- Prevent access to the preparations by **unauthorized persons**.
- Before using the reparations make sure that they are **intact**.
- For the purpose of **shielding**, keep the preparations in their safety container.
- To ensure **minimum exposure time** and **minimum activity**, take the preparations out of the safety container only as long as is necessary for carrying out the experiment.
- To ensure **maximum distance**, hold the preparations only at the upper end of the metal holder.

### Experiment description

The relative activity of the nuclides Ra-226 and Pb-210 in a Ra-226 sample is determined and used to determine the age of the sample.

### Equipment list

| | | |
|---|---|---|
| 1 | Sensor-CASSY | 524 010 or 524 013 |
| 1 | CASSY Lab 2 | 524 220 |
| 1 | MCA box | 524 058 |
| 1 | Ra-226 preparation | 559 435 |
| 1 | Alpha spectroscopy chamber | 559 565 |

| | | |
|---|---|---|
| 1 | Semiconductor detector | 559 921 |
| 1 | Discriminator preamplifier | 559 931 |
| 1 | Multicore cable, 6-pole, 1.5 m | 501 16 |
| 1 | HF cable, 1 m | 501 02 |
| 1 | HF cable, 0.25 m | 501 01 |
| 1 | Rotary-vane vacuum pump | 378 73 |
| 1 | T-piece DN 16 KF | 378 005 |
| 1 | Centering ring DN 10/16 KF | from 378 040ET2 |
| 1 | Air inlet valve DN 10 KF | 378 771 |
| 1 | Set of centering rings DN 16 KF | 378 045ET2 |
| 2 | Clamping rings DN 10/16 KF | 378 050 |
| 1 | Small flange DN 16 KF with hose nozzle | 378 031 |
| 1 | Vacuum tubing, 8/18 mm dia. | 667 186 |
| 1 | PC with Windows XP/Vista/7 | |

### Experiment setup (see drawing)

The preparation and the detector are placed in the spectroscopy chamber. The detector is connected to the discriminator-preamplifier via the short BNC cable. The discriminator-preamplifier is connected to the MCA box. The pump is connected to the spectroscopy chamber.

### Carrying out the experiment

☐ Load settings

- Mount the Ra-226 preparation in the spectroscopy chamber
- Evacuate the chamber, and record a spectrum with ⏱
- Vary the gain of the MCA box until the spectrum covers all available channels. This typically occurs at gains around -3.
- Use the outer lines of the spectrum (4785 keV, 7687 keV) for the energy calibration

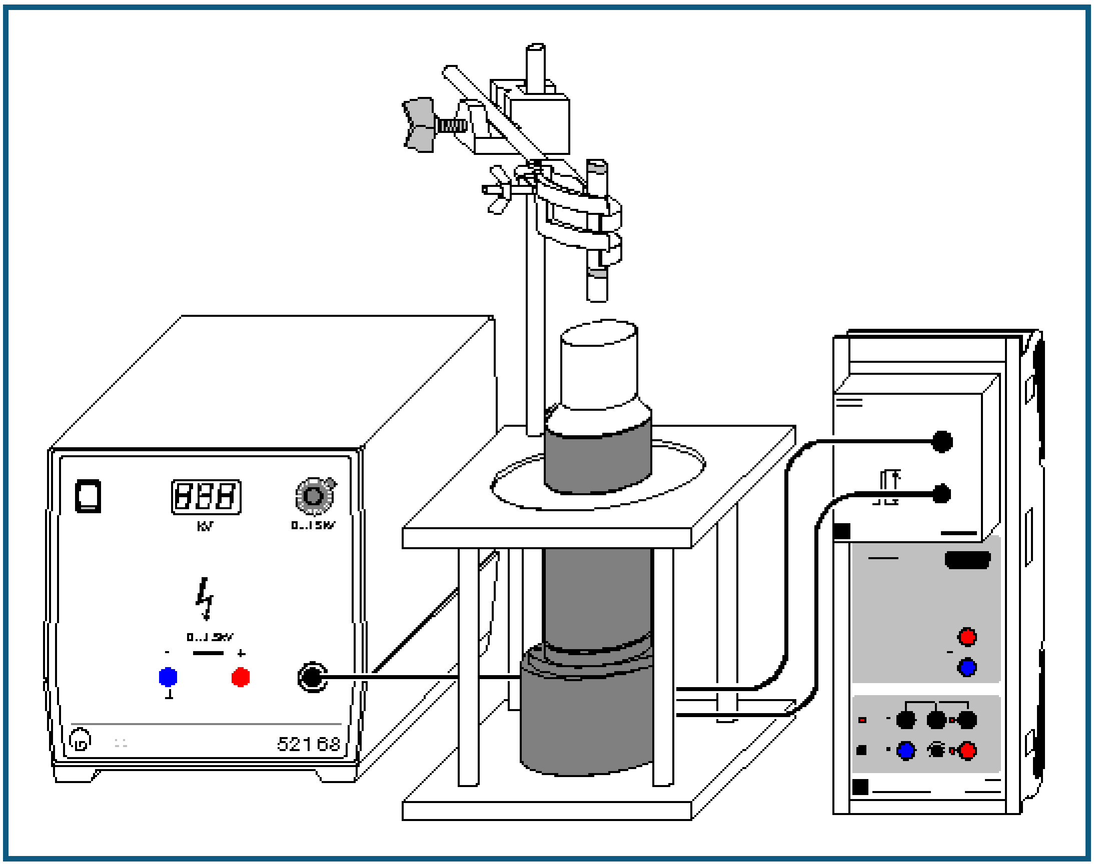
### Evaluation

The age of the preparation is calculated from the counting rates of the observed lines. The evaluation is complicated by the fact that the α energies of Po-210 and Ra-222 are very close to one another so that the two nuclides contribute to one common peak (that in the middle of the group of three peaks). The counting rate for Rn-222 is therefore determined by a linear fit from the counting rates for Ra-226, Po-218 and Po-214. From the ratio of the counting rates for Po-210 and Ra-226 the age of the preparation can be calculated.

### Remark

Due to the cover of the preparations, there is a strong offset in energy when the energy calibration is made with values taken from the literature. The measured spectrum starts only at an energy of 1-2 MeV. Particles with lower energy are stopped before reaching the detector.

## Detecting γ radiation with a scintillation counter (Cs-137)



can also be carried out with Pocket-CASSY

### Safety note

When handling radioactive preparations, in addition to the radiation protection regulations, state-specific requirements and the regulations of the educational authorities are also to be observed, e.g. in the Federal Republic of Germany at the very least the radiation protection regulations (StrlSchV - Strahlenschutzverordnung) and the directives on safety during school lessons. The preparations used in this experiment are type approved according to StrlSchV (2001). For this reason handling without express permission is possible.

Since the used preparations produce ionizing radiation, the following safety rules must nevertheless be kept to:

- Prevent access to the preparations by **unauthorized persons**.
- Before using the reparations make sure that they are **intact**.
- For the purpose of **shielding**, keep the preparations in their safety container.
- To ensure **minimum exposure time** and **minimum activity**, take the preparations out of the safety container only as long as is necessary for carrying out the experiment.
- To ensure **maximum distance**, hold the preparations only at the upper end of the metal holder.

### Experiment description

The γ spectrum of the mixed preparation (Cs-137, Am-241, Sr-90) is recorded, and an energy calibration is carried out with known lines.

### Equipment list

| | | |
|---|---|---|
| 1 | Sensor-CASSY | 524 010 or 524 013 |
| 1 | CASSY Lab 2 | 524 220 |
| 1 | MCA box | 524 058 |
| 1 | Mixed preparation α, β, γ | 559 845 or 559 835 |
| 1 | Scintillation counter | 559 901 |
| 1 | Detector output stage | 559 912 |
| 1 | High-voltage power supply 1.5 kV | 521 68 |

| | | |
|---|---|---|
| 1 | Socket for scintillator screening | 559 891 |
| 1 | Stand rod, 47 cm | 300 42 |
| 1 | Leybold multiclamp | 301 01 |
| 1 | Universal clamp, 0...80 mm | 666 555 |
| 1 | PC with Windows XP/Vista/7 | |

additionally recommended:

| | | |
|---|---|---|
| 1 | Two-channel oscilloscope 400 | 575 212 |

### Experiment setup (see drawing)

The output stage of the scintillation counter is connected to the MCA box and to the high-voltage power supply. The preparation is placed a few centimeters above the scintillation counter with the stand material. In order to prevent the scintillation counter from toppling over, it is recommended to use the socket (559 891) for the setup. This socket is provided with a fixture for the stand rod.

### Carrying out the experiment

■ Load settings

- Set the high-voltage power supply to zero, and switch it on.
- Start the measurement with ⏱.
- Without high voltage, no pulses should be counted at the scintillation counter.
- Slowly increase the high voltage until the spectrum covers the available channels at a voltage of 700-900 V.
- Each time when the high voltage is changed the measured spectrum should be deleted with 🗋 to avoid mixing of different spectra. The measurement goes on then, and the measuring time is restarted.
- When the set measuring time is over, the measurement is stopped.

### Evaluation

The two isotopes Cs-137 and Am-241 in the mixed reparation emit γ radiation, which is registered by the scintillation counter. Am-241 emits one line at 59.5 keV and Cs-137 one line at 662 keV. The measured spectrum exhibits some more details between these two lines. They arise because of the Compton effect taking place in the preparation and in the detector.

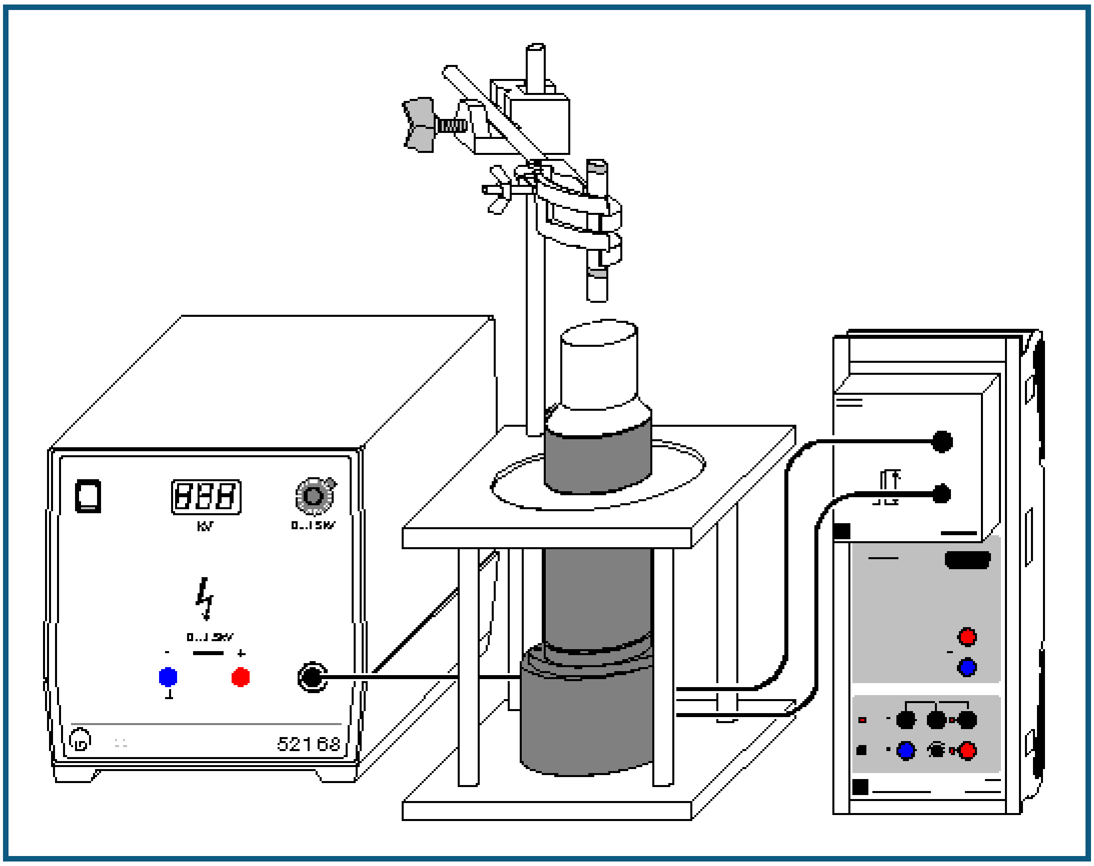
After the measurement the spectrum is not yet calibrated. An energy calibration has to be carried out in order to display it as an energy spectrum. For this the two known lines in spectrum are used (59.5 and 662 keV).

### Remark

For the measurement the preparation should not be put directly onto the detector but placed at a distance of a few centimeters. If the preparation is too close to the detector, the counting rate will be so high that individual pulses add up. This addition with the rest of the previous pulse shifts the lines towards higher energies.

The NaI(Tl) crystal at the end of the scintillation counter is sensitive to mechanical damage. The NaI(Tl) crystal is also sensitive to quick changes in temperature, which can occur, e.g., on unpacking after transport. In both cases cracks in the crystal arise and lead to a reduced sensitivity and, above all, to a worse energy resolution because of scattering.

## Recording and calibrating a γ spectrum



can also be carried out with Pocket-CASSY

### Safety note

When handling radioactive preparations, in addition to the radiation protection regulations, state-specific requirements and the regulations of the educational authorities are also to be observed, e.g. in the Federal Republic of Germany at the very least the radiation protection regulations (StrlSchV - Strahlenschutzverordnung) and the directives on safety during school lessons. The preparations used in this experiment are type approved according to StrlSchV (2001) or they are below the exemption limit and do not require approval. For this reason handling without express permission is possible.

Since the used preparations produce ionizing radiation, the following safety rules must nevertheless be kept to:

- Prevent access to the preparations by **unauthorized persons**.
- Before using the reparations make sure that they are **intact**.
- For the purpose of **shielding**, keep the preparations in their safety container.
- To ensure **minimum exposure time** and **minimum activity**, take the preparations out of the safety container only as long as is necessary for carrying out the experiment.
- To ensure **maximum distance**, hold the preparations only at the upper end of the metal holder.

### Experiment description

The γ spectra of some standard preparations (Cs-137, Co-60, Na-22) are measured. After an energy calibration of the scintillation counter, the γ transitions are identified with the help of values quoted in the literature.

### Equipment list

| | | |
|---|---|---|
| 1 | Sensor-CASSY | 524 010 or 524 013 |
| 1 | CASSY Lab 2 | 524 220 |
| 1 | MCA box | 524 058 |
| 1 | Set of 3 radioactive preparations | 559 835, alternatively 559 845 |
| 1 | Co-60 preparation | 559 855 |
| 1 | Na-22 preparation | 559 865 |

| | | |
|---|---|---|
| 1 | Scintillation counter | 559 901 |
| 1 | Detector output stage | 559 912 |
| 1 | High-voltage power supply 1.5 kV | 521 68 |
| 1 | Socket for scintillator screening | 559 891 |
| 1 | Stand rod, 47 cm | 300 42 |
| 1 | Leybold multiclamp | 301 01 |
| 1 | Universal clamp, 0...80 mm | 666 555 |
| 1 | PC with Windows XP/Vista/7 | |

### Experiment setup (see drawing)

The output stage of the scintillation counter is connected to the MCA box and to the high-voltage power supply. The preparation to be studied is placed a few centimeters above the scintillation counter with stand material. In order to prevent the scintillation counter from toppling over, it is recommended to use the socket (559 891) for the setup.

### Carrying out the experiment

■ Load settings

- Record the spectra of Co-60, Na-22 and Cs-137 one after another with ⏱. It is recommendable to begin with the Co-60 preparation because the radiation it emits has the highest energy so that the high voltage and the gain can be adjusted appropriately from the very beginning.
- In order to get an energy spectrum, an energy calibration has to be carried out. For this e.g. the lines of Na-22 at 511 keV and 1275 keV can be used.

### Evaluation

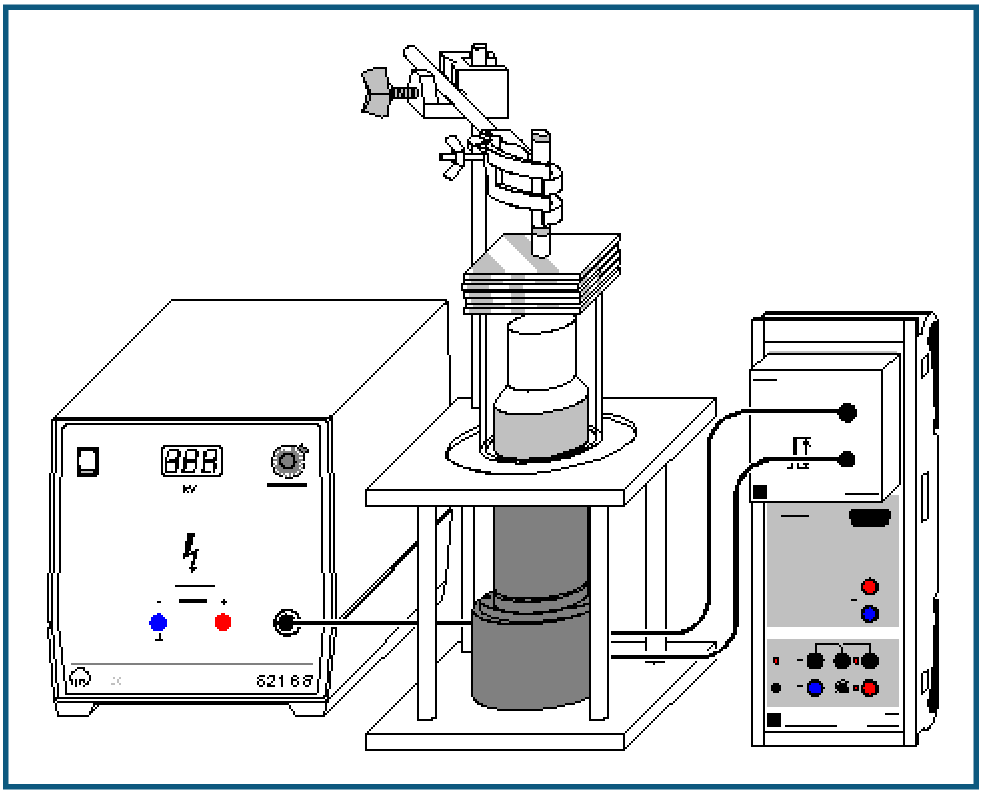
The energies of the individual lines are determined. For this the function Fit Gaussian curves can be used. The radiating isotopes are identified by comparison with values from the literature.

### Remarks

There are several databases available in the internet where the known energies of all radioactive substances are listed, e.g. under http://nucleardata.nuclear.lu.se/nucleardata/toi/. These may be used for identifying the radioactive nuclides.

For the measurement the preparation should not be put directly onto the detector but placed at a distance of a few centimeters. If the preparation is too close to the detector, the counting rate will be so high that individual pulses add up. This addition with the rest of the previous pulse shifts the lines towards higher energies.

## Absorption of γ radiation



can also be carried out with Pocket-CASSY

### Safety note

When handling radioactive preparations, in addition to the radiation protection regulations, state-specific requirements and the regulations of the educational authorities are also to be observed, e.g. in the Federal Republic of Germany at the very least the radiation protection regulations (StrlSchV - Strahlenschutzverordnung) and the directives on safety during school lessons. The preparations used in this experiment are type approved according to StrlSchV (2001) or they are below the exemption limit and do not require approval. For this reason handling without express permission is possible.

Since the used preparations produce ionizing radiation, the following safety rules must nevertheless be kept to:

- Prevent access to the preparations by **unauthorized persons**.
- Before using the reparations make sure that they are **intact**.
- For the purpose of **shielding**, keep the preparations in their safety container.
- To ensure **minimum exposure time** and **minimum activity**, take the preparations out of the safety container only as long as is necessary for carrying out the experiment.
- To ensure **maximum distance**, hold the preparations only at the upper end of the metal holder.

### Experiment description

The intensity of γ radiation behind an absorber is measured as a function of the thickness of the absorber in order to confirm Lambert's law of absorption. The linear attenuation coefficient κ and the half-value depth $d_{1/2}$ are derived.

### Equipment list

| | | |
|---|---|---|
| 1 | Sensor-CASSY | 524 010 or 524 013 |
| 1 | CASSY Lab 2 | 524 220 |
| 1 | MCA box | 524 058 |
| 1 | Co-60 preparation | 559 855 |
| 1 | Set of 3 radioactive preparations | 559 835 |
| 1 | Set of absorbers and targets | 559 94 |
| 1 | Scintillation counter | 559 901 |
| 1 | Detector output stage | 559 912 |
| 1 | High-voltage power supply 1.5 kV | 521 68 |

| | | |
|---|---|---|
| 1 | Socket for scintillator screening | 559 891 |
| 1 | Stand rod, 47 cm | 300 42 |
| 1 | Leybold multiclamp | 301 01 |
| 1 | Universal clamp, 0...80 mm | 666 555 |
| 1 | PC with Windows XP/Vista/7 | |

### Experiment setup (see drawing)

The output stage of the scintillation counter is connected to the MCA box and to the high-voltage power supply. The scintillation counter is mounted in the socket and the tip of the scintillation counter covered with the acrylic glass tube. The preparation is placed a few centimeters above the scintillation counter with the stand material. The absorbers are laid on the acrylic glass tube.

### Carrying out the experiment

■ Load settings

- First clamp the Co-60 preparation, and record the spectrum without absorber with⏱ setting the high voltage so that the spectrum covers the range of measurement.
- Lay the absorbers (aluminum, iron, lead) with different layer thicknesses on the acrylic glass tube one after another, and record a spectrum each time with ⏱.
- Repeat the measurements for the Cs-137 and the Am-241 preparation.

### Evaluation

The counting rates associated with the lines of the spectra are determined using the function Calculate Integral. The counting rates are represented for the individual energies and absorbers as functions of the absorber thickness. From this the linear attenuation coefficient κ and the half-value depth $d_{1/2}$: are derived:

$$I = I_0 e^{-\mu \cdot x}$$

Typical values for κ are:

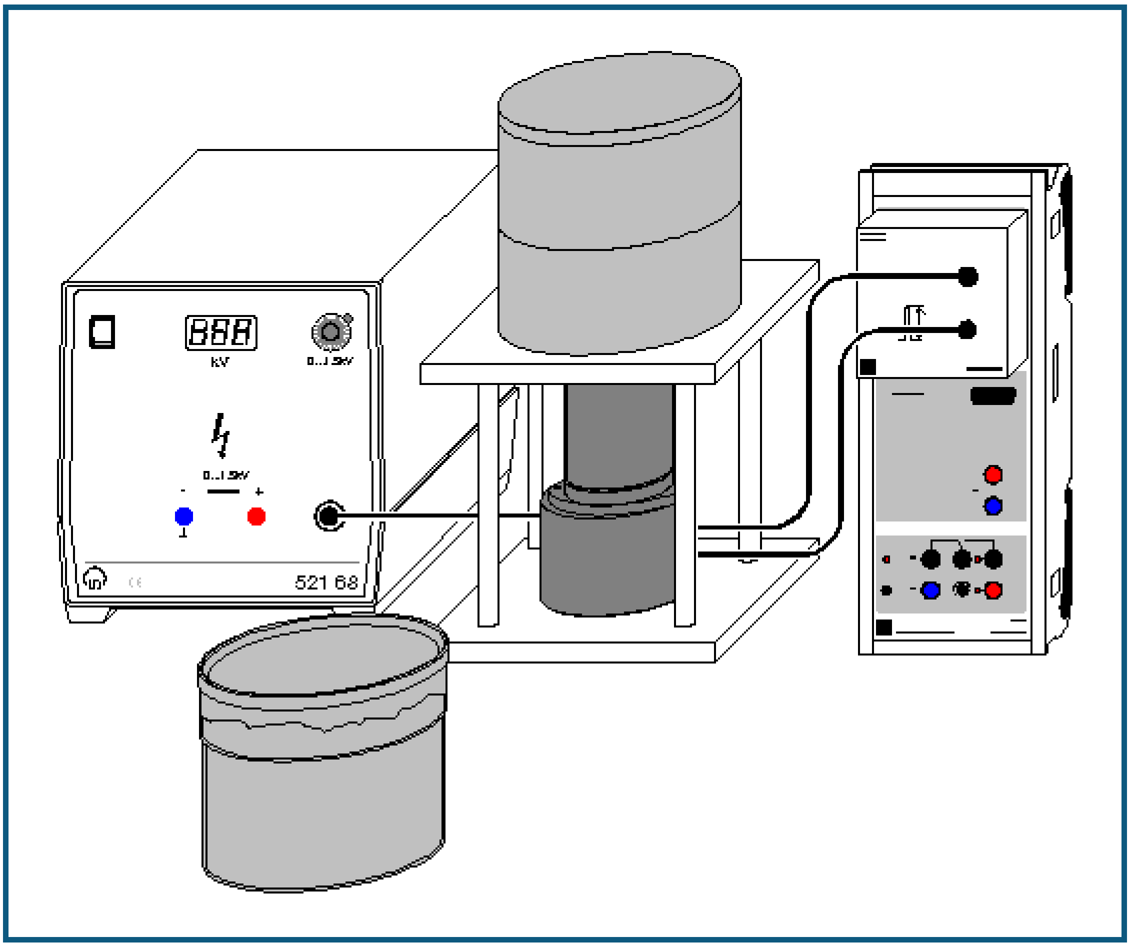
| E | 60 keV | 662 keV | 1253 keV |
|---|---|---|---|
| Al | 0.51 1/cm | 0.16 1/cm | 0.13 1/cm |
| Fe | 7.4 1/cm | 0.43 1/cm | 0.36 1/cm |
| Pb | | 0.86 1/cm | 0.55 1/cm |

### Remark

The NaI(Tl) crystal at the end of the scintillation counter is sensitive to mechanical damage. Be careful when laying the absorbers on the detector. Never place the absorber directly onto the scintillation counter, always use the acrylic glass tube.

Otherwise cracks in the crystal arise and lead to a reduced sensitivity and, above all, to a worse energy resolution because of scattering.

## Identifying and determining the activity of weakly radioactive samples



can also be carried out with Pocket-CASSY

### Safety note

When handling radioactive preparations, in addition to the radiation protection regulations, state-specific requirements and the regulations of the educational authorities are also to be observed, e.g. in the Federal Republic of Germany at the very least the radiation protection regulations (StrlSchV - Strahlenschutzverordnung) and the directives on safety during school lessons. This applies even in cases where the preparation used in this experiment in itself does not require the nomination of a trained radiation officer.

Since the used preparations produce ionizing radiation, the following safety rules must nevertheless be kept to:

- Prevent access to the preparations by **unauthorized persons**.
- Before using the reparations make sure that they are **intact**.
- For the purpose of **shielding**, keep the preparations in their safety container.
- To ensure **minimum exposure time** and **minimum activity**, take the preparations out of the safety container only as long as is necessary for carrying out the experiment.
- To ensure **maximum distance**, hold the preparations only at the upper end of the metal holder.

### Experiment description

The detection probability of the scintillation counter is determined at several γ energies with calibrating preparations. The γ spectrum of a weakly radioactive sample is recorded, and its radioactive components are determined.

### Equipment list

| | | |
|---|---|---|
| 1 | Sensor-CASSY | 524 010 or 524 013 |
| 1 | CASSY Lab 2 | 524 220 |
| 1 | MCA box | 524 058 |
| 2 | Marinelli beakers | 559 88 |
| 1 | Calibrating preparation Cs-137, 5 kBq | 559 885 |

| | | |
|---|---|---|
| 4 | Potassium chloride, 250 g | 672 5210 |
| 1 | Scintillation counter | 559 901 |
| 1 | Detector output stage | 559 912 |
| 1 | High-voltage power supply 1.5 kV | 521 68 |
| 1 | Scintillator screening | 559 89 |
| 1 | Socket for scintillator screening | 559 891 |
| 1 | PC with Windows XP/Vista/7 | |

### Experiment setup (see drawing)

The output stage of the scintillation counter is connected to the MCA box and to the high-voltage power supply. The scintillation counter is mounted in the socket from above with the lead screening. The preparation in the Marinelli beaker is placed above the scintillation counter.

### Carrying out the experiment

☐ Load settings

- Fill 1 kg of potassium chloride into a Marinelli beaker and place it above the scintillation counter.
- Record the spectrum with ⏱ varying the high voltage until the full range of measurement is covered.
- Remove the Marinelli beaker and insert the calibrating preparation Cs-137
- Record the spectrum
- Make an energy calibration using the lines at 1460 keV and 662 keV in the two spectra.
- Remove the preparation
- Equally distribute the test substance in a Marinelli beaker, place the beaker above the scintillation counter, and record the spectrum of the sample.
- Make a background measurement without preparation. The measuring time should be equal to that with the sample.

### Evaluation

The activities of potassium chloride (17 kBq/kg) and the Cs-137 calibrating preparation (approx. 5 kBq, see calibration certificate, mind the half-life) are known. From the integrated counting rate below the lines of the two spectra the detection probability of the scintillation counter at 1460 keV and 662 keV can be determined for this particular geometry.

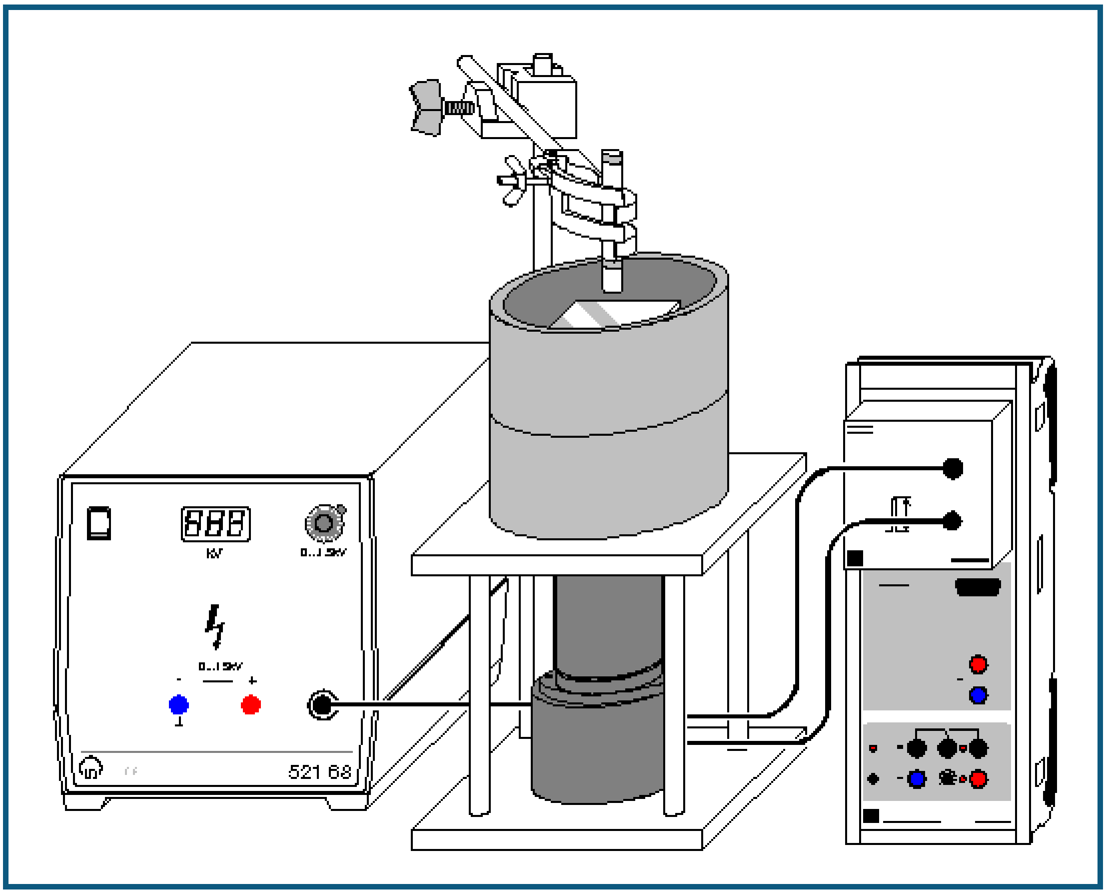
The background spectrum is subtracted from the spectrum of the sample. From the resulting spectrum and the previously determined detection probability the radioactive contamination of the sample can be determined. The observed energies enable the radiating isotope in the sample to be determined, and with the detection probabilities just determined, the quantity can be estimated.

### Remarks

The NaI(TI) crystal at the end of the scintillation counter is sensitive to mechanical damage. Be careful when inserting the Marinelli beakers and when setting up the lead screen.

When making measurements with strongly radiating samples heed the display of the dead time and, if necessary, dilute the sample.

## Recording a β spectrum using a scintillation counter



can also be carried out with Pocket-CASSY

**Safety note**

When handling radioactive preparations, in addition to the radiation protection regulations, state-specific requirements and the regulations of the educational authorities are also to be observed, e.g. in the Federal Republic of Germany at the very least the radiation protection regulations (StrlSchV - Strahlenschutzverordnung) and the directives on safety during school lessons. The preparations used in this experiment are type approved according to StrlSchV (2001) or they are below the exemption limit and do not require approval. For this reason handling without express permission is possible.

Since the used preparations produce ionizing radiation, the following safety rules must nevertheless be kept to:

- Prevent access to the preparations by **unauthorized persons**.
- Before using the reparations make sure that they are **intact**.
- For the purpose of **shielding**, keep the preparations in their safety container.
- To ensure **minimum exposure time** and **minimum activity**, take the preparations out of the safety container only as long as is necessary for carrying out the experiment.
- To ensure **maximum distance**, hold the preparations only at the upper end of the metal holder.

### Experiment description

The β spectrum of Sr-90 is recorded with a scintillation counter. The energy loss per path length dE/dx of the β particles in aluminum is measured.

### Equipment list

| | | |
|---|---|---|
| 1 | Sensor-CASSY | 524 010 or 524 013 |
| 1 | CASSY Lab 2 | 524 220 |
| 1 | MCA box | 524 058 |
| 1 | Set of radioactive preparations | 559 835 |
| 1 | Na-22 preparation | 559 865 |

| | | |
|---|---|---|
| 1 | Set of absorbers and targets | 559 94 |
| 1 | Scintillation counter | 559 901 |
| 1 | Detector output stage | 559 912 |
| 1 | High-voltage power supply 1.5 kV | 521 68 |
| 1 | Scintillator screening | 559 89 |
| 1 | Socket for scintillator screening | 559 891 |
| 1 | Stand rod, 47 cm | 300 42 |
| 1 | Leybold multiclamp | 301 01 |
| 1 | Universal clamp, 0...80 mm | 666 555 |
| 1 | PC with Windows XP/Vista/7 | |

## Experiment setup (see drawing)

The output stage of the scintillation counter is connected to the MCA box and to the high-voltage power supply. The scintillation counter is mounted in the socket from above with the lead screening. The acrylic glass tube is put over the scintillation counter within the lead screening. The preparation is place a few centimeters above the scintillation counter with stand material. The absorber plates are laid on the acrylic glass tube so that they are located between the detector and the preparation.

## Carrying out the experiment

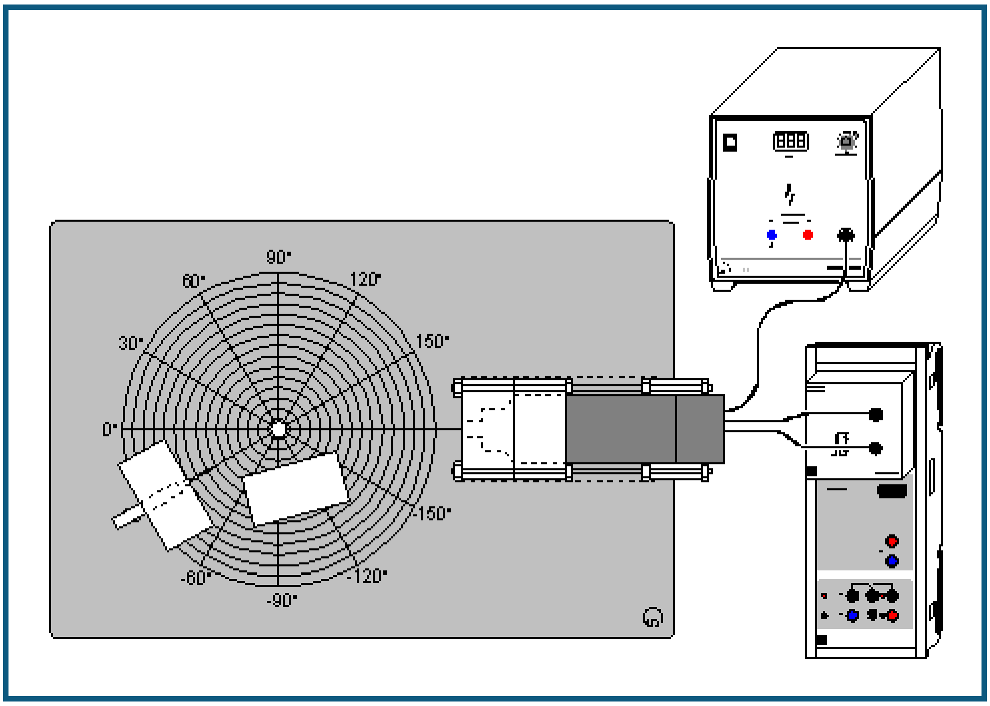
☐ Load settings

- Mount the Sr-90 preparation, and record the spectrum with ⏱. Set the high voltage so that the spectrum is not cut off on the right side.
- For the energy calibration, mount the Na-22 preparation, and calibrate the energy axis with the 511 keV and the 1275 keV line. The Sr-90 spectrum extends to approx. 2000 keV.
- It is recommendable to determine the background without preparation.
- Mount the Sr-90 preparation once more, and see to it that there is enough space for the absorbers.
- One after another record the spectra without absorber, with a 0.5 mm thick aluminum absorber, 1 mm aluminum, and so on up to 3 mm aluminum.

## Evaluation

The aluminum absorber reduces the maximum energy of the electron reaching the detector. The highest energy of each Sr-90 spectrum at which electrons are detected is determined. These energies are compiled in a table together with the corresponding thickness of the absorber. The slope of the regression line gives the energy loss per path length dE/dx, which, in this case, amounts to about 400 – 450 keV/mm.

## Quantitative observation of the Compton effect



can also be carried out with Pocket-CASSY

### Safety note

When handling radioactive preparations, in addition to the radiation protection regulations, state-specific requirements and the regulations of the educational authorities are also to be observed, e.g. in the Federal Republic of Germany at the very least the radiation protection regulations (StrlSchV - Strahlenschutzverordnung) and the directives on safety during school lessons. The preparation used in this experiment requires official permission! Before purchase, the radiation officer has to obtain permission from the authorities.

Since the used preparations produce ionizing radiation, the following safety rules must nevertheless be kept to:

- Prevent access to the preparations by **unauthorized persons**.
- Before using the reparations make sure that they are **intact**.
- For the purpose of **shielding**, keep the preparations in their safety container.
- To ensure **minimum exposure time** and **minimum activity**, take the preparations out of the safety container only as long as is necessary for carrying out the experiment.
- To ensure **maximum distance**, hold the preparations only at the upper end of the metal holder.

### Experiment description

An energy calibration of the scintillation counter is made. The energy distribution of γ quanta scattered in an aluminum scatterer is recorded for several angles between the source and the detector. From this the quantitative confirmation of the Compton effect is obtained.

### Equipment list

| | | |
|---|---|---|
| 1 | Sensor-CASSY | 524 010 or 524 013 |
| 1 | CASSY Lab 2 | 524 220 |
| 1 | MCA box | 524 058 |
| 1 | Mixed preparation α, β, γ | 559 845 or 559 835 |
| 1 | Equipment set Compton | 559 800 |
| 1 | Cs-137 preparation, 3.7 MBq | 559 809 (requires permission) |
| 1 | Scintillation counter | 559 901 |
| 1 | Detector output stage | 559 912 |
| 1 | High-voltage power supply 1.5 kV | 521 68 |
| 1 | PC with Windows XP/Vista/7 | |

### Experiment setup (see drawing)

The output stage of the scintillation counter is connected to the MCA box and to the high-voltage power supply. The experiment panel from the Equipment set Compton is put down and the lead screening set up correspondingly.

### Carrying out the experiment

■ Load settings
- First make an energy calibration of the scintillation counter. For this insert the mixed preparation in the sample holder from the Equipment set Compton, align it at the 0° mark. Leave the aluminum scatterer aside.
- Record the spectrum with ⏱, and make the energy calibration with the lines at 662 keV and 59.5 keV.
- Replace the mixed preparation with the Cs-137 preparation, set up the preparation at 30°, and set up the aluminum scatterer. Place the additional screening in the direct line of vision between the preparation and the detector.
- Record the spectrum with ⏱, then remove the aluminum scatterer, and record a new spectrum.
- The difference between the two spectra (with and without the aluminum scatterer) is the scattering spectrum.
- Repeat the measurement at various angles of the preparation, each time subtracting a spectrum without the aluminum scatterer from a spectrum with the aluminum scatterer. Always shift the additional screening in the setup so that the direct line of vision between the preparation and the detector is blocked.

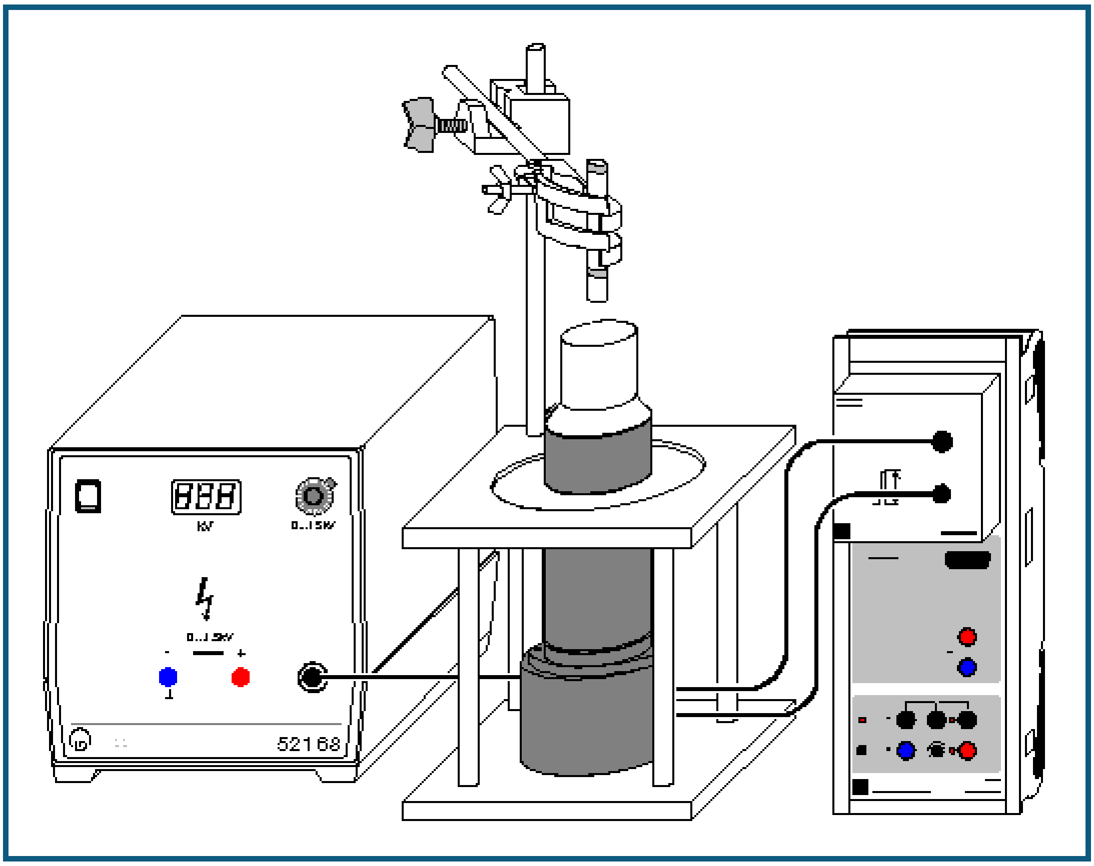
### Evaluation

From the scattering spectra (difference with and without aluminum scatterer) the energy of the scattered g quanta is determined. The values are plotted against the associated angles and compared with the theoretical values:

$$E'_\gamma = E_\gamma \Big/ \left(1 + \frac{E_\gamma}{m_0 c^2}\left(1 - \cos\theta\right)\right)$$

Alternatively a Free fit can be performed.

## Recording the complex γ spectrum of Ra-226 and its decay products



can also be carried out with Pocket-CASSY

### Safety note

When handling radioactive preparations, in addition to the radiation protection regulations, state-specific requirements and the regulations of the educational authorities are also to be observed, e.g. in the Federal Republic of Germany at the very least the radiation protection regulations (StrlSchV - Strahlenschutzverordnung) and the directives on safety during school lessons. The preparations used in this experiment are type approved according to StrlSchV (2001) or they are below the exemption limit and do not require approval. For this reason handling without express permission is possible.

Since the used preparations produce ionizing radiation, the following safety rules must nevertheless be kept to:

- Prevent access to the preparations by **unauthorized persons**.
- Before using the reparations make sure that they are **intact**.
- For the purpose of **shielding**, keep the preparations in their safety container.
- To ensure **minimum exposure time** and **minimum activity**, take the preparations out of the safety container only as long as is necessary for carrying out the experiment.
- To ensure **maximum distance**, hold the preparations only at the upper end of the metal holder.

### Experiment description

The complex spectrum of Ra-226 and its decay products is recorded.

### Equipment list

| | | |
|---|---|---|
| 1 | Sensor-CASSY | 524 010 or 524 013 |
| 1 | CASSY Lab 2 | 524 220 |
| 1 | MCA box | 524 058 |
| 1 | Mixed preparation α, β, γ | 559 845 or 559 835 |
| 1 | Ra-226 preparation | 559 435 |
| 1 | Scintillation counter | 559 901 |
| 1 | Detector output stage | 559 912 |

| | | |
|---|---|---|
| 1 | High-voltage power supply 1.5 kV | 521 68 |
| 1 | Scintillator screening | 559 89 |
| 1 | Socket for scintillator screening | 559 891 |
| 1 | Stand rod, 47 cm | 300 42 |
| 1 | Leybold multiclamp | 301 01 |
| 1 | Universal clamp, 0...80 mm | 666 555 |
| 1 | PC with Windows XP/Vista/7 | |

### Experiment setup (see drawing)

The output stage of the scintillation counter is connected to the MCA box and to the high-voltage power supply. The preparation is placed a few centimeters above the scintillation counter with the stand material.

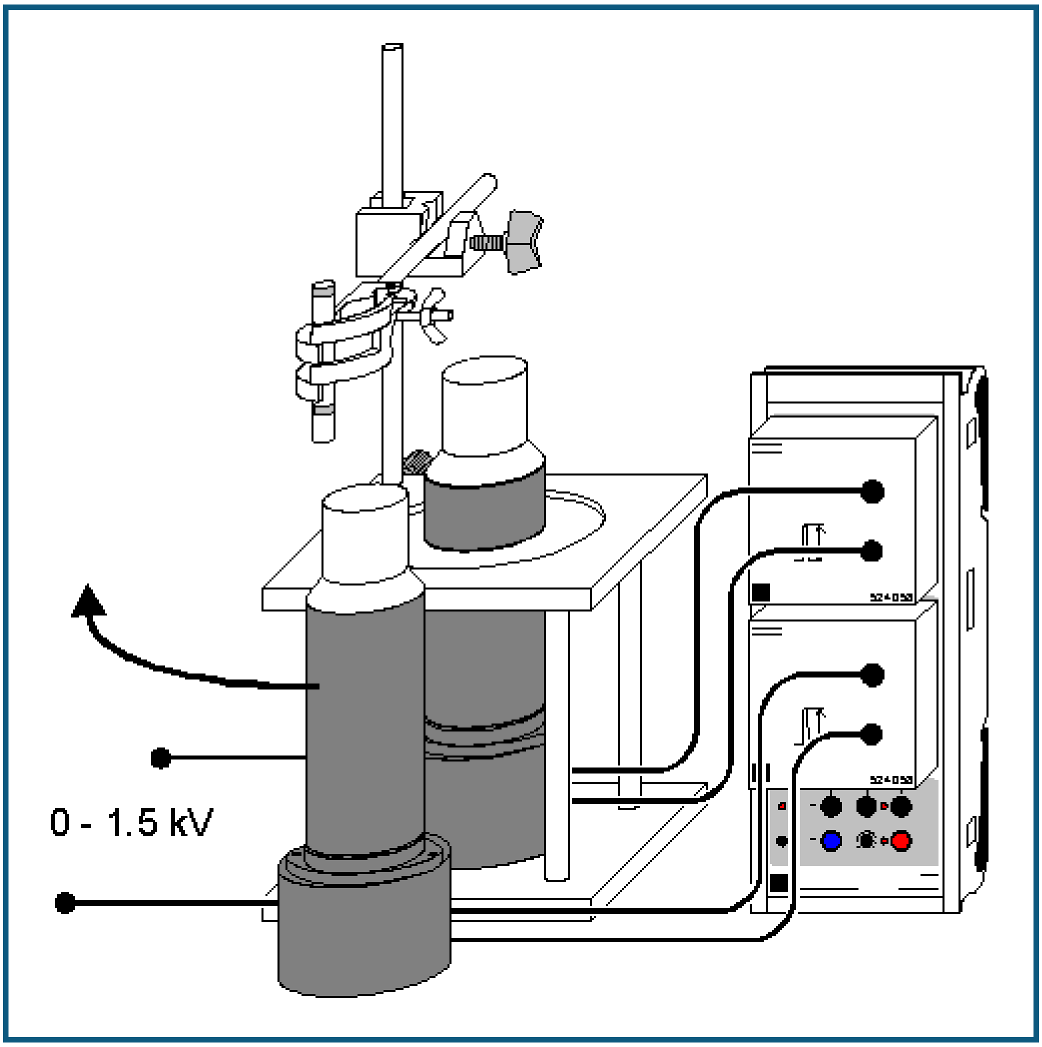
### Carrying out the experiment

☐ Load settings
- For the energy calibration mount the mixed preparation above the detector, record the spectrum with ⏱, and make the calibration with the lines at 662 keV and 59.5 keV.
- Remove the mixed preparation, and mount the Ra-226 preparation. Record the spectrum.

### Evaluation

The measured lines are assigned to the corresponding isotopes of the radium radioactive series with the help of values taken from the literature or from the internet (see e.g. http://nucleardata.nuclear. lu.se/nucleardata/toi/).

## Coincidence and γ-γ angular correlation in positron decay



### Safety note

When handling radioactive preparations, in addition to the radiation protection regulations, state-specific requirements and the regulations of the educational authorities are also to be observed, e.g. in the Federal Republic of Germany at the very least the radiation protection regulations (StrlSchV - Strahlenschutzverordnung) and the directives on safety during school lessons. The preparations used in this experiment are type approved according to StrlSchV (2001) or they are below the exemption limit and do not require approval. For this reason handling without express permission is possible.

Since the used preparations produce ionizing radiation, the following safety rules must nevertheless be kept to:

- Prevent access to the preparations by **unauthorized persons**.
- Before using the reparations make sure that they are **intact**.
- For the purpose of **shielding**, keep the preparations in their safety container.
- To ensure **minimum exposure time** and **minimum activity**, take the preparations out of the safety container only as long as is necessary for carrying out the experiment.
- To ensure **maximum distance**, hold the preparations only at the upper end of the metal holder.

### Experiment description

The spatial coincidence of the two γ quanta in electron-positron pair annihilation is demonstrated. The conservation of momentum requires emission of the two quanta at an angle of 180°, which is visualized in the experiment. Selective measurement of a coincidence spectrum leads to the suppression of non-correlated lines.

### Equipment list

| | | |
|---|---|---|
| 1 | Sensor-CASSY | 524 010 or 524 013 |

| | | |
|---|---|---|
| 1 | CASSY Lab 2 | 524 220 |
| 2 | MCA boxes | 524 058 |
| 1 | Na-22 preparation | 559 865 |
| 1 | Set of 3 radioactive preparations | 559 835 or 559 845 |
| 2 | Scintillation counters | 559 901 |
| 2 | Detector output stages | 559 912 |
| 2 | High-voltage power supplies 1.5 kV | 521 68 |
| 2 | Sockets for scintillator screening | 559 891 |
| 1 | Stand rod, 47 cm | 300 42 |
| 1 | Leybold multiclamp | 301 01 |
| 1 | Universal clamp, 0...80 mm | 666 555 |
| 1 | PC with Windows XP/Vista/7 | |

### Experiment setup (see drawing)

The output stages of the scintillation counters are connected to the MCA boxes and to the high-voltage power supplies. Both MCA boxes must be plugged in the same CASSY. The preparation is placed near one scintillation counter with the stand material so that the other detector can be moved around the setup, in order that the angle detector 1 - preparation - detector 2 can be varied.

### Carrying out the experiment

■ Load settings

- Select the display **Energy calibration**
- Use the two detectors to record the normal Na-22 spectrum each with ⏱
- In the Settings NA calibrate input A, and in the Settings NB calibrate the detector at input B
- Select the display **511 keV**
- In the Settings NA set the measurement to the **Coincidence trigger for the other box** and adjust the coincidence window to the 511 keV line (mark with two vertical lines)
- Place the movable detector so that the preparation is located between the detectors. Record the coincidence spectrum with ⏱.
- Place the movable detector so that it is located perpendicularly to the connecting line preparation - other detector. Record the coincidence spectrum with ⏱.
- Select the display **1275 keV**
- In the Settings NA set the coincidence window to the 1275 keV line (reset the old window by pressing → **0** ← and mark the new window by means of two vertical lines)
- Record the coincidence spectrum at 180° and at 90° each with ⏱.
- Select the display **Cs-137 and Na-22**
- In the Settings NA set the coincidence window to the 511 keV line (reset the old window by pressing → **0** ← and mark the new window by means of two vertical lines)
- Fix the Cs-137 preparation together with the Na-22 preparation between the detectors, place the movable detector so that the preparations are located between the detectors. Record the coincidence spectrum with ⏱.
- Record the normal MCA spectrum of this arrangement.

### Evaluation

The normal Na-22 spectrum consists of a line at 1275 keV and the pair annihilation radiation at 511 keV. The two 511 keV quanta are correlated in time and space (emission under 180°). The 1275 keV quanta are correlated with the 511 keV quanta in time as the delay of 3.7 ps cannot be detected with this setup. This emission is not correlated in space.

In the normal MCA spectrum both lines are visible. At 180° coincidence, the 511 keV line clearly stands out because the other components of the spectrum (1275 keV line, Compton distribution) are correlated in time only and not in space so they are weakened by the solid angle of the second detector relative to the 511 keV line, which is correlated in space. Thereby the absolute counting rate of the 511 keV line drop according to the detection probability of the second detector.

If the detector is swivelled out of the 180° direction, the 511 keV line disappears, whereas those components that are not correlated in space remain unchanged.

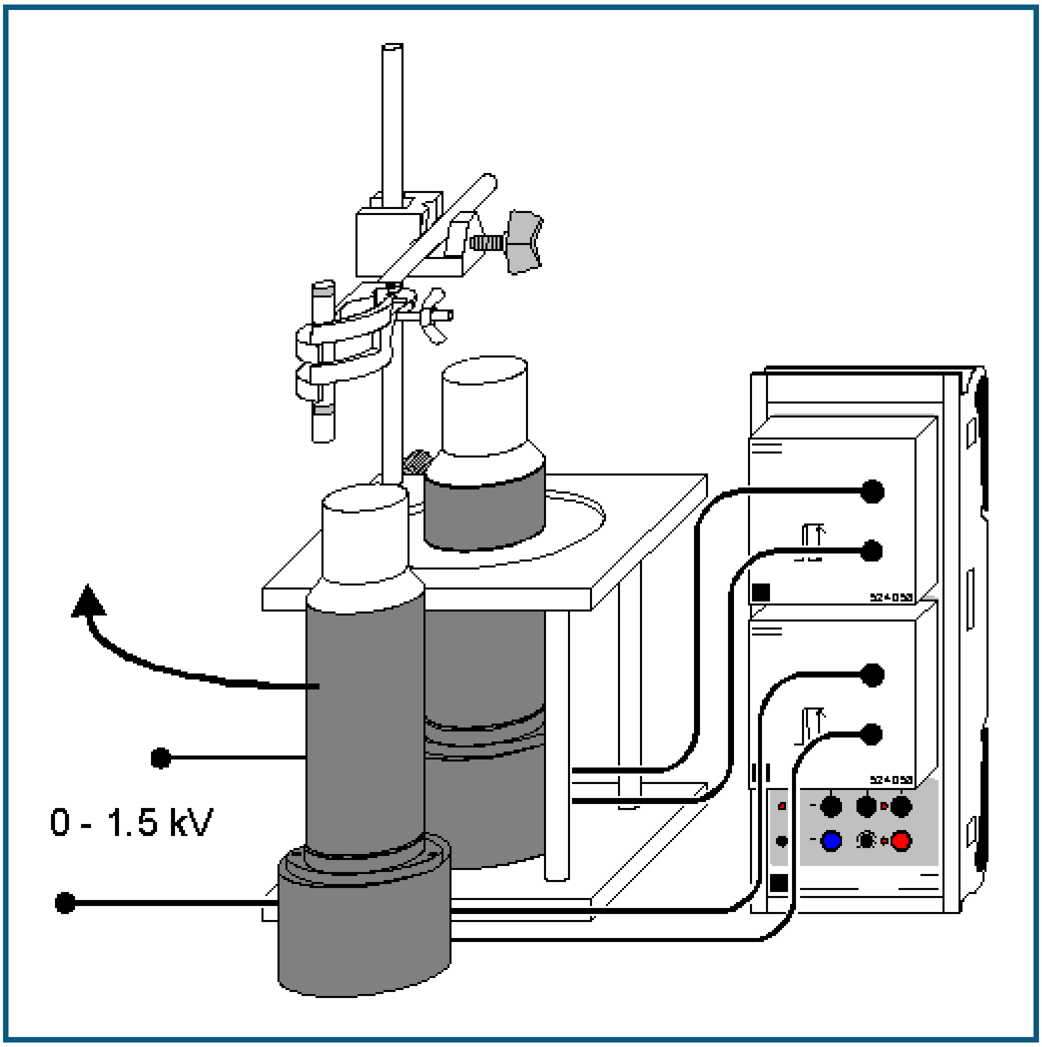
If the measurement is made in coincidence to the 1275 keV line, there is no correlation in space. Therefore the spectra look the same at different angles. Since there is only one 1275 keV quantum per decay, no 1275 keV line is observed in coincidence.

In order to show the suppression of quanta that are not correlated in time, two preparations are used at the same time. Cs-137 provides a non-correlated background, which is only visible in the coincidence measurement because of accidental coincidence, whereas it is clearly visible without coincidence measurement.

## Remark

The time window for coincidences has a fixed default value of 4 κs.

## Coincidence and the decay cascade of Co-60



### Safety note

When handling radioactive preparations, in addition to the radiation protection regulations, state-specific requirements and the regulations of the educational authorities are also to be observed, e.g. in the Federal Republic of Germany at the very least the radiation protection regulations (StrlSchV - Strahlenschutzverordnung) and the directives on safety during school lessons. The preparations used in this experiment are below the exemption limit. For this reason handling without express permission is possible.

Since the used preparations produce ionizing radiation, the following safety rules must nevertheless be kept to:

- Prevent access to the preparations by **unauthorized persons**.
- Before using the reparations make sure that they are **intact**.
- For the purpose of **shielding**, keep the preparations in their safety container.
- To ensure **minimum exposure time** and **minimum activity**, take the preparations out of the safety container only as long as is necessary for carrying out the experiment.
- To ensure **maximum distance**, hold the preparations only at the upper end of the metal holder.

### Experiment description

The coincidence of the two successively emitted γ quanta during the decay of Co-60 is demonstrated. The selective measurement of the coincidence spectrum always shows the other line in the decay cascade.

### Equipment list

| | | |
|---|---|---|
| 1 | Sensor-CASSY | 524 010 or 524 013 |
| 1 | CASSY Lab 2 | 524 220 |
| 2 | MCA boxes | 524 058 |

| | | |
|---|---|---|
| 1 | Co-60 preparation | 559 855 |
| 2 | Scintillation counters | 559 901 |
| 2 | Detector output stages | 559 912 |
| 2 | High-voltage power supplies 1.5 kV | 521 68 |
| 2 | Sockets for scintillator screening | 559 891 |
| 1 | Stand rod, 47 cm | 300 42 |
| 1 | Leybold multiclamp | 301 01 |
| 1 | Universal clamp, 0...80 mm | 666 555 |
| 1 | PC with Windows XP/Vista/7 | |

### Experiment setup (see drawing)

The output stages of the scintillation counters are connected to the MCA boxes and to the high-voltage power supplies. Both MCA boxes must be plugged in the same CASSY. The preparation is placed near one scintillation counter with the stand material so that the other detector can be moved around the setup, in order that the angle detector 1 - preparation - detector 2 can be varied.

### Carrying out the experiment

☐ Load settings
- Select the display **Energy calibration**
- Use the two detectors to record the normal Co-60 spectrum each with ⏱
- In the Settings NA calibrate input A, and in the Settings NB calibrate the detector at input B
- Select the display **Coincidence**
- In the Settings NA set the measurement to the **Coincidence trigger for the other box** and adjust the coincidence window to the 1332 keV line (mark with two vertical lines)
- Record the coincidence spectrum with ⏱.
- In the Settings NA set the coincidence window to the 1173 keV line (reset the old window by pressing → **0** ← and mark the new window by means of two vertical lines)
- Record the coincidence spectrum with ⏱.

### Evaluation

The normal Co-60 spectrum comprises two lines, one at 1332 keV and one at 1175 keV. When the Co-60 nucleus decays, this is initially a β-decay. The exited state of the Ni-60 emits first of all a γ quantum with 1175 keV, the following intermediate status only has a life span of 0.7 ps, then the emission of the 1332 keV γ-quantum follows and the nucleus reaches its basic state. Therefore emissions of the two γ-lines visible in the spectrum are in temporal coincidence.

The emission of the two γ-quanta cannot be temporarily resolved by means of an NaI scintillation detector, however the temporal correlation of the two particles can be convincingly demonstrated.

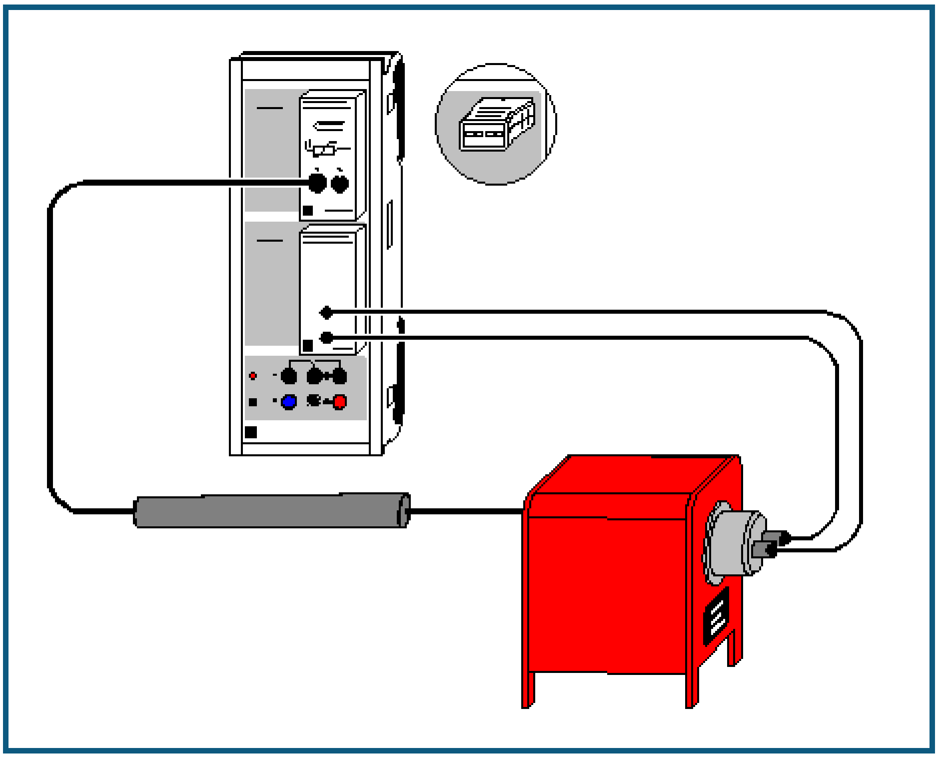
In the normal MCA spectrum both lines are visible. If one of the two lines is selected as the coincidence trigger then the resulting spectrum only shows the other line because the first γ-quantum has arrived in the first detector and has released the trigger. This demonstrates the temporal coincidence of the two γ-quanta and therefore also that they have to be caused by the same atomic decay process.

The coincidence triggering on the 1175 keV line shows another line at 200 keV. Here a different process is active which has nothing to do with the cascade of decay. If a 1332 keV γ-quantum is emitted and Compton backscattering occurs in the coincidence trigger detector, an energy of approx. 1130 keV is transmitted to the electron. This energy is within the trigger window used at approx. 1175 keV and therefore triggers a measurement. The backscattered γ-quantum can now be picked up by the second detector and carries a residual energy of approx. 200 keV. Spatial movement of the detectors will change the intensity and energy of this line.

### Remark

The time window for coincidences has a fixed default value of 4 κs.

## Electrical conduction in solid bodies



can also be carried out with Pocket-CASSY and Mobile-CASSY

### Experiment description

The temperature-dependency of the specific resistance R is a simple test for models of electric conductivity in conductors and semiconductors. In electrical conductors, R rises with the temperature, as the collisions of the quasi-free electrons from the conduction band with the incomplete atoms of the conductor play an increasing role. In semiconductors, on the other hand, the resistance decreases as the temperature increases since more and more electrons move from the valence band to the conduction band, thus contributing to the conductivity.

This experiment measures the resistance values of a noble-metal resistor and a semiconductor resistor as a function of the temperature. For the noble metal resistor, the relationship

$R = R_0 \cdot (1 + \alpha \cdot \vartheta)$ ($R_0$: resistance at $\vartheta = 0$ °C)

is verified with sufficient accuracy in the temperature range under study. For the semiconductor resistor, the evaluation reveals a dependency with the form

$R \propto e^{\Gamma E/2kT}$ ($k = 1.38 \cdot 10^{-23}$ J/K: Boltzmann constant)

with the energy band interval $\Gamma E$.

### Equipment list

| | | |
|---|---|---|
| 1 | Sensor-CASSY | 524 010 or 524 013 |
| 1 | CASSY Lab 2 | 524 220 |
| 1 | Current source box | 524 031 |
| | | |
| 1 | Temperature box | 524 045 |
| 1 | Temperature sensor NiCr-Ni | 666 193 |
| | or | |
| 1 | NiCr-Ni adapter S | 524 0673 |
| 1 | Temperature sensor NiCr-Ni, type K | 529 676 |
| | | |
| 1 | Noble metal resistor | 586 80 |
| 1 | Semiconductor resistor | 586 82 |
| 1 | Electric oven, 230 V | 555 81 |
| 1 | Safety connecting box | 502 061 |

| | | |
|---|---|---|
| 2 | Connecting leads, 100 cm, black | 500 444 |
| 1 | PC with Windows XP/Vista/7 | |

## Experiment setup (see drawing)

The temperature box at Sensor-CASSY input A measures the temperature of the sensor in the electric oven. Insert the measuring tip into the hole on the back of the oven so that the tip is in direct proximity to the resistor element. The current supply box at input B registers the electrical resistance.

## Carrying out the experiment

■ Load settings

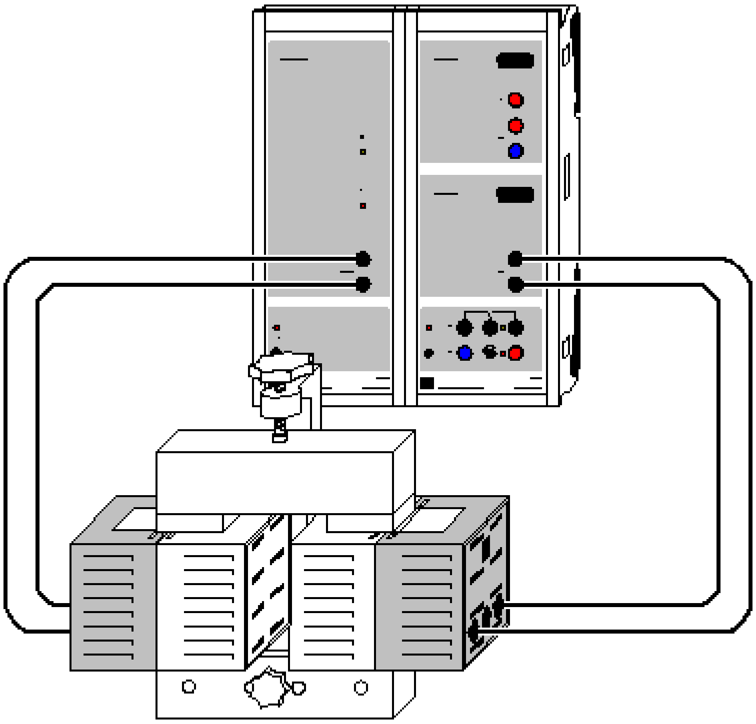
- Start the measurement with ⏱ (a value pair is recorded for every temperature increase of 5 K).
- Switch on the oven.
- Stop the measurement with ⏱ at the latest when the temperature reaches 470 K (approx. 200 °C).
- Switch off the oven and remove the resistor.
- When the oven has cooled off repeat the measurement with a different resistor.

## Evaluation

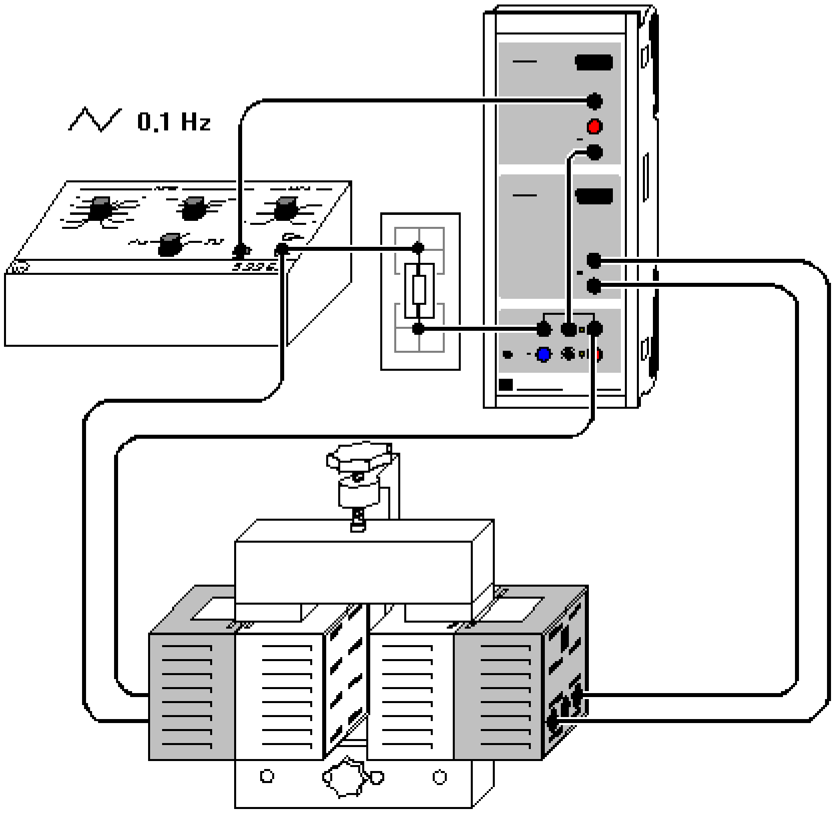
When a noble metal (platinum) resistor is used, we obtain a linear increase in resistance as the temperature rises. The temperature coefficient α of the resistor can be determined easily by fitting a straight line. In this example we observe in increase in resistance of 0.407 Ω/K and a resistance of 100 Ω at 0 °C, i.e. $\alpha = 0.00407$ /K. The agrees very well with the literature value $\alpha = 0.00392$ /K for platinum.

The resistance of the semiconductor resistor does not decrease linearly as the temperature rises. By fitting an exponential function to the 1/T display (click on the display tab with the mouse) we can confirm the relationship $R \propto e^{\Gamma E/2kT}$ for higher temperatures T. In the example, this gives us $2k/\Gamma E = 0.000368$ /K for the semiconductor used here, i.e. $\Gamma E = 7.5 \cdot 10^{-20}$ J = 0.47 eV (1 eV = $1.602 \cdot 10^{-19}$ J).

## Hysteresis of a transformer core



Alternatively (without Power-CASSY):



## Experiment description

In a transformer core (ferromagnet) the magnetic field

$H = N_1/L \cdot I$

is proportional to the coil current I and the effective turns density $N_1/L$ of the primary coil. However, the generated magnetic flux density or magnetic induction

$B = \kappa_r \cdot \kappa_0 \cdot H$ (where $\kappa_0 = 4\pi \cdot 10^{-7}$ Vs/Am)

is not proportional to H. Rather, it reaches a saturation value $B_s$ as the magnetic field H increases. The relative permeability $\kappa_r$ of the ferromagnet depends on the magnetic field strength H, and also on the previous magnetic treatment of the ferromagnet. In a demagnetized ferromagnet, the magnetic field strength is B = 0 T at H = 0 A/m. Normally however, a ferromagnet still retains a residual magnetic flux density B not equal to 0 T when H = 0 A/m (remanence).

Thus, it is common to represent the magnetic induction B in the form of a hysteresis curve as a function of the rising and falling field strength H. The hysteresis curve differs from the magnetization curve, which begins at the origin of the coordinate system and can only be measured for completely demagnetized material (H = 0 A/m, B = 0 T).

In this example H and B are not measured directly; rather, the quantities proportional to these, i.e. the primary current $I = L/N_1 \cdot H$ and magnetic flux $\Phi = N_2 \cdot A \cdot B$ through the secondary coil are used ($N_2$: number of turns of secondary coil; A: cross-section of ferromagnet). The magnetic flux Φ is calculated as the integral of the voltage U induced in the secondary coil.

## Equipment list

| | | |
|---|---|---|
| 1 | Power-CASSY | 524 011 |
| 1 | Sensor-CASSY | 524 010 or 524 013 |
| 1 | CASSY Lab 2 | 524 220 |
| 1 | U-core with yoke | 562 11 |
| 1 | Clamping device with spring clip | 562 121 |
| 2 | Coils with 500 turns | 562 14 |
| 4 | Connecting leads, 100 cm, black | 500 444 |
| 1 | PC with Windows XP/Vista/7 | |

## Alternatively (without Power-CASSY)

| | | |
|---|---|---|
| 1 | Sensor-CASSY | 524 010 or 524 013 |
| 1 | CASSY Lab 2 | 524 220 |
| 1 | U-core with yoke | 562 11 |
| 1 | Clamping device with spring clip | 562 121 |
| 2 | Coils with 500 turns | 562 14 |
| 1 | Function generator S12 | 522 621 |
| 1 | STE resistor 1 Ω, 2 W | 577 19 |
| 1 | Socket board section | 576 71 |
| 1 | Connecting lead, 50 cm, black | 500 424 |
| 7 | Connecting leads, 100 cm, black | 500 444 |
| 1 | PC with Windows XP/Vista/7 | |

## Experiment setup (see drawing)

Power-CASSY supplies the current for the primary coil of the transformer. The magnetic flux Φ is calculated from the induction voltage U of the secondary coil, which is measured at Sensor-CASSY input B.

Alternatively, you can perform the experiment without Power-CASSY, using the function generator S12. This apparatus must be set to sawtooth signal, frequency around 0.1 Hz and amplitude about 2 V. Recording of the magnetization curve is triggered at I = 0 A. To hit this point exactly, the current is shunted past the transformer by the relay and flows through a 1 Ω resistor prior to recording of the curve.

## Carrying out the experiment

■ Load settings

- Correct the offset if necessary: open Settings UB, select **Correct**, set the first target value 0 V and click on **Correct Offset**.
- Demagnetize the transformer core, e.g. by striking the end face of the yoke against the end faces of the U-core several times.
- Start the measurement with ⏱.

- Stop the measurement with ⏱ after one period of the hysteresis curve or at Φ = 0 Vs (in this case the core does not have to be demagnetized again).
- If the hysteresis curve lies in the second and fourth quadrants, reverse the connections on one of the two coils.
- If the display instrument $U_B$ is overdriven during measurement (display flashes), extend the measuring range in Settings UB.

### Evaluation

As the area of a hysteresis loop B(H)

$$\int B \cdot \mathrm{d}H = \frac{E}{V}$$

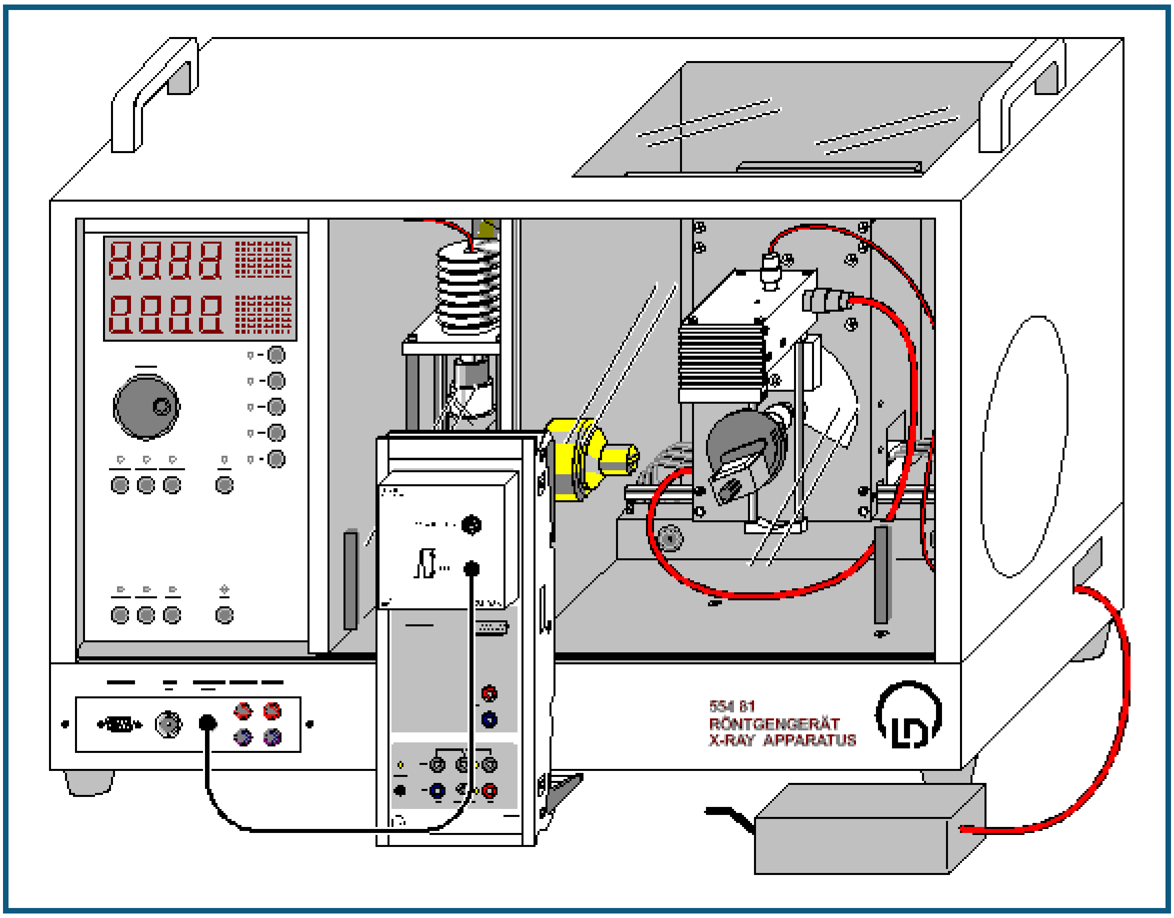
just corresponds to the energy loss in remagnetization per volume V of the demagnetized material, the enclosed area in the diagram Φ(I)

$$\int \Phi \cdot \mathrm{d}I = \int N_2 AB \cdot \frac{L}{N_1} \cdot \mathrm{d}H = \frac{N_2}{N_1} V \int B \cdot \mathrm{d}H = \frac{N_2}{N_1} \cdot E$$

gives us precisely the energy loss E of the remagnetization for $N_1=N_2$.

In the diagram, you can calculate this energy loss using "peak integration" of a hysteresis loop.

## Non-destructive analysis of the chemical composition (x-ray fluorescence)



can also be carried out with Pocket-CASSY

### Safety notes

The X-ray apparatus fulfils all regulations on the design of an X-ray apparatus and fully protected device for instructional use and is type approved for school use in Germany (BfS 05/07 V/Sch RöV or NW 807 / 97 Rö).

The built-in protective and shielding fixtures reduce the dose rate outside the X-ray apparatus to less than 1 µSv/h, which is of the order of magnitude of the natural background radiation.

- Before putting the X-ray apparatus into operation, inspect it for damage and check whether the voltage is switched off when the sliding doors are opened (See instruction sheet of the X-ray apparatus).
- Protect the X-ray apparatus against access by unauthorized persons.

Avoid overheating of the anode in the X-ray tube.

- When switching the X-ray apparatus on, check whether the ventilator in the tube chamber starts rotating.

The goniometer is positioned solely by means of electric stepper motors.

- Do not block the target arm and the sensor arm of the goniometer and do not use force to move them.

### Experiment description

When a sample is irradiated with high energy x-ray photons it will emit characteristic x-ray lines whose energy depends on the atomic number of the element of the sample material. This dependency is the topic of the experimental examples of Moseley's law (K-line and L-line x-ray fluorescence)

If a sample consists of a chemical compound or mixture, its fluorescence spectrum will also be complex. Because the inner electron shells between which the x-ray transitions occur are not involved in the chemical bonds, the characteristic lines are largely independent of the chemical bonds in the element. This means that the x-ray fluorescence spectra of a chemical compound are, to a first approximation, a superposition of the spectra of its components.

For the qualitative analysis of the chemical composition of a sample, initially all the peaks found in the fluorescence spectrum are correlated to the elements. This is done by means of the values for the energies of the characteristic lines found in the table. For the correlation, the "pattern" of each of the spectral series is also considered: for example, together with the $K_\alpha$-line there must also be the $K_\beta$-line with a lesser (approx. one fifth to one tenth) intensity in the spectrum. The $L_\alpha$-line appears accompanied by the $L_\beta$-line of a similar intensity and the $L_\gamma$-line of a lesser intensity.

Information about the relative concentrations of individual elements in the compound can be gained from the relative intensities of their fluorescence lines.

## Equipment list

| | | |
|---|---|---|
| 1 | Sensor-CASSY | 524 010 or 524 013 |
| 1 | CASSY Lab 2 | 524 220 |
| 1 | MCA box | 524 058 |
| 1 | X-ray apparatus with x-ray tube Mo | 554 801 or 554 811 |
| 1 | Target set of alloys | 554 848 |
| 1 | X-ray energy detector | 559 938 |
| 1 | HF cable, 1 m | 501 02 |
| 1 | PC with Windows XP/Vista/7 | |

## Experiment setup (see drawing)

- Guide the connection cable for the table-top power supply through the empty channel of the x-ray apparatus and connect it to the mini-DIN socket of the x-ray energy detector.
- Secure the sensor holder with the mounted x-ray energy detector in the goniometer sensor arm
- Connect the signal output of the x-ray energy detector to the BNC socket SIGNAL IN of the x-ray apparatus by means of the BNC cable included
- Feed enough connection cable through to make complete movement of the sensor arm possible
- Press the SENSOR button and set the sensor angle with the rotary adjuster ADJUST manually to 90°
- Set the distances between the slit aperture of the collimator and the axis of rotation as well as between the axis of rotation and the window of the x-ray energy detector both to 5 to 6 cm
- Press the TARGET button and adjust the target angle manually using the rotary button ADJUST to 45°.
- Connect Sensor-CASSY to the computer and connect the MCA box
- Connect the SIGNAL OUT output in the connection panel of the x-ray apparatus to the MCA box by means of the BNC cable.

## Carrying out the experiment

■ Load settings

- Connect the table-top power supply to the mains (after approx. 2 min the LED will glow green and the x-ray energy detector will be ready for use)
- Place the calibration target (galvanized steel plate) from the scope of delivery for the x-ray energy detector onto the table
- Set the tube high voltage U = 35 kV, emission current I = 1.00 mA and switch the high voltage on
- Start the spectrum recording with ⏱
- Then record spectra for the four targets in the target set of alloys

## Energy calibration

The energy calibration of the spectra is made using the spectrum of the calibration target (Fe+Zn).

- Open in the Settings EA (right mouse button) the Energy calibration, select **Global for all spectra of this input** and enter on the right-hand side the energies of the Fe $K_\alpha$-line (6.40 keV) and of the Zn $K_\alpha$-line (8.64 keV).
- In the context menu of the diagram select Calculate peak center, mark the Fe $K_\alpha$-line and enter the result in the left-hand side of the Energy calibration (e.g. with drag & drop from the status line)
- Then determine the centre for the Zn $K_\alpha$-line and also enter it on the left-hand side
- Switch the display to energy (e.g. with Drag & Drop of $E_A$ into the diagram)
- In the context menu of the diagram select Set Marker → X-ray Energies → Fe and Set Marker → X-ray Energies → Zn for identification and labeling of the lines.

It becomes apparent that four of the measured peaks have been caused by the fluorescence of the main components Fe and Zn of the galvanized steel plate.

## Evaluation

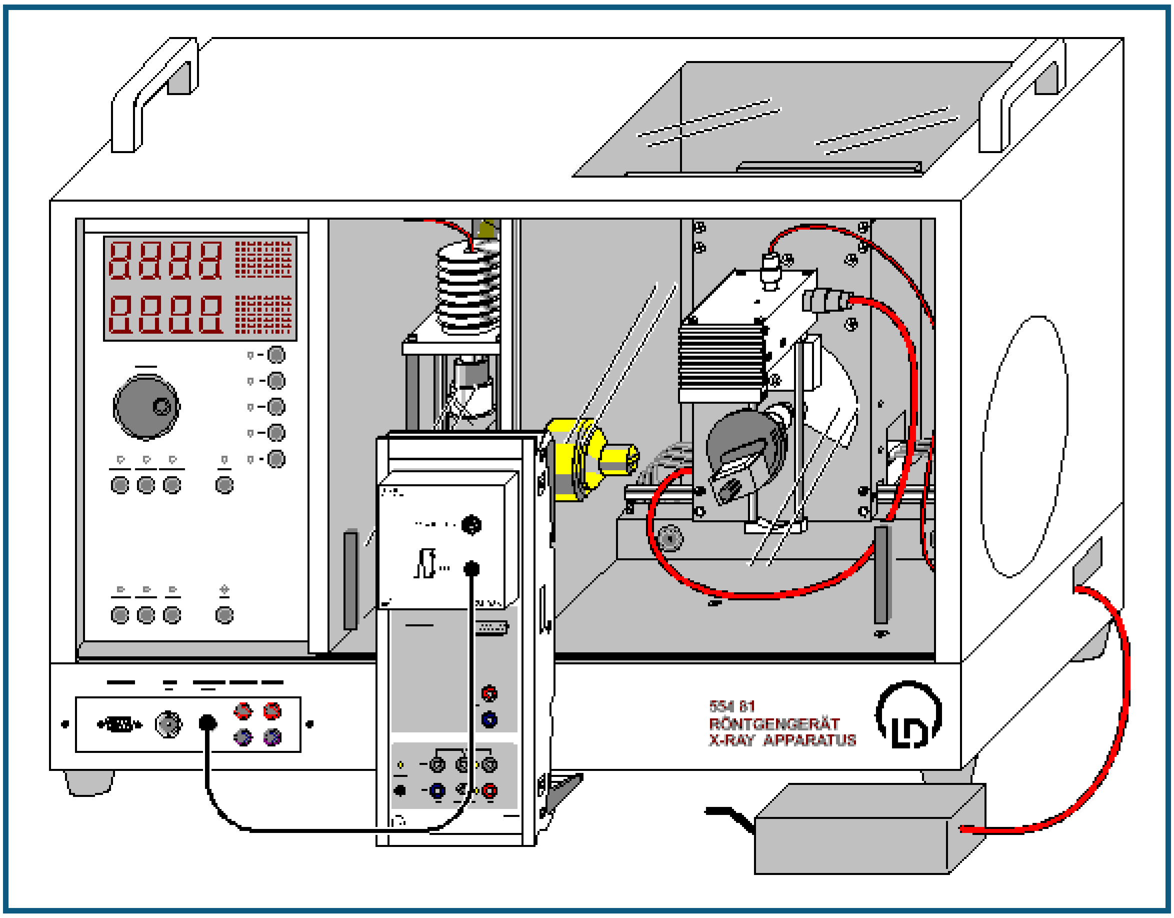
For the identification of the components of the alloys:

- Select spectrum and mark a suitable section
- In the context menu of the diagram select Set Marker → X-ray Energies and an element symbol and determine a suitable element by means of the displayed markers for its x-ray energies.
- Place the markers by clicking on the element symbol and determine further components of the alloy.

The results of the qualitative investigation of the alloys by means of their x-ray fluorescence spectra correspond to the known chemical composition:

- Target 1: Stainless steel X5CrNi18-10 – contains 72 % Fe, 18 % Cr, 10 % Ni.
- Target 2: Brass CuZn36 – contains 64 % Cu, 36 % Zn.
- Target 3: Brass CuZn39Pb3 – contains 58 % Cu, 39 % Zn, 3% Pb.
- Target 4: Praseodymium-samarium-cobalt magnet. These magnets can, in addition to Co, Sm, Pr, also contain Fe, Cu and Zr. Also the K-lines of bromium can be found, which originate from the fire-retardant in the plastic support.

## Determination of the chemical composition of a brass sample (x-ray fluorescence)



can also be carried out with Pocket-CASSY

### Safety notes

The X-ray apparatus fulfils all regulations on the design of an X-ray apparatus and fully protected device for instructional use and is type approved for school use in Germany (BfS 05/07 V/Sch RöV or NW 807 / 97 Rö).

The built-in protective and shielding fixtures reduce the dose rate outside the X-ray apparatus to less than 1 µSv/h, which is of the order of magnitude of the natural background radiation.

- Before putting the X-ray apparatus into operation, inspect it for damage and check whether the voltage is switched off when the sliding doors are opened (See instruction sheet of the X-ray apparatus).
- Protect the X-ray apparatus against access by unauthorized persons.

Avoid overheating of the anode in the X-ray tube.

- When switching the X-ray apparatus on, check whether the ventilator in the tube chamber starts rotating.

The goniometer is positioned solely by means of electric stepper motors.

- Do not block the target arm and the sensor arm of the goniometer and do not use force to move them.

When handling heavy metals or allergen substances from the target set, observe their operating instructions.

### Experiment description

In this experiment, the quantitative analysis of the chemical composition of a brass sample containing lead is carried out. The components in this alloy were already identified in the experiment Non-destructive analysis of the chemical composition.

For calculating the mass ratios, the fact is made use of that the height of a peak is proportional to the number n of radiating atoms. In the reference spectrum this number $n_0$ is determined by the density of the substance ρ, its atomic weight A, the radiated area S and the effective thickness d of the irradiated layer:

$n_0 = S \cdot d \cdot \rho / A$.

For the number of atoms of each type in the alloy, to first approximation the expression

$n = n_0 \cdot H/H_0 = V \cdot \rho/A \cdot H/H_0$

can be used. In this H and $H_0$ are the peak heights in the spectrum to be analyzed and in the reference spectrum is V= S·d the irradiated volume. Using this information, the mass ratio $C_i$ of the element number i in the alloy is

$$C_i = \frac{n_i \cdot A_i}{\sum\limits_j n_j \cdot A_j} = \frac{\rho_i \cdot \dfrac{H_i}{H_{0i}}}{\sum\limits_j \rho_j \cdot \dfrac{H_{0j}}{H_{0j}}}$$

## Equipment list

| | | |
|---|---|---|
| 1 | Sensor-CASSY | 524 010 or 524 013 |
| 1 | CASSY Lab 2 | 524 220 |
| 1 | MCA box | 524 058 |
| 1 | X-ray apparatus with x-ray tube Mo | 554 801 or 554 811 |
| 1 | Target set of alloys | 554 848 |
| 1 | Target set for K-line fluorescence | 554 844 |
| 1 | Target set for L-line fluorescence | 554 846 |
| 1 | X-ray energy detector | 559 938 |
| 1 | HF cable, 1 m | 501 02 |
| 1 | PC with Windows XP/Vista/7 | |

## Experiment setup (see drawing)

- Guide the connection cable for the table-top power supply through the empty channel of the x-ray apparatus and connect it to the mini-DIN socket of the x-ray energy detector.
- Secure the sensor holder with the mounted x-ray energy detector in the goniometer sensor arm
- Connect the signal output of the x-ray energy detector to the BNC socket SIGNAL IN of the x-ray apparatus by means of the BNC cable included
- Feed enough connection cable through to make complete movement of the sensor arm possible
- Press the SENSOR button and set the sensor angle with the rotary adjuster ADJUST manually to 90°
- Set the distances between the slit aperture of the collimator and the axis of rotation as well as between the axis of rotation and the window of the x-ray energy detector both to 5 to 6 cm
- Press the TARGET button and adjust the target angle manually using the rotary button ADJUST to 45°.
- Connect Sensor-CASSY to the computer and connect the MCA box
- Connect the SIGNAL OUT output in the connection panel of the x-ray apparatus to the MCA box by means of the BNC cable.

## Carrying out the experiment

☐ Load settings

- Connect the table-top power supply to the mains (after approx. 2 min the LED will glow green and the x-ray energy detector will be ready for use)
- Place target 3 (brass containing lead) from the target set of alloys onto the target table
- Set the tube high voltage U = 35 kV, emission current I = 1.00 mA and switch the high voltage on
- Start the spectrum recording with ⏱
- Finally, record the spectra for the targets Cu, Zn and Pb from the target sets for K-lines and L-lines fluorescence as reference spectra

## Energy calibration

The energy calibration is carried out using the spectra of copper and lead (reference spectra).

- Open in the Settings EA (right mouse button) the Energy calibration, select **Global for all spectra of this input** and enter on the right-hand side the energies of the Cu $K_\alpha$-line (8.04 keV) and of the Pb $L_\alpha$-line (10.56 keV).
- In the context menu of the diagram select Calculate peak center, mark the Cu $K_\alpha$-line and enter the result in the left-hand side of the Energy calibration (e.g. with drag & drop from the status line)
- Then determine the centre for the Pb $L_\alpha$-line and also enter it on the left-hand side.
- Switch the display to energy (e.g. with Drag & Drop of $E_A$ into the diagram)

## Evaluation

For identifying and labeling the lines in the brass spectrum:

- In the context menu of the diagram select Set Marker → X-ray Energies → Fe
- Then enter the lines of zinc (**Zn**) and lead (**Pb**)

It becomes apparent that the second-highest peak in the spectrum consists of two lines which are not resolved: Zn $K_\alpha$ and Cu $K_\beta$. The Cu $K_\beta$-line is in part superimposed with the Zn $K_\alpha$-line.

The mass ratios of the alloy components are calculated by comparing the heights of the strongest lines in the fluorescence spectrum of brass and the reference spectra. These lines are: the copper $K_\alpha$, the zinc $K_\alpha$ and the lead $L_\alpha$.

For the determination of the heights of the Cu $K_\alpha$ and the Zn $K_\alpha$, the brass fluorescence spectrum must be resolved in the energy range from 7.5 keV to 9.1 keV. For this the spectrum in this range is fitted with three Gaussian curves of equal width at the known energies of the Cu $K_\alpha$-line (E = 8.04 keV), the Cu $K_\beta$-line (8.91 keV) and the Zn $K_\alpha$-line (8.64 keV). The best way to do this is using the fit Gaussians of specified Energies. When selecting the area, it must be observed that all the three required energy lines are contained in the area (do not include the Pb $L_l$-line).

The result is a fitted contour of the fluorescence spectrum. The determined heights H are found in the status line and are to be entered in the **Mass Proportion** diagram (e.g. by drag & drop) together with the densities ρ for Cu (ρ = 8.96 g/cm$^3$), Zn (ρ = 7.10 g/cm$^3$) and Pb (ρ = 11.34 g/cm$^3$).

The same applies to the heights $H_0$ for the three reference spectra. When the three densities and the six heights have been entered, the three mass ratios are automatically calculated.

The determined mass ratios of the alloy components in the brass sample correspond well to the known chemical composition (CuZn39Pb3).

| Element | Stated | Experimental |
|---|---|---|
| Copper | 58 % | 61.6 % |
| Zinc | 39 % | 35.6 % |
| Lead | 3 % | 2.9 % |

## Additional information

The example of the copper-zinc alloy (brass) shows how the secondary fluorescence modifies the spectrum shape. During the irradiation of such a sample with x-ray photons, the K-lines of both copper and zinc are excited. But because the $K_\beta$-line of zinc (E = 9.57 keV) lies above the K-edge of copper (E = 8.99 keV), it can also "secondarily" excite the copper L-lines.

Therefore, in the fluorescence radiation emitted, the intensity of the copper lines is higher at the cost of the Zn $K_\beta$-line, and the ratio of the Zn $K_\alpha$ and the $K_\beta$-lines does not correspond to the ratio found in pure zinc. For this reason, the mass ratio of the alloy components determined from the $K_\alpha$-lines indicates a slightly too high proportion of copper.

## Experiment examples chemistry

These experiment examples support you in using CASSY Lab. Where applicable, the corresponding experiment number is also given. The measurement data or settings for the examples can be loaded directly into CASSY Lab. Simply click the symbols ▢ in the descriptions. New examples are labeled with a red •.

### Inorganic Chemistry

- The Bunsen burner
- C1.3.1.6a pH measurement on foodstuffs
- C1.3.1.6b pH measurement on cleaning agents
- C1.3.1.7 Determining the pKa value of acetic acid
- C1.3.1.8 Titration of phosphoric acid

### Analytical Chemistry

- C3.1.1.2 Melting and solidification point of palmitic acid
- Supercooling a melt of sodium thiosulphate
- C3.1.4.5 Determining the molar mass by way of freezing-point depression
- Titration of hydrochloric acid with caustic soda solution (pH and conductivity)
- C3.3.7.2 Titration of household vinegar
- Titration of acetic acid with caustic soda solution (pH and conductivity)
- Automatic titration of NH3 with NaH2PO4 (piston burette)
- Automatic titration (drop counter)
- C3.4.4.1 Gas chromatography (separation of alkanes from lighter gas)
- C3.4.4.2 Gas chromatography (separation of alcohols)
- C3.4.4.3 Gas chromatography (separation of air)
- C3.5.2.1 Recording the spectrum of a solution of crude chlorophyll (with the spectrophotometer 667 3491)

### Physical Chemistry

- Reaction of marble with hydrochloric acid (determining the carbonate content)
- Splitting of urea by urease (zero-order reaction)
- C4.3.2.3 Hydrolysis of tertiary butyl chloride (determining the reaction order)
- Reaction of marble with hydrochloric acid (determining the reaction order)
- C4.3.2.4 Alkaline hydrolysis of ethyl acetate (determining the reaction order)
- Alkaline hydrolysis of ethyl acetate (determining the activation parameters)
- C4.4.3.5 Differential thermal analysis of copper sulphate
- Preparing a freezing mixture
- C4.4.4.5 Determining the melting enthalpy of ice
- C4.6.1.1 Determining the conductivity of different solutions
- C4.6.1.4 Determining the limiting equivalent conductivity of sodium chloride
- C4.6.1.5 Determining the dissociation constant of acetic acid

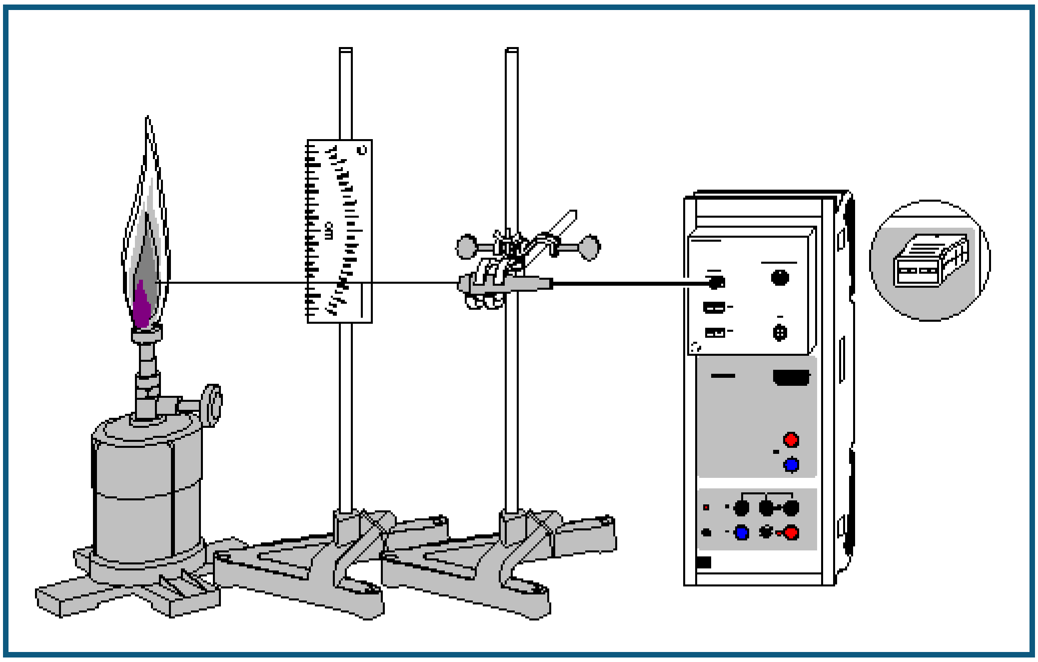
### Technical Chemistry

- C5.2.4.2 Separation of a two-component mixture using the rectification apparatus CE2

### Environmental Technology

- Absorption of UV radiation
- C6.1.4.3 Simulation of the ozone hole
- C6.1.4.4 Greenhouse effect of CO2

## The Bunsen burner



can also be carried out with Pocket-CASSY and Mobile-CASSY

### Safety note

- Danger of burn. Tie back your hair and take off scarves in order to prevent them from catching fire by mistake.
- Close the gas supply immediately when the flame strikes back because of excess air supply.
- If the gas burner is not used for some time, set it to luminous flame and reduce the gas flow.
- Do not set up the gas burner near the edge of a table.

### Experiment description

The gas burner is a device which is particularly often used in chemistry laboratories. In consists of a barrel with adjustable air supply. Gas can flow into the barrel through a nozzle. Depending on the design, the air supply is adjusted by means of a screw disc or another adjustable opening. If the air supply is closed, the flame obtained will luminesce in a color between yellow and orange and reach temperatures of up to 600 °C. If the air supply is opened, the gas air mixture will burn with a rustling, bluish, non-luminous flame and produce substantially higher temperatures. The temperature regions of the flame, which depend on the height over the burner tip, can be studied very well by means of a NiCr-Ni temperature sensor.

### Equipment list

| | | |
|---|---|---|
| 1 | Sensor-CASSY | 524 010 or 524 013 |
| 1 | CASSY Lab 2 | 524 220 |
| | | |
| 1 | Chemistry box or NiCr-Ni adapter S | 524 067(3) |
| 1 | Temperature sensor NiCr-Ni, type K | 529 676 |
| | or | |
| 1 | Temperature box | 524 045 |
| 1 | Temperature sensor NiCr-Ni, DIN plug | 666 193 |
| | | |
| 1 | Gas burner, e.g. | 666 714 |
| 2 | Stand bases, V-shape, 20 cm | 300 02 |
| 2 | Stand rods, 47 cm | 300 42 |
| 1 | Dual scale | 340 82 |
| 1 | Clamping block MF | 301 25 |
| 2 | Support clips, for plugging in | 314 04 |
| 1 | Crossed bosshead | 666 543 |
| 1 | Miniature clamp | 666 551 |
| | Matches or lighter | |

1 PC with Windows XP/Vista/7

### Experiment setup (see drawing)

Connect the chemistry box (or, alternatively, the temperature box) to input A of the Sensor-CASSY, and plug the temperature sensor into input $T_1$.

Using the stand material, set up two stands: attach the dual scale to one stand by means of the clamping block and the support clips so that the lower edge of the scale is at the same height as the tip of the gas burner. Using the miniature clamp, attach the temperature sensor to the other stand, and align it exactly horizontally.

Set up the two stands around the gas burner so that the height over the burner tip is indicated by the test prod of the temperature sensor on the centimeter scale. At the same time, the outermost tip of the temperature sensor should be located immediately over the opening of the burner. When setting up the stands, see to it that you can adjust the height of the thermocouple without getting burnt.

### Carrying out the experiment

■ Load settings

Remark: By means of NiCr-Ni temperature sensors, temperatures of up to 1150 °C (temperature sensor for chemistry box) or 1100 °C (temperature sensor for temperature box), respectively, can be measured. Do not exceed this measuring range.

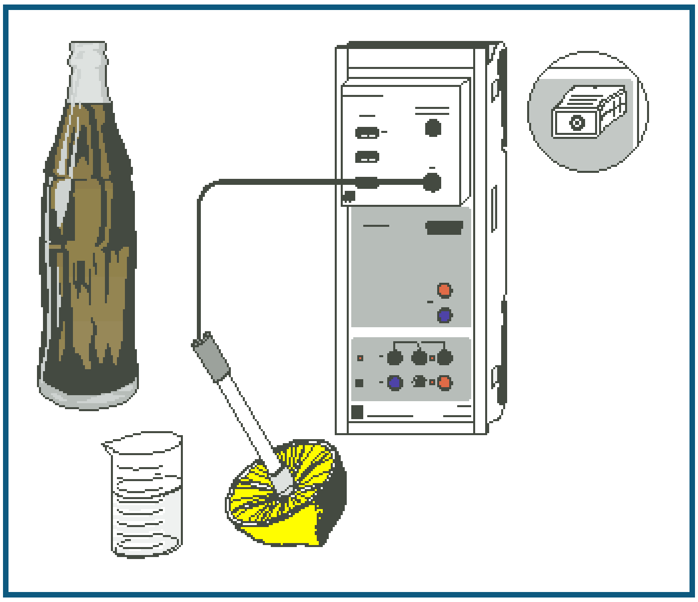
- Light the gas burner with luminous flame (air supply closed). Then open the air supply until the flame rustles.
- Fix the temperature sensor at the upper end of the measuring scale. See to it that the tip is exactly in the centre of the flame.
- Wait until the displayed measured value is almost stable (±5 °C). Record the measured value with ⏱. Via the display instrument, which is accessed via the $\vartheta_{A11}$ button at the upper edge of the screen, the instantaneous value of the temperature can be displayed on the full screen so that persons who are sitting at a distance are able to read the temperature.
- Click the corresponding cell of the table, and enter the height over the burner tip associated with the measured value via the key board.
- When accessing another color region of the flame (outer cone: weakly bluish, inner cone: light blue), select Diagram → Set Marker → Vertical Line, and mark the position by a vertical line. With Diagram → Set Marker → Text a text related to the mark can be added.
- Lower the temperature sensor by 1 cm and repeat the measurement.
- When reaching the light blue region of the flame, make the measurements in steps of 0.5 cm.

### Evaluation

As expected, the temperature in the central region of the burner flame is higher than at a certain height above the flame. However, the temperatures generated by the light blue flame just above the outlet opening is much lower than the temperature generated by the weakly bluish flame a few centimeters above. From this it can be concluded that the gas used is only completely burnt above the light blue region of the flame.

When chemical experiments are carried out, the different temperatures of the regions of the burner flame can be taken advantage of. If particularly high temperatures are desired, the region immediately above the light blue flame is used for heating. If the heating temperature should be lower, a greater distance from the burner tip is chosen.

## pH measurement on foodstuffs



can also be carried out with Pocket-CASSY and Mobile-CASSY

### Experiment description

In this experiment, the pH values of foodstuffs, particularly of drinks, are investigated.

The pH value is a measure for the acidic strength or basic strength, respectively, of a solution. It is defined as the negative decimal logarithm of the concentration of $H_3O^+$ ions in an aqueous solution:

$$pH = - \lg c(H_3O^+)$$

The concentration of $H_3O^+$ ions depends on the autoprotolysis equilibrium of water:

$$H_2O + H_2O \rightleftharpoons H_3O^+ + OH^-$$

In dilute solutions, the equilibrium is independent of the concentration of water molecules; at 25 °C, the equilibrium constant is:

$$K = c(H_3O^+) \cdot c(OH^-) = 10^{-14}\ mol^2/l^2$$

That means, the concentration of hydronium ions and the concentration of hydroxyl ions in a solution are related via the protolysis equilibrium of water; their product always equals $10^{-14}$ mol²/l². Therefore acidic solutions (hydronium ions predominate) have a pH value between 0 an 7, and basic solutions (hydroxyl ions predominate) have a pH value between 7 and 14.

Measuring the pH value is one of the most important procedures in chemical analysis. It is employed, e.g., for monitoring water quality, determining the concentrations of acidic and basic solutions, monitoring manufacturing processes (e.g. foodstuffs, body care products, paint and lacquer) and determining air pollution (acidic rain). In many biochemical processes, e.g. digestion, the pH value plays an important role.

### Equipment list

| | | |
|---|---|---|
| 1 | Sensor-CASSY | 524 010 or 524 013 |
| 1 | CASSY Lab 2 | 524 220 |
| 1 | Chemistry box or pH adapter S | 524 067(2) |
| 1 | pH electrode with BNC plug | 667 4172 |
| 1 | Temperature sensor NiCr-Ni (if needed) | 529 676 |
| 1 | Beaker, 250 ml, squat shape | 664 130 |
| 1 | Laboratory knife | 667 018 |
| 1 | PC with Windows XP/Vista/7 | |

### Required substances

Tap water
Foodstuffs/drinks, e.g.:

| | |
|---|---|
| mineral water with and without carbonic acid | |
| water from a furred boiler | |
| fizzy drinks/cola | |
| fruit juice | |
| 1 lemon | |
| coffee | |
| various kinds of tea | |
| vinegar | |
| cooking oil | |
| milk | |
| Buffer solution pH 4.00 e.g. 250 ml | 674 4640 |
| Buffer solution pH 7.00 e.g. 250 ml | 674 4670 |

### Experiment setup (see drawing)

Plug the chemistry box with the connected pH electrode into input A of the Sensor-CASSY.

Alternatively, connect the pH box with the single-rod pH electrode to input A of the Sensor-CASSY.

Prepare hot drinks (coffee, tea) in good time in order that they have sufficiently cooled down when you start the measurements. If the solutions are still hot and if the chemistry box is used, a temperature sensor can be connected to input $T_1$ for temperature compensation. In this case, the pH electrode and the temperature sensor are immersed together in the solution. CASSY Lab then automatically calculates the pH value corresponding to a temperature of 25 °C.

Cut the lemon open with the knife, and form a hollow where the juice can accumulate. The hollow has to be deep enough for the pH electrode to be immersed up to the diaphragm.

Be sure to read the Instruction Sheet for the pH electrode.

### Calibration

In order to obtain accurate measuring results, you have to calibrate the pH electrode when you use it for the first time. Afterwards the calibration should be repeated from time to time:

Load settings

- Select **Correct** in Settings pHA1.
- Rinse the pH electrode with distilled water, immerse it in the buffer solution pH 7.00, and agitate it briefly.
- Enter 7.00 as the first target value. When the measured value is stable, press the **Correct Offset** button.
- Rinse the pH electrode with distilled water, immerse it in the buffer solution pH 4.00, and agitate it briefly.
- Enter 4.00 as the second target value. When the measured value is stable, press the **Correct Factor** button.
- Mark the Sensor-CASSY, the pH electrode, and the chemistry or pH box in order that they can be used at the same input later on (otherwise the stored calibration will not be applicable).

### Carrying out the experiment

Load settings

In the order: tap water, mineral waters, fizzy drinks/coke, fruit juices, lemon, teas, coffee, milk, vinegar, oilkeep to the following sequence:

- Pour the liquid into the beaker (leave the lemon juice in the hollow for the measurement).
- Immerse the pH electrode so that the diaphragm is just immersed, and wait until a stable value is displayed.
- Record the measured value with ⏱.
- Add a caption to the measured value in the diagram with Diagram → Set Marker → Text and entering the examined substance.
- Pour the substance away (do not drink it!), and rinse the beaker thoroughly.

### Evaluation

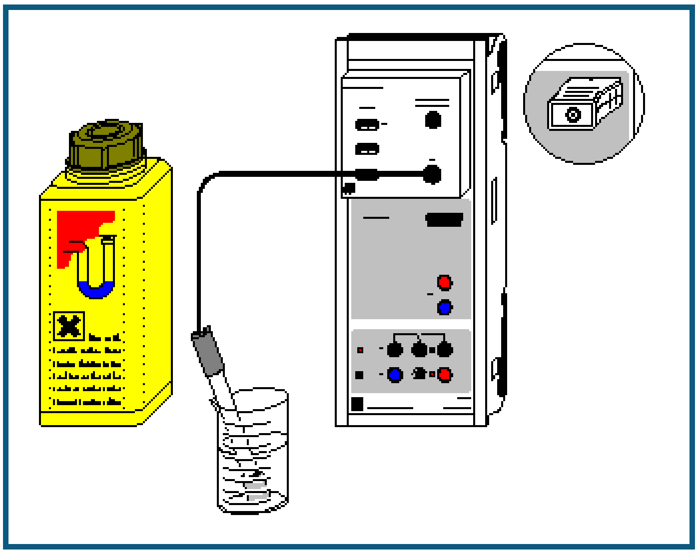
Almost all of the liquids examined in this experiment have a pH value below 8, i.e. they are acidic or neutral. Drinks such as fruit juices, fruit teas, and fizzy drinks have pH values between 2.5 and 4, which indicates that they are clearly acidic, whereas none of the substances examined exhibits a comparable degree of basic strength. The solution with a pH value of 8.9, which was the one with the strongest basicity, was obtained by warming water in a heavily furred water boiler; in this case, small amounts of dissolving calcium carbonate lead to an increase of the pH value by approx. 2 compared with tap water.

Drinks with a fruit juice content usually exhibit relatively strong acidic properties: This is particularly well seen on comparing the two kinds of tea examined in this example. The acidic character is caused by acids contained in fruit: organic acids such as citric acid, manic acid, and tartaric acid. Some of these acids also occur in human and animal metabolism (citric-acid cycle). Compared with drinks containing fruit juice, carbonic acid ($H_2CO_3$) in mineral water leads to a significantly weaker acidification. The low pH value of cola is above all caused by the phosphoric acid contained in it.

The predominantly acidic character of the examined foodstuffs stated, the process of neutralization of an acid or a base can be considered. What would happen in the stomach if strong basic liquids entered it? Maybe it is possible to examine the neutralizing function of remedies against heartburn (Maaloxan, sodium bicarbonate, salt of hartshorn).

The diagram generated can be printed via the printer symbol in the upper line on the screen.

## pH measurement on cleaning agents



can also be carried out with Pocket-CASSY and Mobile-CASSY

### Experiment description

In this experiment, the pH values of cleaning agents are investigated. Depending on the purpose of the cleaning agents, they may have any pH value from the entire pH scale.

The pH value is a measure for the acidic strength or basic strength, respectively, of a solution. It is defined as the negative decimal logarithm of the concentration of $H_3O^+$ ions in an aqueous solution:

$$pH = -\lg c(H_3O^+)$$

The concentration of $H_3O^+$ ions depends on the autoprotolysis equilibrium of water:

$$H_2O + H_2O \rightleftharpoons H_3O^+ + OH^-$$

In dilute solutions, the equilibrium is independent of the concentration of water molecules; at 25 °C, the equilibrium constant is:

$$K = c(H_3O^+) \cdot c(OH^-) = 10^{-14}\ mol^2/l^2$$

That means, the concentration of hydronium ions and the concentration of hydroxyl ions in a solution are related via the protolysis equilibrium of water; their product always equals $10^{-14}$ $mol^2/l^2$. Therefore acidic solutions (hydronium ions predominate) have a pH value between 0 an 7, and basic solutions (hydroxyl ions predominate) have a pH value between 7 and 14.

Measuring the pH value is one of the most important procedures in chemical analysis. It is employed, e.g., for monitoring water quality, determining the concentrations of acidic and basic solutions, monitoring manufacturing processes (e.g. foodstuffs, body care products, paint and lacquer) and determining air pollution (acidic rain). In many biochemical processes, e.g. digestion, the pH value plays an important role.

### Equipment list

| | | |
|---|---|---|
| 1 | Sensor-CASSY | 524 010 or 524 013 |
| 1 | CASSY Lab 2 | 524 220 |
| 1 | Chemistry box or pH adapter S | 524 067(2) |
| 1 | pH electrode with BNC plug | 667 4172 |
| 1 | Beaker, 100 ml, tall shape | 664 137 |
| 1 | Laboratory knife | 667 018 |
| 1 | PC with Windows XP/Vista/7 | |

### Required substances

Tap water
Cleaning agents, e.g.:
  washing-up liquid
  detergents containing acetic acid

| | |
|---|---|
| tube cleaner | |
| cleaning agents that are ecologically friendly | |
| For comparison: | |
| vinegar | |
| 1 lemon | |
| Buffer solution pH 4.00 e.g. 250 ml | 674 4640 |
| Buffer solution pH 7.00 e.g. 250 ml | 674 4670 |

## Experiment setup (see drawing)

Plug the chemistry box with the connected pH electrode into input A of the Sensor-CASSY.

Alternatively, connect the pH box with the single-rod pH electrode to input A of the Sensor-CASSY.

Cut the lemon open with the knife, and form a hollow where the juice can accumulate. The hollow has to be deep enough for the pH electrode to be immersed up to the diaphragm.

Be sure to read the Instruction Sheet for the pH electrode.

## Calibration

In order to obtain accurate measuring results, you have to calibrate the pH electrode when you use it for the first time. Afterwards the calibration should be repeated from time to time:

☐ Load settings

- Select **Correct** in Settings pHA1.
- Rinse the pH electrode with distilled water, immerse it in the buffer solution pH 7.00, and agitate it briefly.
- Enter 7.00 as the first target value. When the measured value is stable, press the **Correct Offset** button.
- Rinse the pH electrode with distilled water, immerse it in the buffer solution pH 4.00, and agitate it briefly.
- Enter 4.00 as the second target value. When the measured value is stable, press the **Correct Factor** button.
- Mark the Sensor-CASSY, the pH electrode, and the chemistry or pH box in order that they can be used at the same input later on (otherwise the stored calibration will not be applicable).

## Carrying out the experiment

☐ Load settings

For all cleaning agents examined in the experiment keep to the following sequence:

- Keeping to safety notes and dosage instructions (calculate the dosage for the volume of the beaker, which is 100 ml) that may be written on the package, prepare the solution to be examined in the beaker. If a cleaning agent is to be used undiluted, pour as little as possible (approx. 30 ml) into the beaker.
- Leave the lemon juice in the hollow for the measurement.
- Immerse the pH electrode in the solution so that the diaphragm is just immersed, and wait until a stable value is displayed.
- Record the measured value with ⏱.
- Add a caption to the measured value in the diagram with Diagram → Set Marker → Text and entering the examined substance.
- Pour the substance away, and rinse the beaker thoroughly with tap water.

## Evaluation

Depending on the purpose, cleaning agents can have any pH value from strongly acidic to strongly basic.

Particularly agents for removing lime deposits and for cleaning bathrooms have relatively low pH values, which may even correspond to hydrochloric acid of approx. 0.3 mol/l concentration. This is due to the lime dissolving reaction of $CaCO_3$ with acids, which is used for removing lime deposits:

$$CaCO_3 + 2H_3O^+ \xrightarrow[aq]{} Ca^{2+} + CO_2\uparrow + 3H_2O$$

As the acidity of these cleaning agents is sometimes quite strong, the instruction saying that protective gloves should be worn is right in place on the package.

The ecologically friendly agent containing citric acid does not dissolve $CaCO_3$ through the acidic character of citric acid, but through formation of a water soluble complex of citric acid and calcium ions. In this way the low pH value of other cleaning agents can be avoided.

As basic soap solution also damages the skin, nowadays washing-up liquids for dissolving fat and oil mainly contain neutral surfactants instead of basic soaps. This shows up in the pH value of the examined washing-up liquid, which indicates approximate neutrality. However, as the surface of human skin is slightly acidic (around pH 5.5), this washing-up liquid will also mean stress to the skin although to a lesser extent.

Among strongly basic cleaning agents there are, above all, tube cleaners, which have to dissolve fat deposits and hair at places where mechanical cleaning is impossible. These tube cleaners contain high concentrations of sodium hydroxide (NaOH) and often, in addition, hypochlorites, e.g. NaOCl, as oxidizing agents. Tube cleaners that contain hypochlorites must not get into contact with other cleaning agents as corrosive chlorine gas is generated when acids are added to NaOCl and common salt, which is also contained in tube cleaners:

$$\mathrm{NaOCl} + \mathrm{NaCl} + 2\,\mathrm{H_3O^+} \rightarrow 2\,\mathrm{Na^+} + 3\,\mathrm{H_2O} + \mathrm{Cl_2} \uparrow$$

If usual pH electrodes are used, the pH value measured on the strongly basic tube cleaner is distorted by the so-called alkali error. Starting from pH values of approx. 12, glass electrodes display a value below the real one; therefore you can assume that the examined tube cleaner is even more basic.

As an alternative, economically friendly tube cleaners are supplied today, which are based on enzymes and are almost neutral. The cleaning agent examined in the example is supposed to decompose fat enzymatically. This is achieved under almost neutral conditions, which means that sewage is much less contaminated.

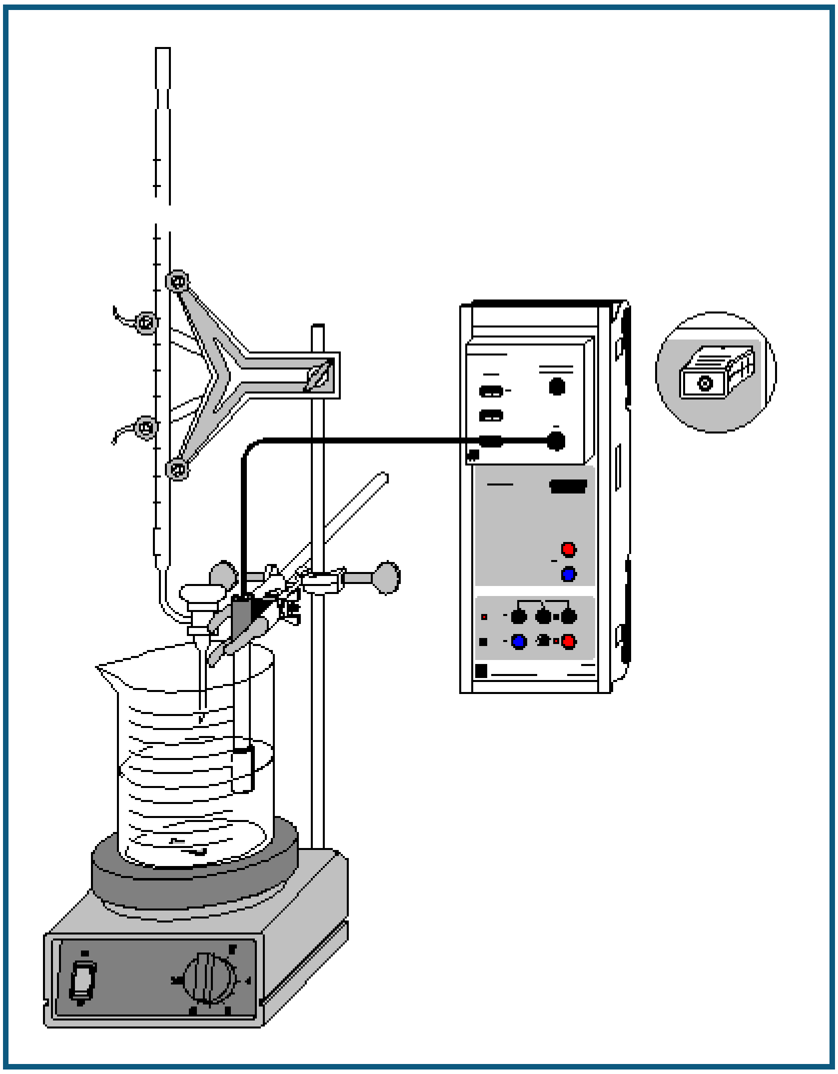
The diagram generated can be printed via the printer symbol in the upper line on the screen.

### Further experiment options

The pH values of other substances that occur in everyday life can be examined as well.

- An insertion electrode with a conical diaphragm enables solid pieces of soap and creams to be examined.
- Determining the pH value of human skin by means of an electrode with flat diaphragm before and after washing the skin with soaps may be interesting with regard to the question of whether these substances are well-tolerated by the skin.

## Determining the $pK_a$ value of acetic acid



can also be carried out with Pocket-CASSY and Mobile-CASSY

**Danger**

Acids and bases are caustic. Wear protective goggles and acid-resistant gloves.

### Experiment description

A measure for the strength of moderately strong or weak acids called the $pK_a$ value is determined from its titration curve with a strong base. Starting from the dissociation equation for the acid,

$$HA + H_2O \rightleftharpoons H_3O^+ + A^-$$

we obtain for the point of half equivalence (where half of the acid has reacted with the base):

$[A^-] = [HA]$.

From the equilibrium equation

$$K_a = \frac{[H_3O^+][A^-]}{[HA]}$$

it therefore follows that

$pK_a = pH$.

Thus the $pK_a$ value can easily be read after the equivalence point and the point of half equivalence of the titration have been determined.

### Equipment list

| | | |
|---|---|---|
| 1 | Sensor-CASSY | 524 010 or 524 013 |
| 1 | CASSY Lab 2 | 524 220 |
| 1 | Chemistry box or pH adapter S | 524 067(2) |
| 1 | pH electrode with BNC plug | 667 4172 |
| 1 | Magnetic stirrer | 666 8451 |
| 1 | Beaker, 250 ml, squat shape | 664 103 |
| 1 | Stand rod, 450 mm, M10 thread | 666 523 |
| 1 | Graduated pipette, 10 ml | 665 997 |
| 1 | Pipetting ball | 666 003 |
| 1 | Burette, 25 ml | 665 845 |
| 1 | Burette filling funnel | 665 816 |
| 1 | Burette clamp simple | 666 559 |
| 1 | Crossed bosshead | 666 543 |
| 1 | Universal clamp, 0...25 mm | 666 551 |
| 1 | PC with Windows XP/Vista/7 | |

### Chemicals

| | |
|---|---|
| Acetic acid, c = 0.1 mol/l | e.g. 500 ml: 671 9560 |
| Caustic soda solution, c = 0.1 mol/l | e.g. 500 ml: 673 8410 |
| Buffer solution pH 4.00 | e.g. 250 ml: 674 4640 |
| Buffer solution pH 7.00 | e.g. 250 ml: 674 4670 |
| Distilled water | |

### Experiment setup (see drawing)

Plug the pH box with the single rod pH electrode into input A of the Sensor-CASSY, which is connected to the PC.

Set up the titration assembly using the stand material, the magnetic stirrer, the beaker and the burette. Put about 100 ml of distilled water into the beaker and add exactly 10 ml of 0.1 M acetic acid by means of the pipette. Fill 0.1 M caustic soda solution into the burette through the funnel up to the zero mark.

Attach the pH electrode so that on the one hand the measuring diaphragm is completely immersed and on the other hand the glass membrane cannot be damaged by the rotating stirrer bar. In order to mark the equivalence point, you may add some drops of a phenolphthalein solution as an indicator.

### Calibration

In order to obtain accurate measuring results, you have to calibrate the pH electrode when you use it for the first time. Afterwards the calibration should be repeated from time to time:

☐ Load settings
- Select **Correct** in Settings pHA1.
- Rinse the pH electrode with distilled water, immerse it in the buffer solution pH 7.00, and agitate it briefly.
- Enter 7.00 as the first target value. When the measured value is stable, press the **Correct Offset** button.
- Rinse the pH electrode with distilled water, immerse it in the buffer solution pH 4.00, and agitate it briefly.
- Enter 4.00 as the second target value. When the measured value is stable, press the **Correct Factor** button.
- Mark the Sensor-CASSY, the pH electrode, and the pH box in order that they can be used at the same input later on (otherwise the stored calibration will not be applicable).

### Carrying out the experiment

☐ Load settings
- If you want to apply other volume steps than 0.2 ml, the entry can be changed in Settings V in the field Formula, e.g. by entering "0.5*n-0.5" for steps of 0.5 ml.
- Determine the first measured value with ⏱.
- Continuously add drops of caustic soda solution at a slow rate, and record the pH value in steps of 0.2 ml with ⏱.

### Evaluation

At the equivalence point ($V = V_{eq}$), the acetic acid has entirely reacted with the caustic soda solution:

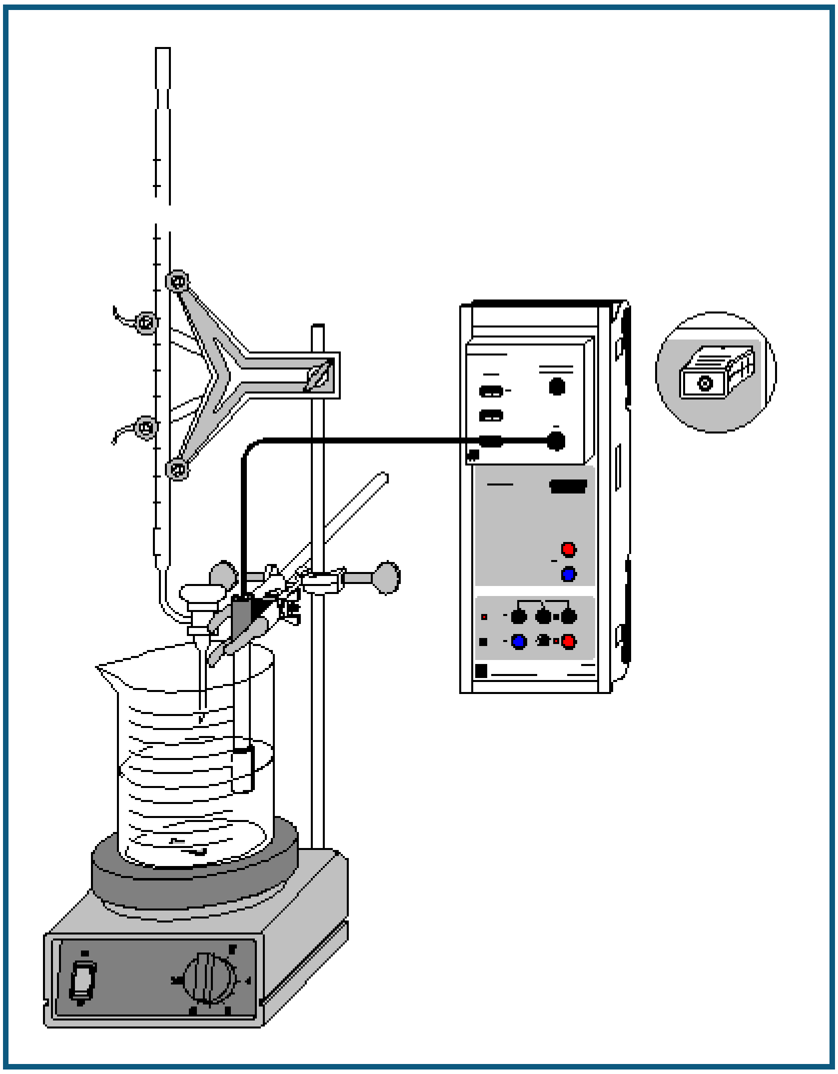
$HAc + NaOH \rightarrow Na^+ + Ac^- + H_2O$

In order to exactly determine the equivalence point with CASSY Lab, press the right mouse button in the diagram, select Other Evaluations → Find Equivalence Point. After marking the curve range, you will obtain a graphical display of the equivalence point and the $pK_a$ value as determined via the point of half equivalence ($V = V_{heq}$). The associated values are written below in the status line and can be inserted as text at an arbitrary place in the diagram.

## Further experiment options

By neutralizing a hydrochloric acid solution of the same pH value as the present acetic acid solution (approx. 10 ml of 0.01 M HCl) and comparing the two titration curves, the concept of a buffer solution can be introduced. The strongly diluted hydrochloric acid is already neutralized after 1 ml of NaOH has been added, whereas for neutralizing the acetic acid of similar acidity approx. 10 ml of NaOH are required. Determining the $pK_a$ value of the hydrochloric acid would not be meaningful.

## Titration of phosphoric acid



can also be carried out with Pocket-CASSY and Mobile-CASSY

**Danger**

Acids and bases are caustic. Wear protective goggles, gloves and clothing.

### Experiment description

Polybasic acids exhibit characteristic titration curves, which enable the $pK_a$ values of individual stages of protolysis to be determined following sections of the curve that have similar shapes.

In aqueous solution, phosphoric acid forms the following equilibria:

1. $H_3PO_4 + H_2O \rightleftharpoons H_2PO_4^- + H_3O^+ \quad (pK_{a1} = 2{,}1)$
2. $H_2PO_4^- + H_2O \rightleftharpoons HPO_4^{2-} + H_3O^+ \quad (pK_{a2} = 7{,}1)$
3. $HPO_4^{2-} + H_2O \rightleftharpoons PO_4^{3-} + H_3O^+ \quad (pK_{a3} = 12{,}3)$

As the differences between the $pK_a$ values amount to approx. 5 in each case, the equilibria can be considered independently of each other.

By titration with caustic potash solution, the equivalence points of the first and the second stage of protolysis can be determined. However, since KOH is not a substantially stronger base than the phosphate ion, the equilibrium 3 does not sufficiently tend to the right-hand side for the third equivalence point to be determined. In aqueous solution, the latter is only accessible in the opposite direction by titrating potassium phosphate, e.g., with hydrochloric acid.

In the pH range of the titration considered here (approx. pH 2 to pH 12), the hydrogenphosphates act as ampholytes, on the right-hand side of an equilibrium they represent the base of the respective acid-base pair, whereas on the left-hand side they have the function of the base.

### Equipment list

| | | |
|---|---|---|
| 1 | Sensor-CASSY | 524 010 or 524 013 |
| 1 | CASSY Lab 2 | 524 220 |
| 1 | Chemistry box or pH adapter S | 524 067(2) |
| 1 | pH electrode with BNC plug | 667 4172 |
| 1 | Temperature sensor NiCr-Ni (if needed) | 529 676 |
| 1 | Magnetic stirrer | 666 8451 |
| 1 | Beaker, 250 ml, squat shape | 664 103 |
| 1 | Stand rod, 450 mm, M10 thread | 666 523 |
| 1 | Graduated pipette, 10 ml | 665 997 |
| 1 | Pipetting ball | 666 003 |
| 1 | Burette, 50 ml | 665 847 |
| 1 | Burette filling funnel | 665 816 |
| 1 | Burette clamp simple | 666 559 |
| 2 | Crossed bossheads | 666 543 |
| 2 | Small universal clamps | 666 551 |
| 1 | PC with Windows XP/Vista/7 | |

### Chemicals

| | |
|---|---|
| Phosphoric acid, 10 %, 100 ml | 674 3440 |
| Caustic potash solution, c = 1 mol/l, 1 l | 672 4460 |
| Buffer solution pH 4.00, 250 ml | 674 4640 |
| Buffer solution pH 7.00, 250 ml | 674 4670 |
| Distilled water | |

### Experiment setup (see drawing)

Plug the chemistry box with the pH electrode into input A of the Sensor-CASSY, which is connected to the PC. If the temperature differs from 25 °C significantly, use of a temperature sensor at input $T_1$ is recommendable. The measured temperature of the solution is automatically used to compensate the voltage determined at the pH electrode.

Set up the titration assembly using the stand material, the magnetic stirrer, the beaker and the burette.

Put just 100 ml of distilled water into the beaker, and add 10 ml of a 10 % solution of phosphoric acid ($c(H_3PO_4)$ approx. 1.1 mol/l) using the pipette. Fill 1 M caustic potash solution into the burette through the funnel up to the zero mark.

Attach the pH electrode so that on the one hand the measuring diaphragm is completely immersed and on the other hand the glass membrane cannot be damaged by the rotating stirrer bar. In order to mark the equivalence point, you may add some drops of a mixture of methyl red and phenolphthalein to the solution as an indicator.

### Calibration

In order to obtain accurate measuring results, you have to calibrate the pH electrode when you use it for the first time. Afterwards the calibration should be repeated from time to time:

▨ Load settings
- Select **Correct** in Settings pHA1.
- Rinse the pH electrode with distilled water, immerse it in the buffer solution pH 7.00, and agitate it briefly.
- Enter 7.00 as the first target value. When the measured value is stable, press the **Correct Offset** button.
- Rinse the pH electrode with distilled water, immerse it in the buffer solution pH 4.00, and agitate it briefly.
- Enter 4.00 as the second target value. When the measured value is stable, press the **Correct Factor** button.
- Mark the Sensor-CASSY, the pH electrode, and the chemistry or pH box in order that they can be used at the same input later on (otherwise the stored calibration will not be applicable).

### Carrying out the experiment

▨ Load settings
- If you want to apply other volume steps than 0.5 ml, the entry can be changed in Settings V in the field Formula, e.g. by entering "0.2*n-0.2" for steps of 0.2 ml.
- Determine the first measured value with ⏱.

- Continuously add 40 ml of caustic potash solution drop by drop at a slow rate, and record the pH value in steps of 0.5 ml by pressing ⏱.

## Evaluation

The curve obtained exhibits several characteristic ranges, which correspond to the three protolysis equilibria. The equivalence points ($V = V_{eq}$) are easily determined in CASSY Lab: after pressing the right mouse button in the diagram **Standard** and selecting **Other Evaluations → Find Equivalence Point**, you can mark the curve range in which the equivalence point is to be determined. After the range has been marked, the calculated equivalence point and the $pK_a$ value are displayed automatically; the associated values are written below in the status line and can be inserted as text at an arbitrary place in the diagram.

## Further evaluation

The parallel shape of the buffer ranges can be made clearer. There are several possibilities of doing this:

1. In the representation **Straight line evaluation**: after clicking the right mouse button in the diagram, select the menu point Fit Function → Best-fit Straight Line and mark a narrow curve range in one of the buffer regions symmetrically around the point of half-equivalence $V_{heq}$ as determined in the **Standard** diagram. As a result you obtain a straight line with the average slope of the marked range. Repeat this procedure in the two remaining buffer regions. In addition, calculate the third equivalence point from the first and the second one. The three straight lines that you obtain should be almost parallel according to the general formula for buffer regions

$$\left[H_3O^+\right] = K_a \frac{[HA]}{\left[A^-\right]}$$

(a slight inaccuracy occurs because of changes in volume due to the addition of KOH and because the limits of the measuring range of the pH electrode are exceeded).

2. In the representation **Straight line evaluation**: the menu point Fit Function → Free Fit enables you to define an own fit function. Enter the general equation for a straight line, "A*x+B", into the appropriate line. After **Continue with marking a range**, click a narrow curve range which is symmetrical around the second point of half-equivalence. As a result you obtain a straight line whose slope A appears in the status line. Now set A **constant** in the menu point Fit Function → Free Fit, mark the corresponding ranges around the other two points of half-equivalence.

If the series of measurements is all right, the buffer regions near the points of half-equivalence should have almost equal slopes and should be well described by the fitted straight lines.

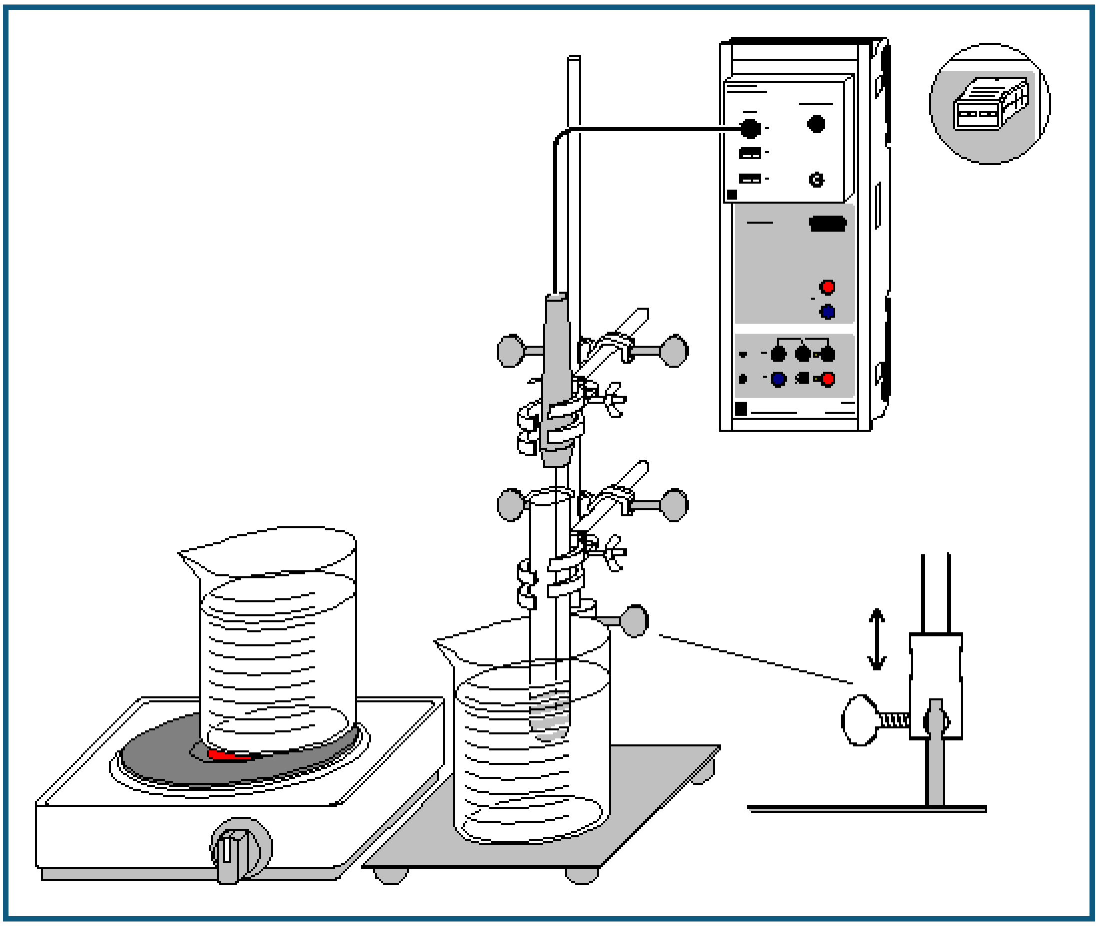
3. In the representation **Buffering Curves**: in order to plot the pH value against the degree of neutralization N of the respective protolysis stage in percent, enter the volumes associated with the three equivalence points in Settings Veq1, Veq2 and Veq3 instead of the entries of the experiment example. The third equivalence point can be calculated from the first two. The degree of neutralization is defined by

$$N = 100 \cdot \left[ \frac{V}{V_{eq1}} \cdot \left(V \le V_{eq1}\right) + \frac{V - V_{eq1}}{V_{eq2} - V_{eq1}} \cdot \left(\left(V > V_{eq1}\right) \text{and} \left(V < V_{eq2}\right)\right) + \frac{V - V_{eq2}}{V_{eq3} - V_{eq2}} \cdot \left(V \ge V_{eq2}\right) \right]$$

and describes the progress of the neutralization of the respective protolysis stage in percent. The first expression of each term in the square brackets is the volume ratio for each protolysis stage and the second expression represents the limits within which this ratio is to be calculated.

In the representation **Buffering Curves** ($pH_{A1} = f(N)$), three sections of the titration curve are plotted one over the other in a diagram. Here the similarity of the buffering curves are clearly seen. For further evaluation, you can add straight lines in the diagram as explained above in order to check the slope of the buffer curves.

## Melting and solidification point of palmitic acid



can also be carried out with Pocket-CASSY and Mobile-CASSY

### Experiment description

It is possible to find the melting and solidification point of a substance by recording its temperature curve.

### Equipment list

| | | |
|---|---|---|
| 1 | Sensor-CASSY | 524 010 or 524 013 |
| 1 | CASSY Lab 2 | 524 220 |
| | | |
| 1 | Chemistry box or NiCr-Ni adapter S | 524 067(3) |
| 1 | Temperature sensor NiCr-Ni, type K | 529 676 |
| | or | |
| 1 | Temperature box | 524 045 |
| 1 | Temperature sensor NTC | 666 212 |
| | | |
| 2 | Beakers, 250 ml, ts | 664 113 |
| 1 | Bunsen burner stand | 666 504 |
| 1 | Stand tube, 13 mm ∅ | 666 607 |
| 1 | Universal bosshead | 666 615 |
| 2 | Double bossheads | 301 09 |
| 2 | Universal clamps, 0...80 mm | 666 555 |
| 1 | Test tube, from | 664 043 |
| 1 | Double ended spatula | 666 962 |
| 1 | Hot plate, e.g. | 666 767 |
| 1 | PC with Windows XP/Vista/7 | |

## Chemicals

| | | |
|---|---|---|
| 1 | Palmitic acid, 50 g | 674 0500 |

## Experiment setup (see drawing)

- Fill a beaker around ¾ full with water and heat it to 80 to 90 °C on the hot plate.
- Fill the test tube with about 3 to 4 cm of palmitic acid and melt it in the water bath.
- Slide the 13 mm tube above the 10 mm tube using the universal bosshead so that the two parts can "telescope". Clamp the test tube with the palmitic acid and the NTC temperature sensor to the 13 mm tube so that the sensor is approx. 1 cm above the bottom of the test tube and in the middle (not touching the wall).
- Connect the temperature sensor with input $T_1$ of the temperature box. Connect the box at input A of Sensor-CASSY.
- Cool the sample to at least 40 °C. Use the second beaker with cold water.

## Carrying out the experiment

■ Load settings

Notes on calibration

The connected temperature sensor can be calibrated as necessary. To do this, open the Settings ϑA11 (right mouse button) and, after **correction**, enter the two set values 0 °C and 100 °C, and click on **Correct Offset** (temperature sensor immersed in ice/water mixture) and **Correct Factor** (temperature sensor immersed in boiling water).

- Using your telescopic stand, place the test tube with the solidified palmitic acid and the embedded temperature sensor in the water bath at approx. 80 °C.
- Start the measurement with ⏱.
- When the temperature starts to climb steadily again above about 60 °C, lift the sample with the sensor out of the hot water bath using the stand and place in a beaker of cold water to cool it down more quickly (you can also let the sample cool in air, but this takes longer).
- When the temperature has fallen significantly below the solidification point (approx. 60 °C), stop the measurement with ⏱.

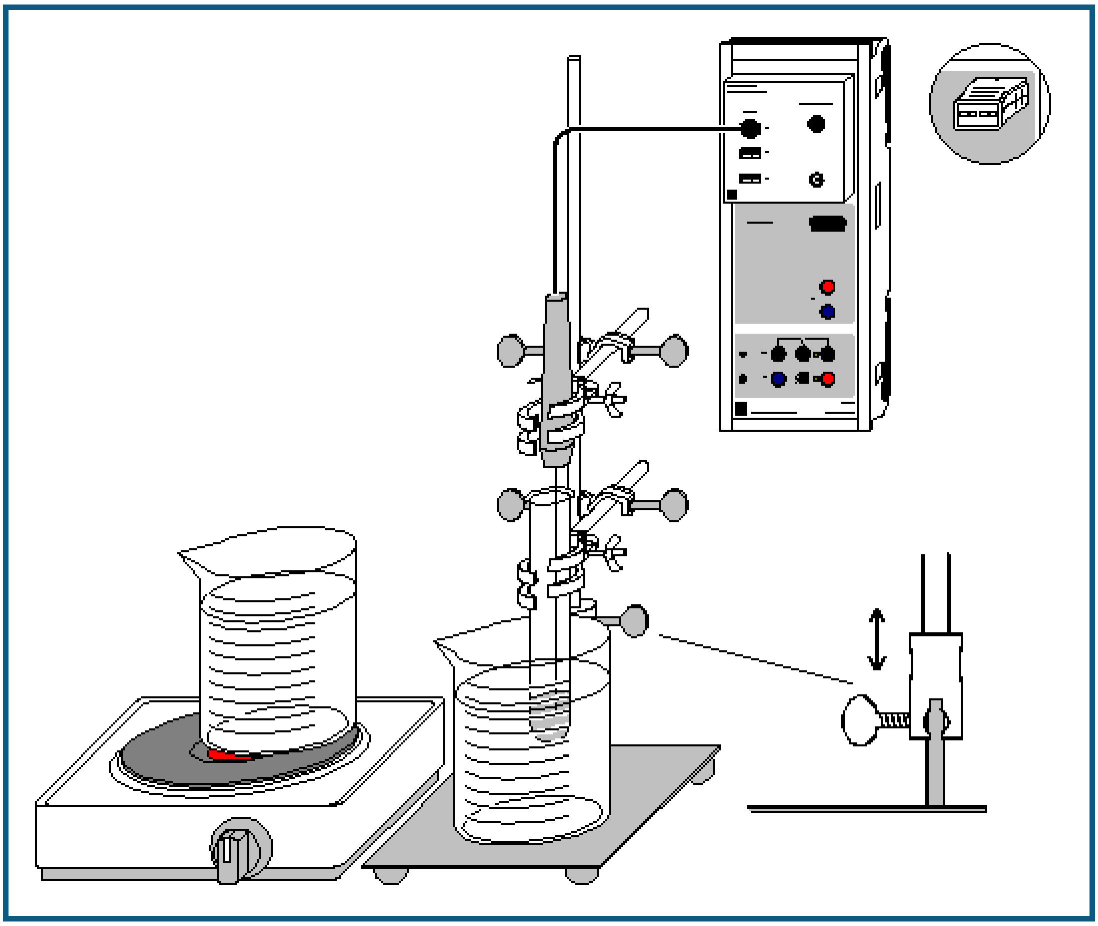
## Evaluation

- You can vary areas of the windows for optimum diagram display. To do this, click on the respective axis with the right mouse button or zoom the graph.
- To determine and mark the melting and solidification point, draw a horizontal line (click on the graph with the right mouse button and select Set Marker → Horizontal Line) and position this line so that it runs through the constant solidification range.
- You can insert the value shown in the status line (bottom left) in the diagram as text (click on the graphic with the right mouse button and select Set Marker → Text). You can also edit this text if desired.

## Further experiment options

- Recording the temperature curve of other substances, e.g. sodium thiosulfate-5-hydrate
- Comparing the temperature curves of different substances by superimposing
- Comparing the temperature curves for a single substance in differing purities
- Investigating the melting and solidification behavior of mixtures with different compositions, determining the eutectic mixture, preparing a phase diagram

## Supercooling a melt of sodium thiosulphate



✓ ✓ can also be carried out with Pocket-CASSY and Mobile-CASSY

### Experiment description

The melting and crystallization curve of sodium thiosulphate pentahydrate exhibits some peculiarities. The substance melts at approx. 48 °C. However, given a sufficient purity and vibration-free storage, it crystallizes only when it is strongly supercooled under 30 °C. During solidification, the temperature of sodium thiosulphate increases again reaching almost the melting point.

The corresponding regions (melting, supercooling, crystallization) are very well seen when the melting and crystallization curve is recorded.

Supercooling of a melt occurs when, due to the lack of crystal nuclei, the establishment of the equilibrium between solid and melt is delayed. States, such as a supercooled melt, which are thermodynamically instable, but inhibited kinematically are called metastable.

The property of sodium thiosulphate which consists in forming a relatively stable supercooled melt which warms up during solidification is used for the chemical generation of heat. Hand warmers and packages of single servings of food or drinks (e.g. for travellers) can be warmed this way.

### Equipment list

| | | |
|---|---|---|
| 1 | Sensor-CASSY | 524 010 or 524 013 |
| 1 | CASSY Lab 2 | 524 220 |
| 1 | Chemistry box or NiCr-Ni adapter S | 524 067(3) |
| 1 | Temperature sensors NiCr-Ni, type K | 529 676 |
| 2 | Beakers, 250 ml, squat shape | 664 103 |
| 1 | Bunsen burner stand | 666 504 |
| 1 | Stand tube, 13 mm ∅ | 666 607 |
| 1 | Universal bosshead | 666 615 |
| 2 | Double bossheads | 301 09 |

| | | |
|---|---|---|
| 2 | Universal clamps, 0...25 mm | 666 551 |
| 1 | Test tube, e.g. from | 664 043 |
| 1 | Double ended spatula | 666 962 |
| 1 | Hot plate, e.g. | 666 767 |
| 1 | PC with Windows XP/Vista/7 | |

## Chemicals

| | | |
|---|---|---|
| 1 | sodium thiosulphate pentahydrate, e.g. 100 g | 673 8000 |

## Experiment setup (see drawing)

- Plug the chemistry box with the temperature sensor being connected to $T_1$ into input A of the Sensor-CASSY.
- Fill the two beakers to about ¾ of their height with water. Put one beaker on the hot plate and the other beside it.
- Fill the test tube to a height of 2 or 3 cm with sodium thiosulphate.
- Slide the 13 mm tube over the 10 mm rod and fix it with the universal bosshead so that it can be moved in a telescope-like manner.
- Using the small universal clamps, attach the test tube and the temperature sensor to the 13 mm tube so that the tip of the sensor is positioned some mm over the bottom and in the centre of the test tube embedded in the substance (it must not touch the wall of the test tube).

## Calibration

In order to obtain accurate measuring results, calibrate the temperature sensor before carrying out the experiment for the first time:

▨ Load settings
- Immerse the temperature sensor in a mixture of water and ice, enter the target value "0 °C" in the upper line in Settings ϑA11 under **Correct**, and click **Correct Offset**.
- Then immerse the temperature sensor in boiling water, enter the target value "100 °C" in the upper line in Settings ϑA11 under **Correct**, and click **Correct Factor**. If necessary, take into account the influence of the air pressure on the boiling point.
- Store the calibrated settings with 💾 under a new name.
- Mark the Sensor-CASSY, the chemistry box, and the temperature sensor in order that they can be used again in the same combination. Otherwise the stored calibration will not be applicable.

## Carrying out the experiment

- Use or load the calibrated settings.
- Switch the hot plate on.
- Put the test tube with the temperature sensor into the beaker on the hot plate with the aid of the telescope-like stand.
- Start the measurement with ⏱.
- When the sodium thiosulphate has completely melted and reached a temperature of approx. 65 °C, take the test tube out of the hot water bath by means of the stand, and put it into the beaker with cold water in order that it cools down more quickly (alternatively the sample can be cooled down more slowly in the air).
- In order to reach low supercooling temperatures, see to it that the assembly is not subject to vibrations or shocks. On the other hand, crystallization can be initiated and enhanced by knocking slightly at the test tube.
- Maximum crystallization temperature is reached if the test tube is taken out of the water bath on the onset of crystallization ($\vartheta_{A11}$ rises again) and by continuing knocking at the test tube.
- When the crystallization of the sodium thiosulphate is accomplished, stop the measurement with ⏱.

## Evaluation

Several regions are discernible in the curve:

a) Warming of the solid substance.

b) Melting range of sodium thiosulphate pentahydrate. As the warming takes place more quickly than the establishment of the thermodynamic equilibrium, only a melting range, but not an exact melting point is seen.

c) Warming of the melt.

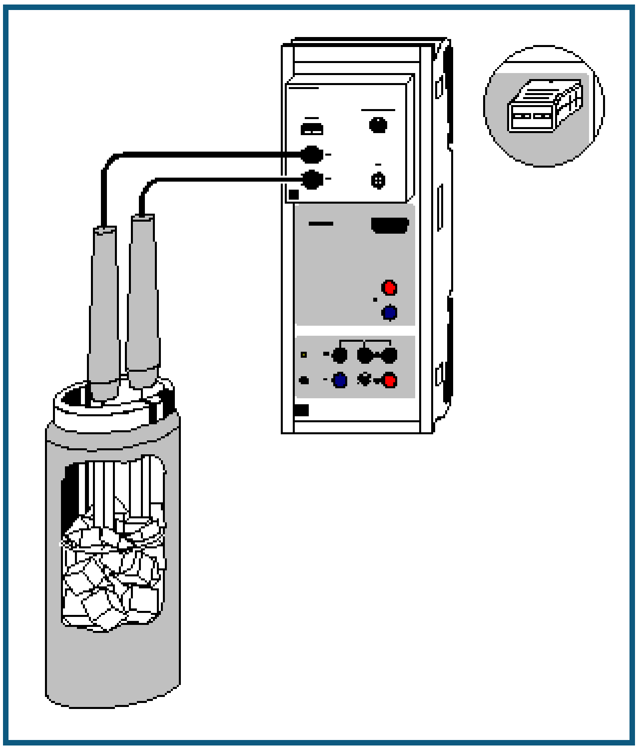
d) Cooling of the melt. It is clearly seen that the temperature falls below the melting range without a plateau showing up, which would be typical of a phase transition.

e) The minimum of the temperature curve marks the onset of the crystallization of sodium thiosulphate pentahydrate, which, in turn, leads to a rise in temperature up to the crystallization temperature. The latter can be determined by selecting Diagram → Draw Mean and marking the approximately horizontal range in the temperature maximum of the crystallization region. The average crystallization temperature is displayed in the status line and can be inserted in the diagram with Diagram → Set Marker → Text.

f) Cooling of the completely solidified substance.

The different regions of the measured curve can be marked by vertical lines for better separation.

## Determining the molar mass by way of freezing-point depression

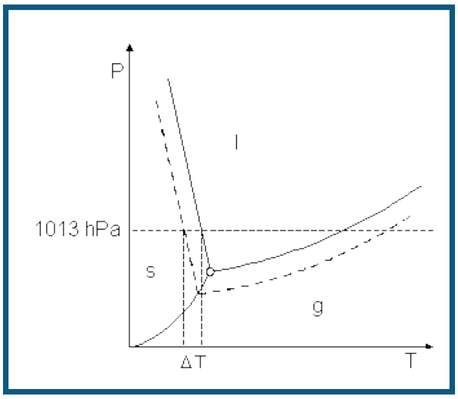


can also be carried out with Pocket-CASSY and Mobile-CASSY

### Experiment description

A relatively simple method of determining the molar mass of a substance is given by measuring the freezing-point depression of dilute solutions of this substance in a solvent. Being a colligative property of dilute solutions, the freezing-point depression only depends on the amount of substance of the dissolved particles, but not on the kind of these particles.

If a substance is dissolved in a solvent, this leads to a shift of the boundaries between the phases solid (s), liquid (l), and gaseous (g) in the phase diagram (solid lines: pure solvent, dashed lines: solution). This shift leads to an elevation of the boiling point and a depression of the freezing point (ΓT) of the solution as compared with the pure solvent.



For the freezing-point depression, the equation

$$\Delta T = \left(\frac{R \cdot T^{*2} \cdot M_2}{\Delta H_f}\right) \cdot \frac{n_1}{m_2}$$

can be derived, where R is the general gas constant, T* and $M_2$ are the freezing point and molar mass of the pure solvent, and $\Gamma H_f$ is its molar enthalpy of fusion. The term in brackets is defined as the cryoscopic constant $K_k$, which is characteristic of every solvent. For water $K_k$ is 1853 K*g/mol; in chemical analysis, however, often camphor is preferred as a solvent because of its high constant $K_k$ = 40000 K*g/mol. The second fraction in the above equation is called the molality (amount of substance $n_1$ / mass $m_2$ of solvent) of the dissolved substance.

From the freezing-point depression the molar mass of the dissolved substance is easily determined:

$$\Delta T = K_k \cdot \frac{n_1}{m_2} = K_k \cdot \frac{m_1}{M_1 \cdot m_2}$$

($m_1$: mass of the dissolved substance in g, $m_2$: mass of the solvent in g, $M_1$: molar mass of the dissolved substance in g/mol)

Solving for $M_1$ gives:

$$M_1 = \frac{K_k \cdot m_1}{\Delta T \cdot m_2}$$

This equation does not only apply to dissociating substances. In the case of salts, acids, and bases, the number of dissolved particles and the degree of dissociation α have to be taken into account.

In the experiment example, an approximately 1.0-M solution of ethylene glycol ($HO\text{-}CH_2\text{-}CH_2\text{-}OH$) in water is examined. Ethylene glycol is found, e.g., in cars as an antifreeze agent for the cooling water and the windscreen wiper system.

For the purpose of cooling, a freezing mixture of common salt and water in a Dewar flask is used (see Preparing a freezing mixture).

### Equipment list

| | | |
|---|---|---|
| 1 | Sensor-CASSY | 524 010 or 524 013 |
| 1 | CASSY Lab 2 | 524 220 |
| 1 | Chemistry box or NiCr-Ni adapter S | 524 067(3) |
| 2 | Temperature sensors NiCr-Ni, type K | 529 676 |
| 1 | Dewar flask, 0.5 l | 667 320 |
| 2 | Test tubes, 16x160 mm | e.g. from 664 043 |
| 1 | Pasteur pipette | e.g. from 665 950 |
| 1 | Bulb for the Pasteur pipette | e.g. from 665 954 |
| 1 | Rubber stopper, ∅ 14-18 mm | 667 253 |
| 1 | Beaker, 250 ml, tall shape | 664 138 |
| 1 | Laboratory balance,resolution ≤ 0.01 g, Range ≥ 300 g | |
| 1 | PC with Windows XP/Vista/7 | |

### Required substances

| | |
|---|---|
| Sodium chloride, e.g. 250 g | 673 5700 |
| Ethylene glycol, e.g. 250 ml | 671 9800 |
| Ice, approx. 200 g | |
| Distilled water | |

### Calibration

In order to obtain accurate measuring results, calibrate the temperature sensors when using it for the first time. Afterwards the calibration should be repeated from time to time.

■ Load settings

- Immerse the two temperature sensors in ice water (mixture of ice and water), stir with the temperature sensors, and wait until the displays show measured values that are stable up to ± 0.1 °C.
- For each of the sensors, enter the target value "0" in the first line in Settings ϑA12, ϑA13 and ΓTA1 under **Correct**, and press the **Correct Offset** button. The calibration of the temperature difference is absolutely necessary.
- Store the calibrated settings with 💾 under a new name.
- Mark the Sensor-CASSY, the chemistry box, and the temperature sensor in order that they can be used again in the same combination (otherwise the stored calibration will not be applicable).

### Experiment setup (see drawing)

- Plug the chemistry box with the temperature sensors being connected to $T_2$ and $T_3$ into input A of the Sensor-CASSY.
- For preparing the freezing mixture, crush the ice as fine as possible, and put it into the Dewar flask.
- Using the balance, weigh in approx. 40-50 g of NaCl into the beaker.

- Step by step add the salt to the ice in the Dewar flask and stir with a temperature sensor. If the ice is difficult to stir, add some distilled water.
- Stir until a uniform temperature distribution is achieved in the Dewar flask. A temperature of approx. -18 to -20 °C is to be expected. This can be checked by means of the display instrument associated with the temperature sensor.
- Put two dry test tubes into the beaker on the balance, and set the balance to 0.
- Use the Pasteur pipette to put approx. 0.5-0.7 g of ethylene glycol into one of the test tubes and determine the exact mass. Set the balance to 0, add 10-12 g of distilled water to the ethylene glycol, and determine the exact mass. In the Comment, the values can be entered and stored along with the measurement.
- Close the test tube with the rubber stopper, and dissolve the ethylene glycol by shaking.
- Put approx. 9-10 g of distilled water into the second test tube.
- Immerse the clean temperature sensor which is connected to $T_2$ in the ethylene glycol solution and the other sensor, which should be clean as well, in the distilled water.

## Carrying out the experiment

- Use or load the calibrated settings.
- The temperature sensors being immersed, put the two test tubes into the freezing mixture at the same time and to the same depth. The liquid levels in the test tubes should be below the level of the freezing mixture. See to it that no salt solution from the freezing mixture comes into the test tubes.
- Start the measurement with ⏱.
- Permanently stir the content of the test tubes with the two temperature sensors until the liquids are completely frozen.
- Continue the measurement until $\Gamma T_{A1}$ is almost back to 0 and the temperatures are virtually constant.
- Stop the measurement with ⏱.

## Evaluation

During the measurement, three curves were recorded at the same time: the two freezing curves ($\vartheta_{A12}$ and $\vartheta_{A13}$) - one for the sample and a reference curve of distilled water - and the difference curve ($\Gamma T_{A1}$).

The freezing curves exhibit several regions:

a) At the beginning of the measurement, the temperatures $\vartheta_{A12}$ and $\vartheta_{A13}$ drop sharply as long as the two liquids are cooled quickly.

b) The steep drop in temperature ends - above all in the case of $\vartheta_{A12}$ - in a local minimum, the so-called supercooling of the liquids.

c) This temperature minimum is followed by the solidification region of the curve, which is the relevant part for determining the freezing-point depression. In the case of pure solvents, the temperature remains exactly constant during solidification giving rise to a plateau region in the freezing curve (see the curve $\vartheta_{A13}$ in the example).

In the case of solutions, the solidification region has another shape: as here almost pure solvent crystallizes and the dissolved substance remains in the liquid phase, the concentration of the dissolved substance increases steadily. For this reason, the freezing point of the solution drops even more (see the curve $\vartheta_{A12}$ in the example). That means, the looked-for freezing point of the original solution lies in the maximum at the beginning of the solidification process.

d) When the solidification process is accomplished, the substances quickly cool down to the ambient temperature following an exponential course. As the pure ice crystal has no phase boundaries, in contrast to the frozen solution, it cools down at a much quicker rate.

For evaluating the measuring data, first determine the freezing point of the ethylene glycol solution from the freezing curve $\vartheta_{A12}$. This point shows up as a maximum at the beginning of the solidification region of the curve. The coordinates of this narrow range can be read from the table of measured values (to do this click the maximum with the left mouse button - thereby the associated value in the table is marked). The temperature difference between the two freezing curves in this range determines the freezing-point depression ΓT of the solution as compared with pure water. As the measurement of the temperature difference $\Gamma T_{A1}$ can be performed at a higher resolution with the chemistry box, this curve is used for determining the freezing-point depression.

Select Diagram → Zoom and the range of the freezing and difference curve which is relevant for the evaluation with the left mouse button to obtain a magnified representation of this range. Then select Diagram → Draw Mean, and mark those measured values on the difference curve $\Gamma T_{A1}$ with the mouse which belong to the solidification region of $\vartheta_{A12}$. While setting the marks, you can check the position of the mouse pointer in the status line. The mean value of $\Gamma T_{A1}$ is marked by a horizontal line in the diagram; the associated numerical value is found in the status line and can be inserted in the diagram via Diagram → Set Marker → Text.

From the freezing-point depression found in this way, the molar mass of the substance under consideration can be determined according to the equation:

$$M_1 = \frac{K_k \cdot m_1}{\Delta T \cdot m_2}$$

With the values from the experiment example ($m_1$ = 0.63 g; $m_2$ = 11.56 g; $\Gamma T$ = $|\Gamma T_{A1}|$ = 1.59 K; $K_k$ = 1853 K*g/mol) the molar mass of ethylene glycol turns out to be

$M_1$ = 63.51 g/mol.

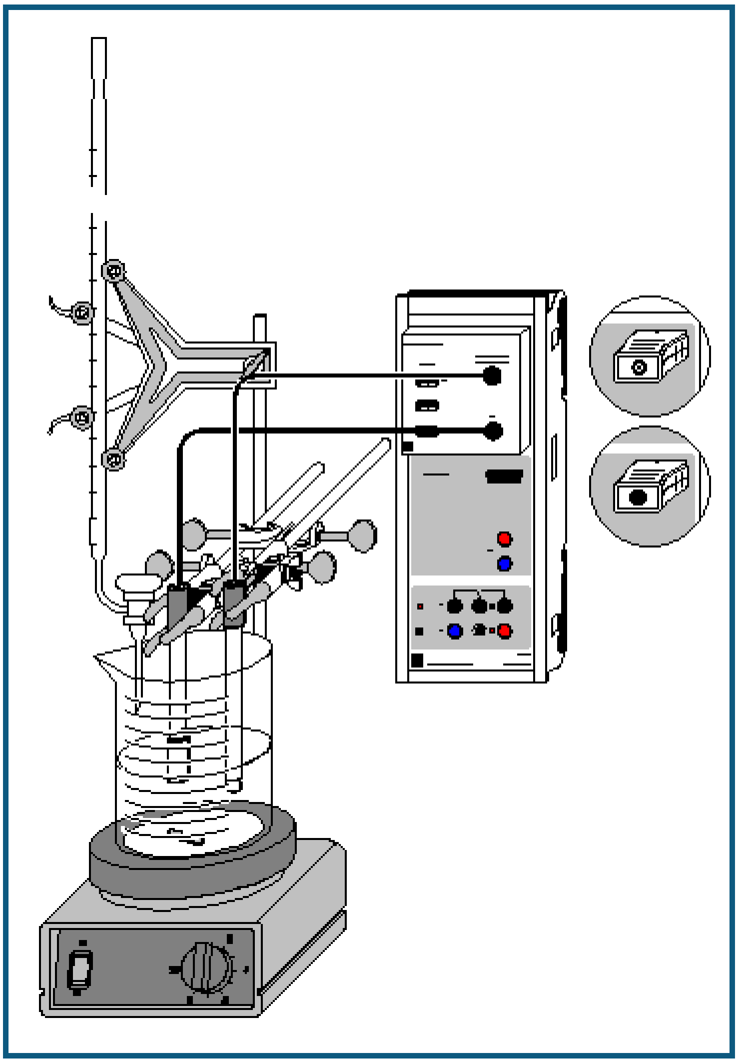
Compared with the literature value of 62.07 g/mol, this corresponds to an error of 2.3 %.

### Further experiment options

This experiment setup is well suited to record the freezing curves of many other substances.

Provided the composition is known, the degree of dissociation at a certain concentration can be obtained from the freezing curves of salts, acids, and bases. For this the freezing-point depression of a certain amount of salt is measured, from which the total amount of dissolved particles is derived. From the result the degree of dissociation can be calculated.

## Titration of hydrochloric acid with caustic soda solution (pH and conductivity)



✓ ✓ can also be carried out with Pocket-CASSY and Mobile-CASSY

**Danger**

Acids and bases are caustic. Wear protective goggles.

### Experiment description

During titration the pH value and the conductivity are measured simultaneously, and the equivalence point and the $pK_a$ value of the titration are determined in the evaluation.

### Equipment list

| | | |
|---|---|---|
| 1 | Sensor-CASSY | 524 010 or 524 013 |
| 1 | CASSY Lab 2 | 524 220 |
| 1 | Chemistry box or pH/conductivity adapter S | 524 067(2+1) |
| 1 | Conductivity sensor | 529 670 |
| 1 | pH electrode with BNC plug | 667 4172 |
| 1 | Magnetic stirrer | 666 8451 |
| 1 | Beaker, 250 ml, ts | 664 113 |
| 1 | Stand rod, 450 mm, M10 thread | 666 523 |
| 3 | Crossed bossheads | 666 543 |
| 3 | Universal clamps, 0...80 mm | 666 555 |
| 1 | Burette, 50 ml | 665 847 |
| 1 | Burette filling funnel | 665 816 |
| 1 | Pipette, 10 ml | 665 975 |

| | | |
|---|---|---|
| 1 | Pipetting ball | 666 003 |
| 1 | PC with Windows XP/Vista/7 | |

### Chemicals

| | |
|---|---|
| Hydrochloric acid, c = 0.1 mol/l, 500 ml | 674 6950 |
| Caustic soda solution, c = 0.1 mol/l, 500 ml | 673 8410 |
| Distilled water | |

### Experiment setup (see drawing)

The pH and conductivity are measured by Sensor-CASSY via the pH box at input A and the conductivity box at input B.

Set up the titration assembly using the magnetic stirrer, the beaker, the stand material and the burette. Put approx. 100 ml water in the beaker and add 10 ml hydrochloric acid with the pipette.

Attach the electrodes so that they are immersed to a sufficient depth but cannot be struck by the rotating stirrer bars.

### Calibration

In order to obtain accurate measuring results, you have to calibrate the pH electrode when you use it for the first time. Afterwards the calibration should be repeated from time to time:

☐ Load settings
- Select **Correct** in Settings pHA1.
- Rinse the pH electrode with distilled water, immerse it in the buffer solution pH 7.00, and agitate it briefly.
- Enter 7.00 as the first target value. When the measured value is stable, press the **Correct Offset** button.
- Rinse the pH electrode with distilled water, immerse it in the buffer solution pH 4.00, and agitate it briefly.
- Enter 4.00 as the second target value. When the measured value is stable, press the **Correct Factor** button.
- The cell constant of the conductivity sensor for the chemistry box has already been set to 0.58 in CASSY Lab. If another conductivity sensor is used, its cell constant has to be entered as a factor in Settings CA1 under **Correct**. Then the **Correct Factor** button has to be pressed.
- For a more precise determination of the cell constant, calibration solutions can be used: rinse the beaker and the conductivity sensor first with distilled water and then with approx. 30-40 ml of calibration solution. Immerse the conductivity sensor in another 50 ml of calibration solution as if it was for a conductivity measurement (pay attention to the distances from the walls of the beaker), enter the target value in the second line in Settings CA1 under **Correct**, and press the **Correct Factor** button when a stable measured value is reached.
- Mark the Sensor-CASSY, the electrodes, and the chemistry box in order that they can be used at the same input later on (otherwise the stored calibration will not be applicable).

### Carrying out the experiment

☐ Load settings
- Record the inital values with ⏱.
- Allow the caustic soda solution to drip continuously and register the corresponding pH and conductivity values every 0.5 ml with ⏱.

### Evaluation

There are two ways to determine the equivalence point:

pH

Click on the diagram with the right mouse button, select Other Evaluations → Find Equivalence Point and mark the desired curve range. The value appears in the status line at the bottom left and can be inserted anywhere in the diagram as text. The $pK_a$ value is automatically given, but under these conditions (hydrochloric acid with a concentration of 0.01 mol/l) this is not a sensible value.

Conductivity

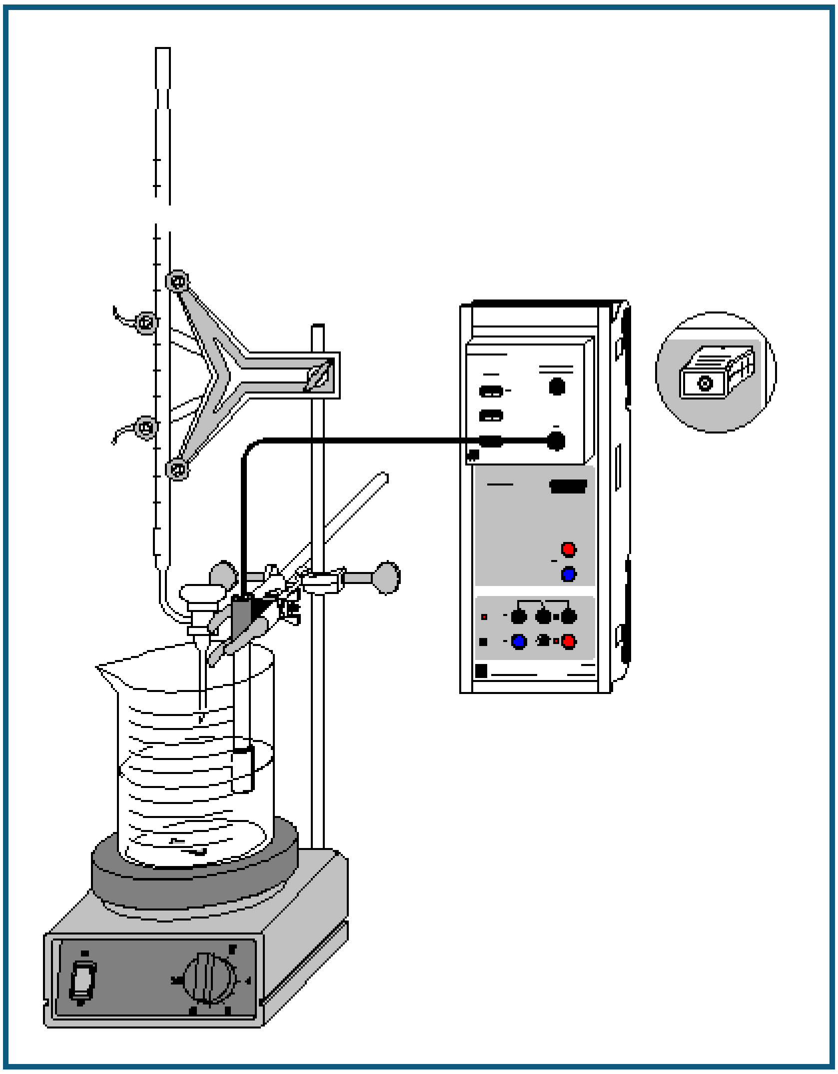
Click on the diagram with the right mouse button, select Fit Function → Best-fit Straight Line and mark the left branch of the conductivity curve. Do the same with the right branch. You can place a vertical line to mark the intersection of the two lines. It is also possible to display the coordinates.

### Further experiment options

- Recording of a single measurement quantity (e.g. pH)
  Click on the conductivity window with the right mouse button and select **Delete**. The display window disappears, along with all other data relating to conductivity. The experiment now only measures pH.

- Using a synchronous burette or motor piston burette (automatic titration)
  In the Measuring Parameters (**Window → Show Measuring Parameters**) select **Automatic Recording** and set an interval of e.g. 1 s.
  In the **Settings V** for the volume, enter the formula t/20 (this assumes that 1 ml is metered every 20 s. You may need to match this value as well as the maximum volume).
- Registering volume using a balance (automatic titration)
  Select **Balance** in the Settings CASSYs and specify the serial interface for the balance. Match the settings of the balance (transmission rate, mode) to the balance program (refer to the manual for that balance if necessary).
  In the Settings V for the volume, enter the formula **m/1.05** (this assumes a density of the titrant of 1.05 g/ml. You may need to match this value as well as the maximum volume).

## Titration of household vinegar



can also be carried out with Pocket-CASSY and Mobile-CASSY

**Danger**

Acids and bases are caustic. Wear protective goggles and acid-resistant gloves.

### Experiment description

The concentration of acids (and bases) can be determined via titration with a standard solution. For this purpose, the equivalence point of a volume V of the acid, which has been measured exactly, is obtained by way of titration. If the valence n of the acid is known, its concentration c can be determined by means of the equation:

$n_1 \cdot c_1 \cdot V_1 = n_2 \cdot c_2 \cdot V_2$

With household vinegar as an example, the determination can be easily performed using 1 M NaOH as standard solution.

### Equipment list

| | | |
|---|---|---|
| 1 | Sensor-CASSY | 524 010 or 524 013 |
| 1 | CASSY Lab 2 | 524 220 |
| 1 | Chemistry box or pH adapter S | 524 067(2) |
| 1 | pH electrode with BNC plug | 667 4172 |
| 1 | Temperature sensor NiCr-Ni (if needed) | 529 676 |
| 1 | Magnetic stirrer | 666 8451 |
| 1 | Beaker, 250 ml, squat shape | 664 103 |

| | | |
|---|---|---|
| 1 | Stand rod, 450 mm, M10 thread | 666 523 |
| 1 | Graduated pipette, 10 ml | 665 997 |
| 1 | Pipetting ball | 666 003 |
| 1 | Burette, 25 ml | 665 845 |
| 1 | Burette filling funnel | 665 816 |
| 1 | Burette clamp simple | 666 559 |
| 1 | Crossed bosshead | 666 543 |
| 1 | Universal clamp, 0...25 mm | 666 551 |
| 1 | PC with Windows XP/Vista/7 | |

### Chemicals

| | |
|---|---|
| Household vinegar | |
| Distilled water | |
| Caustic soda solution, | e.g. 500 ml: 673 8420 |
| Buffer solution pH 4.00 | e.g. 250 ml: 674 4640 |
| Buffer solution pH 7.00 | e.g. 250 ml: 674 4670 |

### Experiment setup (see drawing)

Plug the chemistry box with the pH electrode into input A of the Sensor-CASSY, which is connected to the PC. If the temperature differs from 25 °C significantly, use of a temperature sensor at input $T_1$ is recommendable. The measured temperature of the solution is automatically used to compensate the voltage determined at the pH electrode.

Set up the titration assembly using the stand material, the magnetic stirrer, the beaker and the burette. Put about 100 ml of distilled water into the beaker, and add exactly 10 ml of household vinegar using the pipette. Fill 1 M caustic soda solution into the burette through the funnel up to the zero mark.

Attach the pH electrode so that on the one hand the measuring diaphragm is completely immersed and on the other hand the glass membrane cannot be damaged by the rotating stirrer bar. In order to mark the equivalence point, you may add some drops of a phenolphthalein solution as an indicator.

### Calibration

In order to obtain accurate measuring results, you have to calibrate the pH electrode when you use it for the first time. Afterwards the calibration should be repeated from time to time:

■ Load settings
- Select **Correct** in Settings pHA1.
- Rinse the pH electrode with distilled water, immerse it in the buffer solution pH 7.00, and agitate it briefly.
- Enter 7.00 as the first target value. When the measured value is stable, press the **Correct Offset** button.
- Rinse the pH electrode with distilled water, immerse it in the buffer solution pH 4.00, and agitate it briefly.
- Enter 4.00 as the second target value. When the measured value is stable, press the **Correct Factor** button.
- Mark the Sensor-CASSY, the pH electrode, and the chemistry or pH box in order that they can be used at the same input later on (otherwise the stored calibration will not be applicable).

### Carrying out the experiment

■ Load settings
- If you want to apply other volume steps than 0.2 ml, the entry can be changed in Settings V in the field Formula, e.g. by entering "0.5*n-0.5" for steps of 0.5 ml.
- Determine the first measured value with ⏱.
- Continuously add drops of caustic soda solution at a slow rate, and record the pH value in steps of 0.2 ml with ⏱.

### Evaluation

At the equivalence point ($V = V_{eq}$), the acetic acid has entirely reacted with the caustic soda solution:

$$HAc + NaOH \rightarrow Na^+ + Ac^- + H_2O$$

As the two substances react with one another in a ratio of 1:1, the concentration of the acetic acid is calculated according to the formula

$$c_{HAc} \cdot V_{HAc} = c_{NaOH} \cdot V_{eq}$$

For the determination of the required volume of NaOH, the equivalence point is determined by CASSY Lab. This is simply achieved by clicking the diagram with the right mouse button, selecting the item Other Evaluations → Find Equivalence Point. Just mark the desired curve range. The equivalence point and the $pK_a$ value of the curve will immediately be displayed graphically. The associated values below on the left in the status line and can be inserted as text at an arbitrary place in the diagram.

### Further evaluation

More advanced calculations can be performed to discuss the measured concentration in mol/l and the indication on the label of the vinegar in Vol.-%.

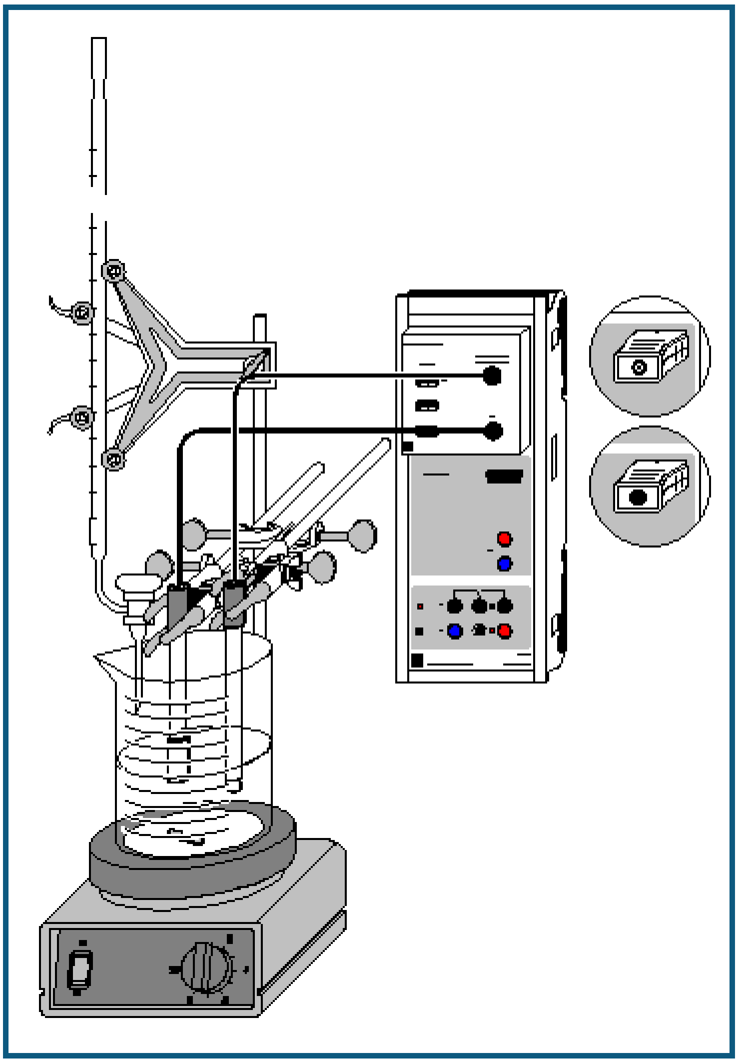
First calculate the mass of pure acetic acid in the vinegar solution by multiplying its concentration by the molar mass ($M_{HAc}$ = 60.05 g/mol):

$$c_{HAc} \cdot M_{HAc} = \frac{m_{HAc}}{1\,l}$$

Divide the value obtained by the density of pure acetic acid ($\rho_{Hac}$ = 1050 g/l) to obtain the proportion per volume of pure acetic acid in the titrated household vinegar. The percentage is then calculated by multiplying by a factor of 100:

$$\frac{m_{HAc} \cdot 100}{1\,l \cdot \rho_{HAc}} = Vol\%_{HAc}$$

## Titration of acetic acid with caustic soda solution (pH and conductivity)



can also be carried out with Pocket-CASSY and Mobile-CASSY

**Danger**

Acids and bases are caustic. Wear protective goggles and acid-resistant gloves.

### Experiment description

With the chemistry box several experiments can be carried out simultaneously. This enables several aspects of a single experiment to be considered at the same time. Therefore it is possible to obtain information on the course of the reaction from both the pH measurement and the conductivity during the titration of acetic acid with caustic soda solution.

### Equipment list

| | | |
|---|---|---|
| 1 | Sensor-CASSY | 524 010 or 524 013 |
| 1 | CASSY Lab 2 | 524 220 |
| 1 | Chemistry box or pH/conductivity adapter S | 524 067(2+1) |
| 1 | Conductivity sensor | 529 670 |
| 1 | pH electrode with BNC plug | 667 4172 |
| 1 | Magnetic stirrer | 666 8451 |
| 1 | Beaker, 250 ml, squat shape | 664 103 |
| 1 | Stand rod, 450 mm, M10 thread | 666 523 |
| 1 | Graduated pipette, 10 ml | 665 997 |
| 1 | Pipetting ball | 666 003 |
| 1 | Burette, 25 ml | 665 845 |

| | | |
|---|---|---|
| 1 | Burette filling funnel | 665 816 |
| 1 | Burette clamp simple | 666 559 |
| 2 | Crossed bossheads | 666 543 |
| 2 | Small universal clamps | 666 551 |
| 1 | PC with Windows XP/Vista/7 | |

### Chemicals

| | |
|---|---|
| Acetic acid, c = 0.1 mol/l | e.g. 500 ml: 671 9560 |
| Caustic soda solution, c = 0.1 mol/l | e.g. 500 ml: 673 8410 |
| Distilled water | |
| Buffer solution pH 4.00 | e.g. 250 ml: 674 4640 |
| Buffer solution pH 7.00 | e.g. 250 ml: 674 4670 |

### Experiment setup (see drawing)

Plug the chemistry box with the conductivity sensor and the pH electrode into input A of the Sensor-CASSY, which is connected to the PC.

Set up the titration assembly using the stand material, the magnetic stirrer, the beaker and the burette.

Put about 120 ml of distilled water into the beaker, and add exactly 10 ml of acetic acid using the pipette; fill caustic soda solution into the burette through the funnel up to the zero mark.

In order to prevent distortion of the conductivity measurement by contamination of reference electrolyte from the pH electrode, rinse the pH electrode thoroughly with distilled water before using it in the experiment. In addition, the upper opening of the electrode should be laid open for the purpose of pressure compensation. When attaching the pH electrode, see to it that on the one hand the measuring diaphragm is completely immersed and on the other hand the glass membrane cannot be damaged by the rotating stirrer bar.

Because of its stray field, the conductivity sensor has to be immersed to a depth of at least 2 cm in way that its distance from the wall of the vessel and from other material in the liquid (pH sensor, stirrer bar) is at least 1 cm.

### Calibration

In order to obtain accurate measuring results, you have to calibrate the pH electrode when you use it for the first time. Afterwards the calibration should be repeated from time to time:

▨ Load settings
- Select **Correct** in Settings pHA1.
- Rinse the pH electrode with distilled water, immerse it in the buffer solution pH 7.00, and agitate it briefly.
- Enter 7.00 as the first target value. When the measured value is stable, press the **Correct Offset** button.
- Rinse the pH electrode with distilled water, immerse it in the buffer solution pH 4.00, and agitate it briefly.
- Enter 4.00 as the second target value. When the measured value is stable, press the **Correct Factor** button.
- The cell constant of the conductivity sensor for the chemistry box has already been set to 0.58 in CASSY Lab. If another conductivity sensor is used, its cell constant has to be entered as a factor in Settings CA1 under **Correct**. Then the **Correct Factor** button has to be pressed.
- For a more precise determination of the cell constant, calibration solutions can be used: rinse the beaker and the conductivity sensor first with distilled water and then with approx. 30-40 ml of calibration solution. Immerse the conductivity sensor in another 50 ml of calibration solution as if it was for a conductivity measurement (pay attention to the distances from the walls of the beaker), enter the target value in the second line in Settings CA1 under **Correct**, and press the **Correct Factor** button when a stable measured value is reached.
- Mark the Sensor-CASSY, the electrodes, and the chemistry box in order that they can be used at the same input later on (otherwise the stored calibration will not be applicable).

### Carrying out the experiment

▨ Load settings
- If you want to apply other volume steps than 0.2 ml, the entry can be changed in Settings V in the field Formula, e.g. by entering "0.5*n-0.5" for steps of 0.5 ml.
- Determine the first measured value with ⏱.
- Continuously add 20 ml of caustic soda solution drop by drop at a slow rate, and record the pH value in steps of 0.2 ml with ⏱.
- If you are interested in the use of a piston burette and a light barrier for automatic titration, see the corresponding experiment examples.

## Evaluation

The determination of the equivalence point via the conductivity is done graphically. First click the coordinate system with the right mouse button, and select Fit Function → Best-fit Straight Line. Then mark one of the two curve sections to which the straight line is to be fitted. The appropriate sections are those to the right and to the left of the cusp of the conductivity curve. The intersection of the two fitted straight lines marks the neutralization volume for the titrated acetic acid on the x axis. It can be marked with Set Marker → Vertical Line.

For determining the equivalence point via the pH measurement, click the diagram with the right mouse button, and select Other Evaluations → Find Equivalence Point. When you have marked the curve, the equivalence point and the point of half-equivalence are calculated and displayed automatically. The pH value at the point of half equivalence also gives you the $pK_a$ value of acetic acid. The corresponding numerical values are found in the status line and can be dragged into the diagram with the left mouse button as labels.

## Remarks

At the equivalence point t ($V = V_{eq}$), almost exclusively sodium and acetate ions are found in the solution:

$$HAc + Na^+ + OH^- \rightarrow Na^+ + Ac^- + H_2O$$

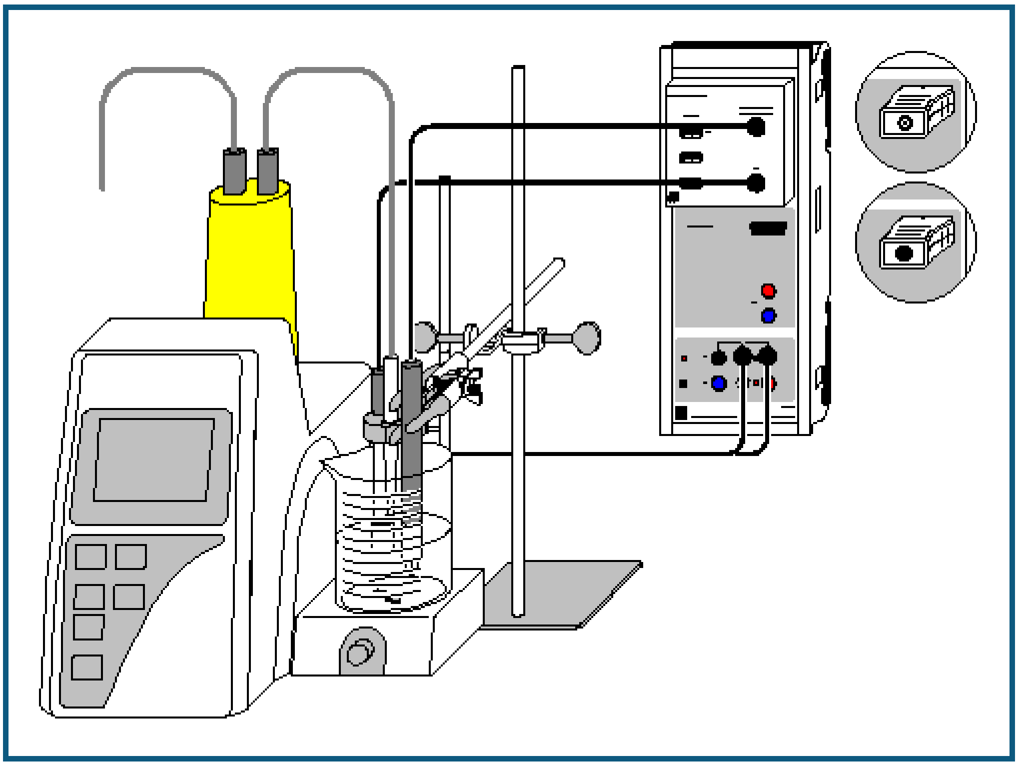
The concentrations of $H_3O^+$ and $OH^-$ ions are very low (pH approx. 8). As the ion mobility of hydroxide ions is much greater than that of acetate ions, the conductivity curve exhibits a clear cusp at the equivalence point: Before the neutralization, the hydroxide ions react completely with the acetic acid so that the increase in conductivity can only be attributed to the produced acetate and sodium ions (slight rise of the conductivity curve).

The short drop in conductivity at the beginning of the titration corresponds to the somewhat steeper rise of the pH value in the same range: due to the buffer equation that applies for weak acids,

$$\left[H_3O^+\right] = K_a \frac{[HA]}{\left[A^-\right]}$$

the concentration of $H_3O^+$ ions is determined by the ratio $[HA]/[A^-]$, which decreases at a particularly high rate at the beginning of the titration because $[A^-]$ is almost zero in the initial acetic acid and increases quickly when caustic soda solution is added. As the ion mobility of $H_3O^+$ ions is particularly high, the conductivity drops correspondingly.

## Automatic titration of $NH_3$ with $NaH_2PO_4$ (piston burette)



### Experiment description

If a piston burette is used in conjunction with CASSY, a titration can be performed totally automatically including the acquisition of measured values.

The titration of a weak base such as ammonia with a weak acid such as sodium dihydrogenphosphate results in a very weak slope of the pH curve. In this case, measuring the conductivity leads to data that is easier to evaluate. By recording both curves simultaneously with CASSY, you can compare the two methods directly and assess the accuracy of the determination of the equivalence point for each case.

### Equipment list

| | | |
|---|---|---|
| 1 | Sensor-CASSY | 524 010 or 524 013 |
| 1 | CASSY Lab 2 | 524 220 |
| 1 | Chemistry box or pH/conductivity adapter S | 524 067(2+1) |
| 1 | Conductivity sensor | 529 670 |
| 1 | pH electrode with BNC plug | 667 4172 |
| 1 | Piston burette | 665 825 |
| 1 | Connecting cable for piston burette | 665 8251 |
| 1 | Beaker, 250 ml, squat shape | 664 103 |
| 2 | Volumetric flasks, 100 ml | 665 793 |
| 1 | Bulb pipette, 5 ml | 665 974 |
| 1 | Pipetting ball | 666 003 |
| 1 | Bunsen burner stand, 450 mm | 666 502 |
| 1 | Crossed bosshead | 666 543 |
| 1 | Universal clamp, 0...25 mm | 666 551 |
| 1 | Spatula | 666 962 |
| 1 | Watch glass dish, e.g. 80 mm | 664 154 |
| 1 | Powder funnel, e.g. 60 mm | 602 681 |
| 1 | Balance (at least up to 100 g, resolution 0.01 g) | |
| 1 | PC with Windows XP/Vista/7 | |

### Chemicals

| | |
|---|---|
| Distilled water | |
| Ammonia solution, dilute | e.g. 500 ml: 670 3650 |

| | |
|---|---|
| $NaH_2PO_4 * 2 H_2O$ | e.g. 50 g: 673 6000 |
| Buffer solution pH 4.00 | e.g. 250 ml: 674 4640 |
| Buffer solution pH 7.00 | e.g. 250 ml: 674 4670 |

### Preparing the solutions

Weigh in exactly 1.56 g of sodium dihydrogenphosphate (0.01 mol) on a watch glass dish on the balance, rinse it via a funnel into a 100 ml volumetric flask with distilled water and fill up to 100 ml. Using the bulb pipette, put 5 ml of ammonia into the other volumetric flask and fill up to the mark with distilled water. As a result you have a 0.1 M solution of each of the two substances.

### Experiment setup (see drawing)

Plug the chemistry box with the conductivity sensor and the pH electrode into input A of the Sensor-CASSY, which is connected to the PC.

Rinse and fill the piston burette (read the instruction sheet) with the $NaH_2PO_4$ solution just prepared, and put the beaker with 10 ml of ammonia solution, 100 ml of distilled water, and a stirrer bar on the magnetic stirrer of the piston burette. In the menu "Dosing" of the burette, set the target volume to 20 ml and the feed rate to 2.0 ml/min.

Plug one end of the connecting cable into the two inputs on the right of the relay R of the Sensor-CASSY and the other end into the push-button input of the piston burette.

In order to prevent distortion of the conductivity measurement by contamination of reference electrolyte from the pH electrode, rinse the pH electrode thoroughly with distilled water before using it in the experiment. In addition, the upper opening of the electrode should be laid open for the purpose of pressure compensation. When attaching the pH electrode (to the stand of the piston burette), see to it that on the one hand the measuring diaphragm is completely immersed and on the other hand the glass membrane cannot be damaged by the rotating stirrer bar.

Because of its stray field, the conductivity sensor has to be immersed to a depth of at least 2 cm in way that its distance from the wall of the vessel and from other material in the liquid (pH sensor, stirrer bar) is at least 1 cm. Therefore it is recommendable to attach the conductivity sensor to a separate Bunsen burner stand.

### Calibration

In order to obtain accurate measuring results, you have to calibrate the pH electrode when you use it for the first time. Afterwards the calibration should be repeated from time to time:

■ Load settings

- Select **Correct** in Settings pHA1.
- Rinse the pH electrode with distilled water, immerse it in the buffer solution pH 7.00, and agitate it briefly.
- Enter 7.00 as the first target value. When the measured value is stable, press the **Correct Offset** button.
- Rinse the pH electrode with distilled water, immerse it in the buffer solution pH 4.00, and agitate it briefly.
- Enter 4.00 as the second target value. When the measured value is stable, press the **Correct Factor** button.
- The cell constant of the conductivity sensor for the chemistry box has already been set to 0.58 in CASSY Lab. If another conductivity sensor is used, its cell constant has to be entered as a factor in Settings CA1 under **Correct**. Then the **Correct Factor** button has to be pressed.
- For a more precise determination of the cell constant, calibration solutions can be used: rinse the beaker and the conductivity sensor first with distilled water and then with approx. 30-40 ml of calibration solution. Immerse the conductivity sensor in another 50 ml of calibration solution as if it was for a conductivity measurement (pay attention to the distances from the walls of the beaker), enter the target value in the second line in Settings CA1 under **Correct**, and press the **Correct Factor** button when a stable measured value is reached.
- Mark the Sensor-CASSY, the pH electrode, and the chemistry box in order that they can be used at the same input later on (otherwise the stored calibration will not be applicable).

### Carrying out the experiment

■ Load settings

- If you wish another dosage than the target volume of 20 ml and the feed rate of 2.0 ml/min at the piston burette, the default values in CASSY Lab have to be changed, namely the quantity n (table index) in the Measuring parameters and in Settings Relay/Voltage Source and the formula in Settings Volume V.
- Start the titration with ⏱. The measured values and the dosage of the titrator from 0 to 20 ml are recorded automatically.

### Evaluation

$NH_3$ and $NaH_2PO_4$ react according to the following equation:

$$NH_3 + Na^+ + H_2PO_4^- \rightleftharpoons NH_4^+ + Na^+ + HPO_4^{2-}$$

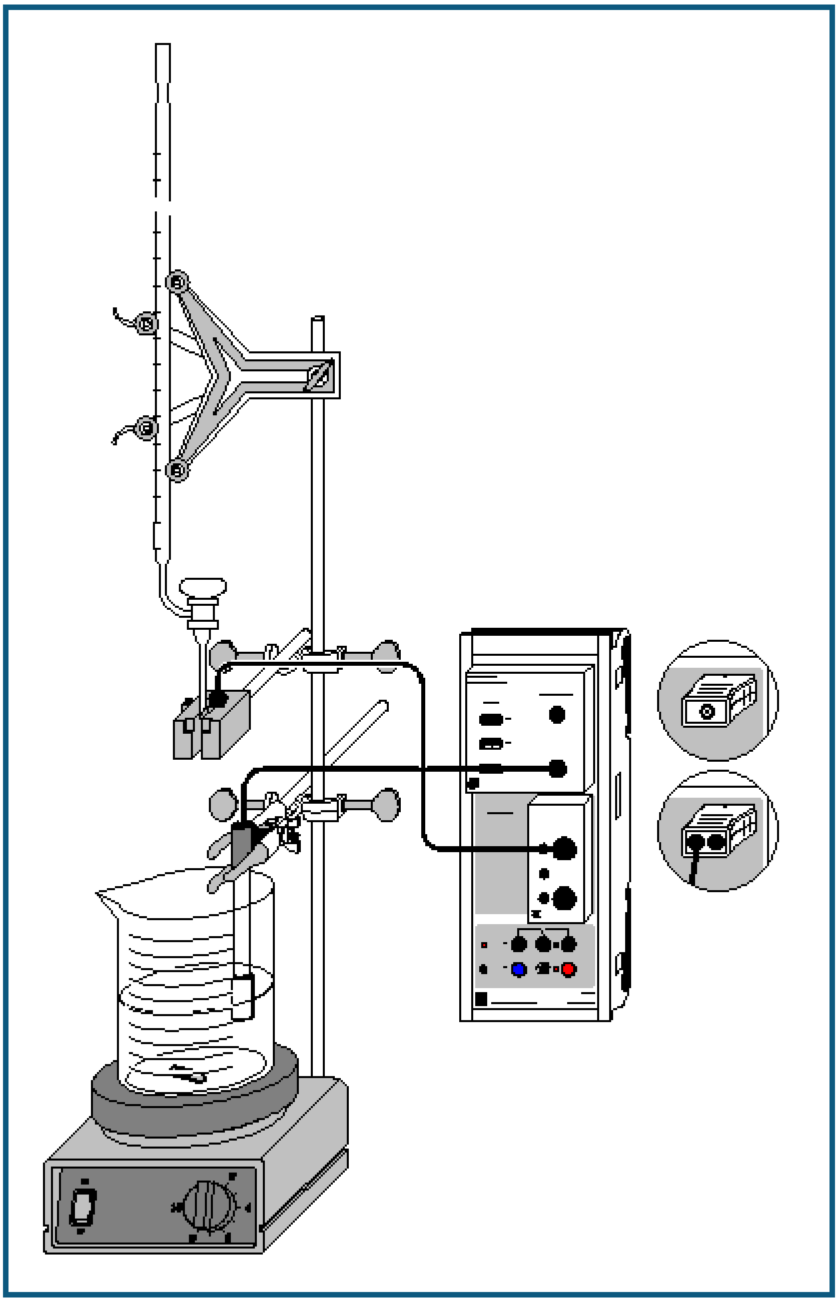
As ammonia is only a weak base, very few $OH^-$ ions are in the solution at the beginning of the reaction. For this reason, the initial conductivity is very small and increases in the course of the titration due to the formation of the reaction products. When the equivalence point has been reached, i.e., when the ammonia has entirely reacted, the conductivity only increases by the amount of sodium and dihydrogenphosphate ions, which leads to a marked cusp of the conductivity curve at the equivalence point.

In order to determine the equivalence point from the conductivity graphically, first click the coordinate system with the right mouse button, and select Fit Function → Best-fit Straight Line. Then mark one of the two curve sections to which the straight line is to be fitted. The appropriate sections are those to the right and to the left of the cusp of the conductivity curve. The intersection of the two fitted straight lines marks the neutralization volume for the titrated acetic acid on the x axis. It can be marked with Set Marker → Vertical Line.

For determining the equivalence point via the pH measurement, click the diagram with the right mouse button, and select Other Evaluations → Find Equivalence Point. When you have marked the curve, the equivalence point and the point of half-equivalence are usually calculated and displayed automatically. The corresponding numerical values are found in the status line and can be dragged into the diagram with the left mouse button as labels.

In this example, however, the slope of the pH curve is so weak that no meaningful results are obtained when the equivalence point is determined. The determination of the equivalence point via the conductivity turns out to be more reliable in this case.

## Automatic titration (drop counter)



✓ can also be carried out with Pocket-CASSY

**Danger**

Acids and bases are caustic. Wear protective goggles, gloves and clothing.

### Experiment description

A titration experiment can be simplified significantly by using a light barrier as a drop counter. From the number of drops CASSY Lab calculates the dosage automatically. As the pH measurement and the plot in the pH (V) diagram are done automatically as well, you only need to read the exact total volume of the added titrator in order to be able to evaluate the measuring results.

Here the procedure of employing a drop counter is described with the titration of phosphoric acid with caustic potash solution as an example.

In aqueous solution, phosphoric acid forms the following equilibria:

1. $H_3PO_4 + H_2O \rightleftharpoons H_2PO_4^- + H_3O^+ \quad (pK_{a1} = 2{,}1)$
2. $H_2PO_4^- + H_2O \rightleftharpoons HPO_4^{2-} + H_3O^+ \quad (pK_{a2} = 7{,}1)$
3. $HPO_4^{2-} + H_2O \rightleftharpoons PO_4^{3-} + H_3O^+ \quad (pK_{a3} = 12{,}3)$

As the differences between the $pK_a$ values amount to approx. 5, the three equilibria can be considered independently of each other.

By titration with caustic potash solution, the equivalence points of the first and the second stage of protolysis can be determined. However, since KOH is not a substantially stronger base than the phosphate ion, the equilibrium 3 does not sufficiently tend to the right-hand side for the third equivalence point to be determined.

## Equipment list

| | | |
|---|---|---|
| 1 | Sensor-CASSY | 524 010 or 524 013 |
| 1 | CASSY Lab 2 | 524 220 |
| 1 | Chemistry box or pH adapter S | 524 067(2) |
| 1 | pH electrode with BNC plug | 667 4172 |
| 1 | Temperature sensor NiCr-Ni (if needed) | 529 676 |
| 1 | Timer box or Timer S | 524 034 or 524 074 |
| | | |
| 1 | Drop counter | 337 4681 |
| | or | |
| 1 | Combination light barrier | 337 462 |
| 1 | Multi-core cable, 6-pole | 501 16 |
| | | |
| 1 | Magnetic stirrer | 666 8451 |
| 2 | Beakers, 250 ml, squat shape | 664 103 |
| 1 | Stand rod, 450 mm, M10 thread | 666 523 |
| 1 | Graduated pipette, 10 ml | 665 997 |
| 1 | Pipetting ball | 666 003 |
| 1 | Burette, 50 ml | 665 847 |
| 1 | Burette filling funnel | 665 816 |
| 1 | Burette clamp simple | 666 559 |
| 2 | Crossed bossheads | 666 543 |
| 1 | Universal clamp, 0...25 mm | 666 551 |
| 1 | PC with Windows XP/Vista/7 | |

## Chemicals

| | |
|---|---|
| Phosphoric acid, 10 %, 100 ml | 674 3440 |
| Caustic potash solution, c = 1 mol/l, 1 l | 672 4460 |
| Buffer solution pH 4.00, 250 ml | 674 4640 |
| Buffer solution pH 7.00, 250 ml | 674 4670 |
| Distilled water | |

## Experiment setup (see drawing)

Plug the chemistry box with the pH electrode into input A of the Sensor-CASSY, which is connected to the PC. If the temperature differs from 25 °C significantly, use of a temperature sensor at input $T_1$ is recommendable. The measured temperature of the solution is automatically used to compensate the voltage determined at the pH electrode.

Plug the timer box into input B with the light barrier being connected to connector E via the 6-pole cable.

Set up the titration assembly using the stand material, the magnetic stirrer, the beaker and the burette.

Put just 100 ml of distilled water into the beaker, and add 10 ml of a 10 % solution of phosphoric acid ($c(H_3PO_4)$ approx. 1.1 mol/l) using the pipette; fill 1 M caustic potash solution into the burette through the funnel up to the zero mark.

Attach the pH electrode so that on the one hand the measuring diaphragm is completely immersed and on the other hand the glass membrane cannot be damaged by the rotating stirrer bar.

With the aid of the enclosed stand rod, mount the combination light barrier below the outlet of the burette so that the drops escaping from the burette fall through the slit of the light barrier into the beaker and trigger a signal in the sensor of the light barrier. The sensor is located by approx. 1 cm behind the opening of the light barrier. Triggering of a signal is indicated by the display instrument $N_{B1}$ and by the red LED at the light barrier. To check the function, allow some drops to fall through the light barrier into an empty beaker. Then reset the counter to zero in Settings Events NB1.

### Calibration

In order to obtain accurate measuring results, you have to calibrate the pH electrode when you use it for the first time. Afterwards the calibration should be repeated from time to time:

■ Load settings
- In Settings pH pHA1 select **Correct**.
- Rinse the pH electrode with distilled water, immerse it in the buffer solution pH 7.00, and agitate it briefly.
- Enter 7.00 as the first target value. When the measured value is stable, press the **Correct Offset** button.
- Rinse the pH electrode with distilled water, immerse it in the buffer solution pH 4.00, and agitate it briefly.
- Enter 4.00 as the second target value. When the measured value is stable, press the **Correct Factor** button.
- Mark the Sensor-CASSY, the pH electrode, and the chemistry or pH box in order that they can be used at the same input later on (otherwise the stored calibration will not be applicable).

### Carrying out the experiment

■ Load settings
- Start the measurement series with ⏱.
- Carefully open the cock of the burette, and add drops of caustic potash solution at a slow rate.
- Every five seconds a measured value (volume and pH value) is recorded automatically. See to it that the drops are added at a constant rate.
- When approx. 40 ml of KOH have been added, close the cock, stop the measurement with ⏱, and read the total number of drops ($N_0$) and the exact volume of added KOH ($V_0$).

### Evaluation

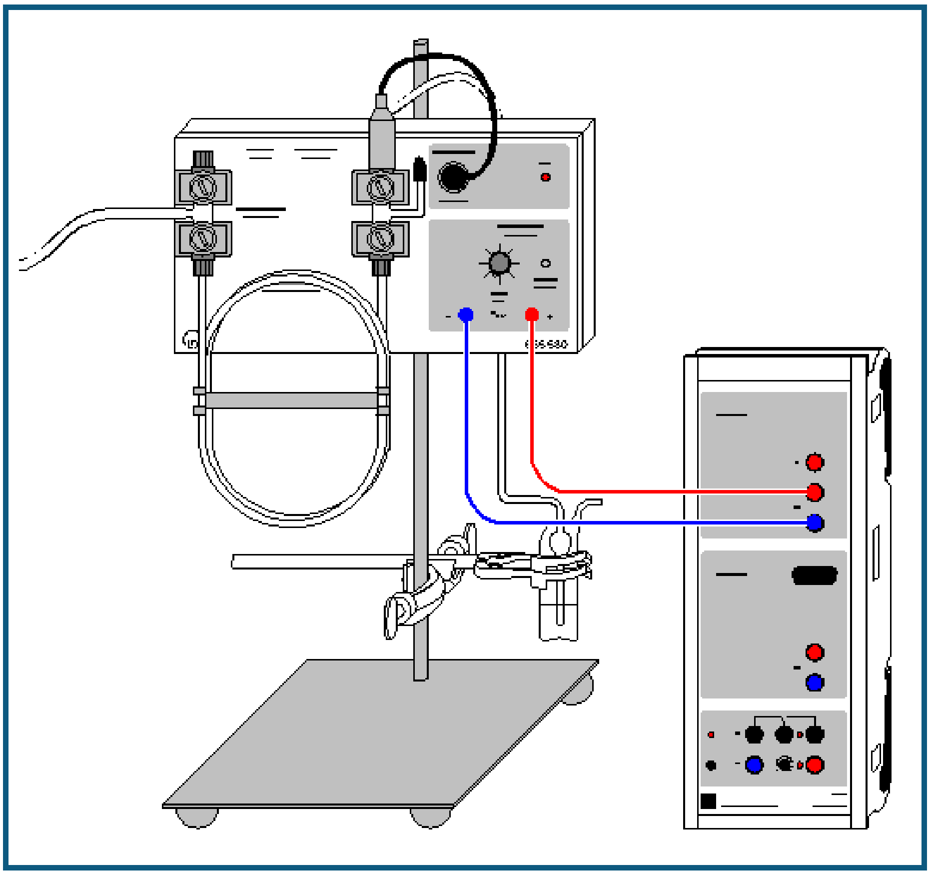
At first the average volume of a drop of KOH is calculated. The general formula to be applied reads "$N_{B1} * V_0 / N_0$", where $N_{B1}$ is the number of drops, $V_0$ the total volume added, and $N_0$ the total number of drops at the end of the titration. Enter the read values for $N_0$ and $V_0$ in the field Formula of the Settings Volume V instead of "754" and "40".

The titration curve, which is determined automatically, exhibits several characteristic ranges, which can be assigned to the three protolysis equilibria of phosphoric acid.

The equivalence points ($V = V_{eq}$) are easily determined in CASSY Lab: after pressing the right mouse button in the diagram and selecting Other Evaluations → Find Equivalence Point, you can mark the curve range in which the equivalence point is to be determined. After the range has been marked, the calculated equivalence point and the $pK_a$ value are displayed automatically; the associated values are written below in the status line and can be inserted as text at an arbitrary place in the diagram.

For further evaluation options in CASSY Lab see experiment example Titration of phosphoric acid.

## Gas chromatography (separation of alkanes from lighter gas)



can also be carried out with Pocket-CASSY and Mobile-CASSY

### Experiment description

In this experiment, in which alkanes are separated from lighter gas, the voltage from the detector is measured at the recorder output of the gas chromatograph as a function of time.

For qualitative analysis, the retention times of the individual peaks can be determined and compared with those of the reference substances.

Be sure to read the Instruction Sheet for your gas chromatograph.

### Equipment list

| | | |
|---|---|---|
| 1 | Sensor-CASSY | 524 010 or 524 013 |
| 1 | CASSY Lab 2 | 524 220 |
| 1 | Gas chromatograph LD1 | 665 580 |
| 1 | Separation column (dinonylphthalate) | 665 583 |
| 1 | Hydrocarbon sensor (detector) | 665 582 |
| 1 | Air pump | 662 2862 |
| 1 | Bubble counter | 664 814 |
| 1 | Syringe, 1 ml | 665 957 |
| 1 | Disposable needles, 10 pieces | 665 960 |
| 1 | Pair of cables, 50 cm, red and blue | 501 45 |
| 1 | PC with Windows XP/Vista/7 | |

### Chemicals

| | |
|---|---|
| Lighter gas (sample) | |
| n butane, Minican gas can (reference) | 660 989 |
| Fine regulating valve | 660 980 |

## Experiment setup (see drawing)

- Set up the gas chromatograph (GC) with the separation column (dinonylphthalate) and the hydrocarbon sensor (detector).
- Connect the input of the GC to the air pump and the output to the bubble counter.
- Switch the air pump on.
- Connect the GC to the plug-in unit. The LED at the GC lights up.

## Carrying out the experiment

■ Load settings

- Use the zero point controllers on the GC to set the zero line at approx. $U_{A1}$=0.05 V.
- Start the test measurement with ⏱.
- As soon as a stable zero line is recorded, stop the test measurement, again with ⏱.
- Draw approx. 1 ml of gas from the lighter into the syringe without needle. Do this several times. Then put a needle on the syringe and push the gas out except 0.05 ml. Inject the remaining 0.05 ml of gas into the injection head of the GC.
- Restart the recording of the voltage with ⏱, and continue measuring until all peaks to be expected have appeared; then stop the measurement with ⏱. Store the measurement series.
- For identifying individual components, repeat the experiment with a reference substance, e.g. n butane. Store this measurement series, too.

## Evaluation

You can zoom in on the relevant curve section so that it covers the diagram (open the Evaluations menu by clicking on the diagram with the right mouse button).

To determine the retention times you can insert a vertical line through the maximum value of a peak or calculate the peak center. You can also insert the retention time in the diagram as text. By comparing the retention time of the reference peak (n butane) with the retention times of the sample, it turns out that the fourth substance is n butane.

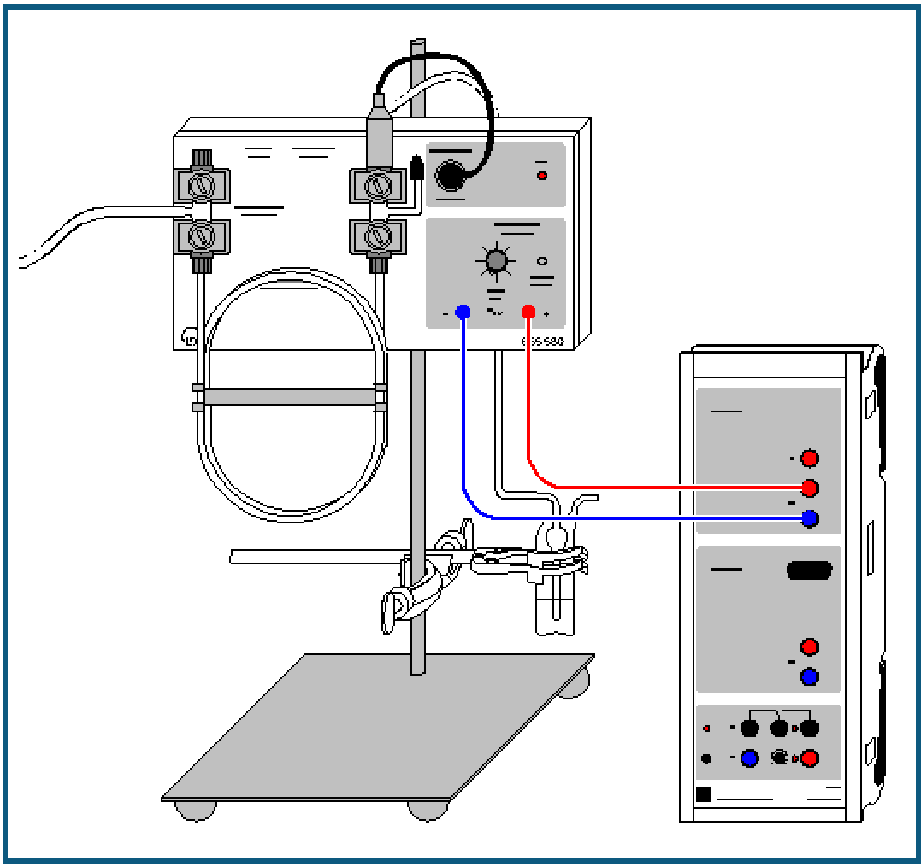
Remark: discrepancies between the retention times can arise because of changes in the room temperature.

## Further experiment options

As described for the example of n butane, other components of the lighter gas can be identified with the corresponding reference substances (ethane, propane, i butane).

By recording the chromatograms of the gases from different lighters, differences in composition can be detected.

## Gas chromatography (separation of alcohols)



can also be carried out with Pocket-CASSY and Mobile-CASSY

### Experiment description

In this experiment, in which different alcohols are separated, the voltage from the detector at the recorder output of the gas chromatograph is measured as a function of time.

For qualitative analysis, the retention times of the individual peaks can be determined. A determination of the peak areas by integration enables quantitative investigation of the sample.

Be sure to read the Instruction Sheet for your gas chromatograph.

### Equipment list

| | | |
|---|---|---|
| 1 | Sensor-CASSY | 524 010 or 524 013 |
| 1 | CASSY Lab 2 | 524 220 |
| 1 | Gas chromatograph LD1 | 665 580 |
| 1 | Separation column (Porapak P) | 665 584 |
| 1 | Hydrocarbon sensor (detector) | 665 582 |
| 1 | Air pump | 662 2862 |
| 1 | Bubble counter | 664 814 |
| 1 | Microliter syringe, 1 κl | 665 617 |
| 1 | Replacement cannulas, set of | 665 616 |
| 1 | Pair of cables, 50 cm, red and blue | 501 45 |
| 1 | PC with Windows XP/Vista/7 | |

### Chemicals

| | |
|---|---|
| Methanol, 250 ml | 673 2700 |
| Ethanol, abs., 250 ml | 671 9700 |
| Propanol-1, 250 ml | 674 4310 |
| Propanol-2, 250 ml | 674 4400 |

## Experiment setup (see drawing)

- Prepare the sample, e.g. a mixture of different alcohols such as: methanol, ethanol and propanol.
- Set up the gas chromatograph with the separation column (Porapak P) and the hydrocarbon sensor (detector).
- Connect the input of the GC to the air pump and the output to the bubble counter.
- Switch the air pump on.
- Connect the GC to the plug-in unit. The LED at the GC lights up.

## Carrying out the experiment

■ Load settings

- Use the zero point controllers on the GC to set the zero line at approx. $U_{A1}$=0.05 V.
- Start the test measurement with ⏱.
- As soon as a stable zero line is recorded, stop the test measurement, again with ⏱.
- Using the microliter syringe, inject 0.5 κl of the alcohol mixture into the injection head of the gas chromatograph.
- Restart the recording of the voltage with ⏱, and continue measuring until all peaks to be expected have appeared; then stop the measurement with ⏱.

## Evaluation

You can zoom in on the relevant curve section so that it covers the diagram (open the Evaluations menu by clicking on the diagram with the right mouse button).

To determine the retention times you can insert a vertical line through the maximum value of a peak or calculate the peak center. You can also insert the retention time in the diagram as text.

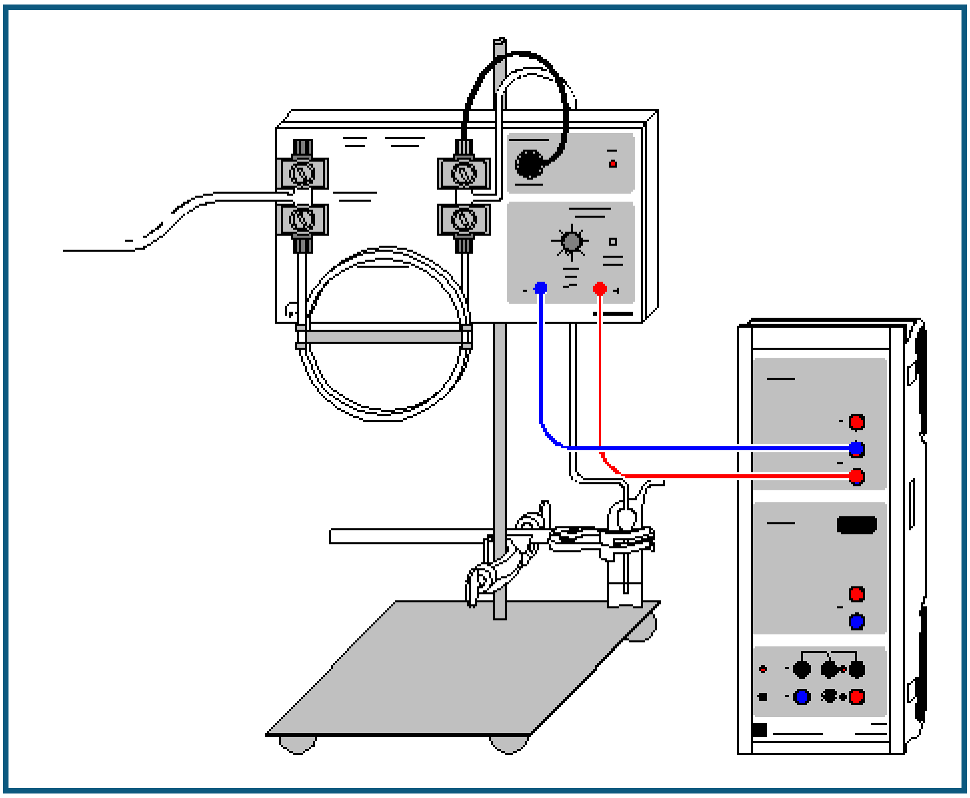
For quantitative analysis of the mixture, the peak areas are determined by integration. Then the fraction of the peak area relative to the total area of all peaks is determined. In this example, the total area of all peaks is 950 Vs. The fractional area of ethanol is thus 206 Vs / 950 Vs = 22 %. The concentration can be determined precisely through calibration with the individual substances or by using the addition method.

## Further experiment options

After recording a calibration series with known alcohol concentrations, you can determine the alcohol content of several alcoholic drinks.

By heating the column in a water bath, you can also separate alcohols of greater chain length.

# Gas chromatography (separation of air)



✓ ✓ can also be carried out with Pocket-CASSY and Mobile-CASSY

## Experiment description

In this experiment, in which the gases present in air are separated, the voltage at the recorder output of the gas chromatograph, which is supplied by the thermal conductivity detector, is measured as a function of time. The carrier gas is hydrogen, which is taken from a hydride reservoir.

Determination of the peak areas by integration enables quantitative investigation of the sample. For a qualitative analysis, the retention times of the individual peaks can be determined and compared with those of the reference substances.

Be sure to read the Instruction Sheet for your gas chromatograph.

## Equipment list

| | | |
|---|---|---|
| 1 | Sensor-CASSY | 524 010 or 524 013 |
| 1 | CASSY Lab 2 | 524 220 |
| 1 | Gas chromatograph LD1 | 665 580 |
| 1 | Separation column with molecular sieve | 665 585 |
| 1 | Thermal conductivity detector | 665 581 |
| 1 | Metal hydride reservoir | 661 005 |
| 1 | Regulating valve | 666 4792 |
| 1 | Bubble counter | 664 814 |
| 1 | Syringe, 5 ml | 665 955 |
| 1 | Disposable needles, 10 pieces | 665 960 |
| 1 | Pair of cables, 50 cm, red and blue | 501 45 |
| 1 | PC with Windows XP/Vista/7 | |

## Experiment setup (see drawing)

- Set up the gas chromatograph (GC) with the separation column (molecular sieve) and the thermal conductivity detector (HCD).
- Connect the input of the GC to the metal hydride reservoir and the regulating valve and the output to the bubble counter.
- Open the regulating valve to allow hydrogen to flow through the GC.

- Connect the GC to the plug-in unit. The LED at the GC lights up.
- In order to get a positive signal, change the polarity of the connecting leads to the CASSY (the thermal conductivity of the substances to be separated is lower than that of hydrogen).

## Carrying out the experiment

■ Load settings

- Use the zero point controllers on the GC to set the zero line at approx. $U_{A1}$=0.05 V.
- Start the test measurement with ⏱.
- As soon as a stable zero line is recorded, stop the test measurement, again with ⏱.
- With the syringe inject 2 ml of air into the injection head of the GC.
- Restart the recording of the voltage with ⏱, and continue measuring until all peaks to be expected have appeared; then stop the measurement with ⏱.

## Evaluation

With Diagram → Zoom you can zoom in on the relevant curve section so that it covers the diagram.

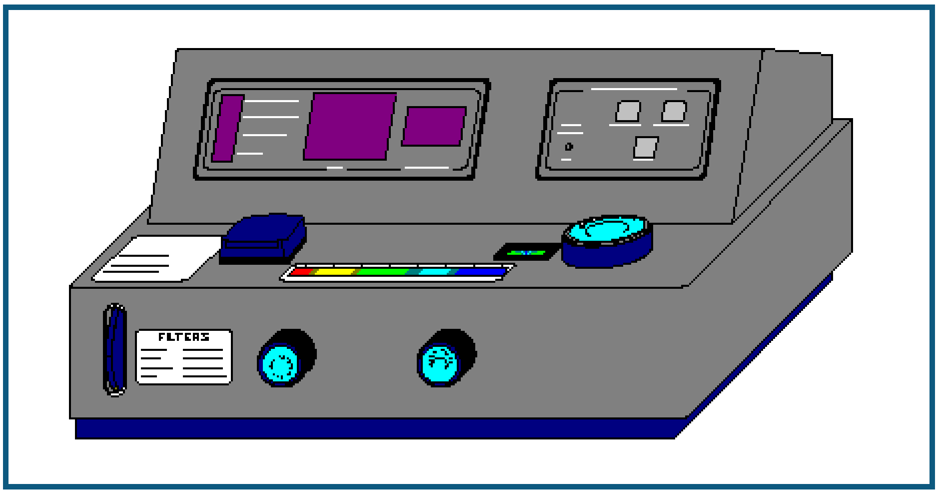
For quantitative analysis of the mixture, the peak areas are determined by integration. Then the fraction of the peak area relative to the total area of all peaks is determined. In the example, the total area of all peaks is 37.85 Vs. The percentage of the first component (oxygen) is therefore 8.12 Vs / 37.85 Vs = 21 %. The percentage of the second substance (nitrogen) is 29.73 Vs / 37.85 Vs = 79 %. As the specific heat of the two gases is similar, it is not necessary to perform a calibration with the individual substances or according to the addition method, which is usually required for an exact determination of the concentrations.

Remark: the rise of the zero line (drift) from the second peak onwards is caused by a change in the room temperature during the measurement.

## Further experiment options

As this setup also enables carbon monoxide and methane to be separated, other gas mixtures, such as biogas, can be examined.

## Recording the spectrum of a solution of crude chlorophyll



### Experiment description

The spectrum is recorded by measuring the transmission of the chlorophyll solution in the wavelength range from 360 to 800 nm. Then the absorption maxima of the leaf-dyes (the spectrum of activity of photosynthesis) can be determined from the spectrum.

### Equipment list

| | | |
|---|---|---|
| 1 | Digital spectrophotometer | 667 3491 or 667 3493 |
| 1 | PC with Windows XP/Vista/7 | |

### Required for preparing the chlorophyll solution

| | | |
|---|---|---|
| 1 | Mortar | 608 352 |
| 1 | Pestle | 667 091 |
| 1 | Erlenmeyer flask, 100 ml, SB 19 | 664 241 |
| 1 | Rubber stopper, SB 19 | 667 255 |
| 1 | Funnel | 602 670 |
| 1 | Round filters, d=110 mm, 100 pcs. | 661 034 |
| 1 | Sea-shore sand, cleaned, 250 g | 674 8200 |
| 1 | Acetone, 250 ml | 670 0400 |

### Danger

Acetone is readily flammable. Keep away from ignition sources.

### Experiment preparation

- Cut dried nettle leaves (tea) - alternatively fresh grass or other leaves - into small pieces, and put them into the mortar.
- Add some sea-shore sand and first only a small quantity of acetone so that the mixture can be grinded until it is a kind of pulp.
- After grinding 1 to 2 minutes, add about 10 to 20 ml of acetone and stir.
- Filter the solution, which now has a clearly green color, into the Erlenmeyer flask with the funnel and a folded round filter.
  If the experiment is not carried out immediately, keep the Erlenmeyer flask with the solution of crude chlorophyll in a dark place.
- For the experiment, part of the solution has to be diluted so that the transmission at 605 nm is larger than 0 %.
- Connect the Digital spectrophotometer to the computer with the serial cable, and switch it on. Mind the instruction sheet of the device.

### Carrying out the experiment with the spectrophotometer 667 3491

Load settings

- In Settings Wavelength ı select the interface used.

- Fill one round cell with the solution of crude chlorophyll (sample solution) and another one with the reference solution (the pure solvent, here: acetone) each to approximately ¾ height.
- Set the starting wavelength to 340 nm at the spectrophotometer.
  (For general explanations on using the device see instruction sheet.)
- Make the 100 %T calibration with the reference cell, then insert the sample cell.
- Take over the displayed measured value and the associated wavelength with ⏱. This value is now displayed in the table and in the plot.
- Increase the measuring wavelength by 5 nm, and repeat the calibration and the measurement.
- The measurement is finished when the measuring wavelength 800 nm has been reached.

### Carrying out the experiment with the spectrophotometer 667 3493

■ Load settings

- In Settings Wavelength ı select the interface used.
- Fill one round cell with the solution of crude chlorophyll (sample solution) and another one with the reference solution (the pure solvent, here: acetone) each to approximately ¾ height.
- Set the starting wavelength to 340 nm at the spectrophotometer.
  (For general explanations on using the device see instruction sheet.)
- Start the measurement with ⏱.
- Make the 100 %T calibration with the reference cell, then insert the sample cell.
- Transfer the value by pressing the FUNC button on the photometer. This value is now displayed in the table and in the plot.
- Increase the measuring wavelength by 5 nm, and repeat the calibration and the measurement.
- After the measuring wavelength of 800 nm is reached stop the measurement with ⏱.

### Remark

Recording the measured values as described here takes about one hour. A shorter measuring time can be achieved by measuring in steps of 10 nm and/or by stopping the measurement already at 730 nm.

### Evaluation

The spectrum can be displayed as transmission T, absorption A = 100-T or as extinction E = -log(T/100).

The strong absorption (lower transmission) around 405 nm (blue light) and 660 nm (red-orange) is clearly discernible. The evaluation menu (click Graphics with the right mouse key) enables individual wavelengths to be marked with a vertical line. With Text the marked wavelength is written near the line or curve.

Due to absorption in these parts of the visible light spectrum the rest of the spectrum stands out more conspicuously when light is reflected (leaf surface) or passes through (solution). This latter part around 550 nm corresponds to the green component of light, and this is the reason why a solution of chlorophyll and leaves appear to be green.

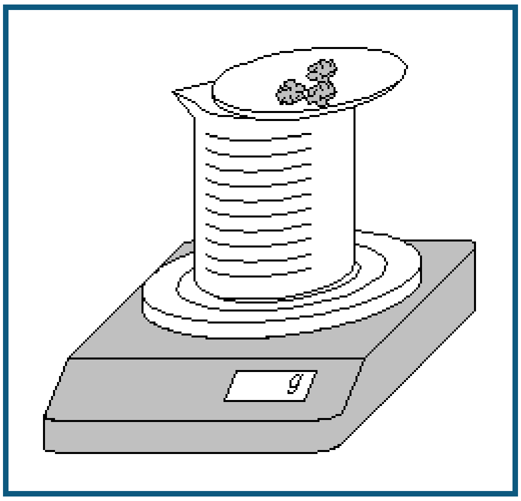
By irradiating with light at wavelengths around the absorption maxima, maximum photosynthetic performance is obtained, i.e. the absorption or extinction curve represents the spectrum of activity of photosynthesis.

If considered more precisely, this spectrum turns out to be the superposition of three individual spectra, namely those of chlorophyll a, chlorophyll b, and β-carotene. The individual leaf-dyes can be separated, e.g. by thin-layer chromatography.

### Further experiment options

- Apart from chlorophyll, the spectra of arbitrary other colored solutions can be studied.
- For carrying out the experiment in a shorter time a rougher resolution (e.g. in steps of 10 nm) and another wavelength range may be chosen.
- The Compact Spectrometer (467 252) makes recording spectra considerably quicker and more comfortable.
- The dependence of the transmission and the extinction on the concentration can be demonstrated by measuring a series of concentrations, e.g. of a copper-sulphate solution, at the absorption maximum.
- For kinetic investigations (e.g. decolorization of crystal violet) the absorption maximum is measured as a function of time. The opportunities provided by specifying a formula and the corresponding displays and evaluations enable the reaction order and the rate constant of the reaction to be determined.

## Reaction of marble with hydrochloric acid (determining the carbonate content)



**Danger**

Hydrochloric acid is corrosive. Wear protective goggles.

### Experiment description

Due to the development of $CO_2$ during the reaction of marble with hydrochloric acid, a loss of mass occurs which is registered using a balance (CASSY interface device not required).

### Equipment list

| | | |
|---|---|---|
| 1 | CASSY Lab 2 | 524 220 |
| 1 | Electronic balance | SATE412 |
| 1 | Interface cable | 667 7800 |
| 1 | Beaker, 250 ml, ss | 664 130 |
| 1 | Watch glass, ∅ = 80 mm | 664 154 |
| 1 | PC with Windows XP/Vista/7 | |

### Chemicals

| | |
|---|---|
| Marble, chips, 250 g | 673 2500 |
| Hydrochloric acid, c = 2 mol/l, 500 ml (approx. 6-7 %) | 674 6920 |

### Experiment setup (see drawing)

The program supports the Sartorius, Mettler and Ohaus balances with a serial data output available from LD Didactic.

Connect the balance to a USB port of the computer via the connecting cable. As the cables of different manufacturers differ from each other, use the interface cable provided by the respective manufacturer to ensure that the computer connection works correctly.

Fill the beaker with about 100 ml 6 % hydrochloric acid and place it on the balance. Place the watch glass on the beaker. Zero the balance by pressing the tare button. Then weigh 5 g marble chips into the watch glass.

### Carrying out the experiment

☐ Load settings
- Adjust the serial port of the USB cable, baud rate and the mode of the balance in Settings mass m:
  Factory settings of Sartorius balances:
  Mode: 7O1
  Baud rate: 1200
  Factory settings of Mettler balances:
  Mode: 8N1
  Baud rate: 9600
- In one respect the factory settings of the balance have to be changed. Read the instruction sheet of the balance:
  Sartorius: data transfer as "Auto print regardless of stability" instead of "Print on request after stability"

Mettler: continuous data transfer ("S.Cont")

- All transferred measured values are displayed (Troubleshooting)
- Enter the mass of the marble chips in the calculation of the mass component. In Settings w change the example value 4.96 to the currently displayed value.
- Start the measurement with ⏱.
- Start the reaction immediately by tilting the watch glass to dump the marble chips into the beaker. Leave the watch glass tilted on the beaker.
- Record and observe the reaction until the marble is completely dissolved.
- Stop the measurement with ⏱.

## Evaluation

You can correct the irritating weight fluctuations which occur when "dumping" the marble by clicking on the "fliers" in the table and setting them to the initial value (in this example 4.96 g).

In the shape of the curve of mass m (in g) respectively mass component w (in %), we can initially observe a high reaction speed, which decreases progressively (exponentially) as the concentration of the reactants (resp. the number or reacting molecules and ions) becomes less.

From the final mass values (best seen in the table), we can determine the amount of escaped $CO_2$ in marble ($CaCO_3$).

$CaCO_3 + 2\ HCl \rightarrow CaCl_2 + CO_2 + H_2O$

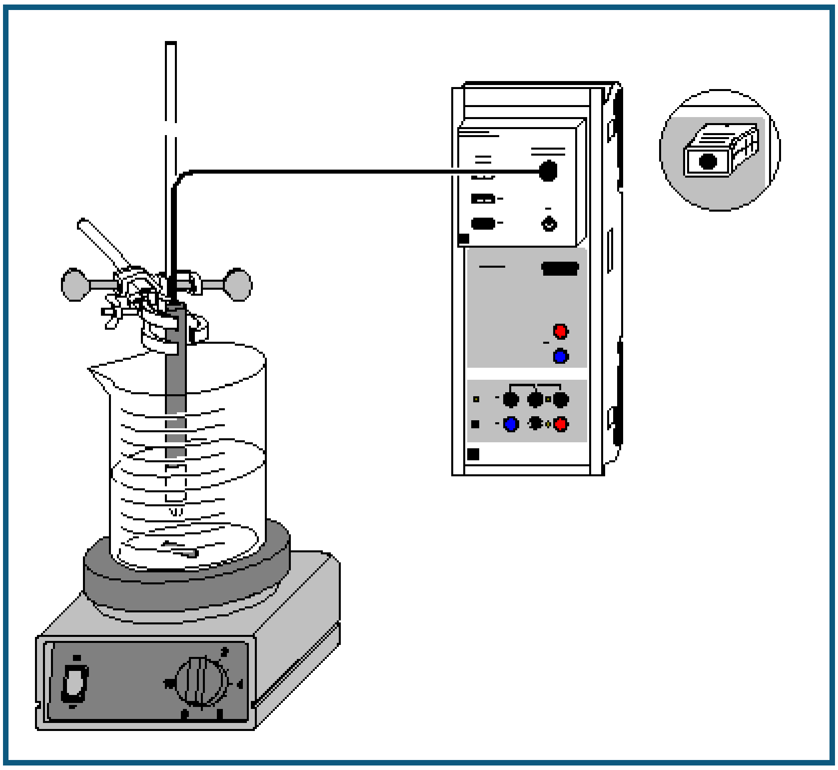
In the example measurement series, the experimentally determined $CO_2$ component is

$m_{CaO} = 2.85\ g/4.96\ g = 57.5\ \%$ $m_{CO2} = 100\ \% - 57.5\ \% = 42.5\ \%$

The theoretical value is

$m_{CO2} = CO_2/CaCO_3 = 44.0\ g/100.0\ g = 44.0\ \%$.

## Splitting of urea by urease (zero-order reaction)



can also be carried out with Pocket-CASSY and Mobile-CASSY

### Experiment description

Enzymatic splitting of urea by urease can be considered from several points of view. At first this reaction can serve as an example of a zero-order reaction. This reaction order is recognized from the linear increase of the product concentration.

Besides, the kinetics of the catalysis can be considered: first there is an equilibrium between the substrate and the enzyme on the one hand and an enzyme-substrate complex on the other hand. This equilibrium can already be compared with the diffusion-controlled addition of a substrate to a catalytically active surface. The enzyme-substrate complex is then quickly converted into the products in a second step.

Moreover, the reaction can be used as an introduction into enzyme kinetics: by carrying out several measurements, the maximum reaction rate, the Michaelis constant, and the enzyme concentration can be determined.

As in the course of the hydrolysis of urea

$$H_2N{-}CO{-}NH_2 + 2\,H_2O \xrightarrow{\text{Urease}} 2\,NH_4^+ + CO_3^{2-}$$

ammonium carbonate is produced, which dissociates into several ions, the reaction can be followed by measuring the conductivity. The concentration of the products and the reaction rate are calculated from the gathered data.

### Equipment list

| | | |
|---|---|---|
| 1 | Sensor-CASSY | 524 010 or 524 013 |
| 1 | CASSY Lab 2 | 524 220 |
| 1 | Chemistry box or conductivity adapter S | 524 067(1) |
| 1 | Conductivity sensor | 529 670 |
| 1 | Magnetic stirrer | 666 8451 |
| 1 | Stand rod, 450 mm, M10 thread | 666 523 |
| 1 | Crossed bosshead | 666 543 |
| 1 | Beaker, 100 ml, tall shape | 664 137 |
| 1 | Beaker, 150 ml, tall shape | 602 010 |
| 2 | Weighing scoops | 602 763 |
| 1 | Graduated pipette, 10 ml | 665 997 |
| 1 | Pipetting ball | 666 003 |
| 1 | Volumetric flask, 100 ml | 665 793 |

| | | |
|---|---|---|
| 1 | Watch glass dish, e.g. 80 mm | 664 154 |
| 1 | Powder funnel, e.g. 60 mm | 602 681 |
| 2 | Test tubes from | 664 043 |
| 2 | Rubber stoppers, ∅ 14...18 mm | 667 253 |
| 1 | Spatula | 666 961 |
| 1 | Balance, resolution 0.01 g | |
| 1 | PC with Windows XP/Vista/7 | |

### Chemicals

| | |
|---|---|
| Ammonium carbonate, e.g. 100 g | 670 3900 |
| Urea, e.g. 100 g | 672 1700 |
| Urease (1 U/mg), e.g. 5 g | 675 2810 |
| Copper(II) sulphate pentahydrate, e.g. 100 g | 672 9600 |
| Distilled water | |

### Note concerning the chemicals

At room temperature, urease degenerates within a few hours. Therefore urease may only stay outside the refrigeration for a few minutes.

In air, ammonium carbonate slowly reacts to ammonium bicarbonate. As this would distort the conductivity measurement, do not use old stocks.

### Preparing the solutions

Weigh in 0.96 g of ammonium carbonate on the watch glass dish, and rinse it via the funnel into the 100 ml volumetric flask. Fill the volumetric flask up to the mark, and dissolve the ammonium carbonate completely.

Weigh in 0.10 g of urease and 0.60 g of urea each in a weighing scoop. Put the substances into the two test tubes, and rinse residues that may have remained in the weighing scoops into the test tubes with the aid of the pipette, in each case using exactly 10 ml of distilled water.

Close the test tubes with the rubber stoppers, and dissolve the substances by shaking. As a result you obtain 10 ml of a 1 M urea solution and 10 ml of a urease solution with an enzyme activity of 10000 U/l - i.e., given the activity of the urease of 1U/mg, 10 mmol of the substrate can be converted per minute and litre.

### Calibration

■ Load settings

The cell constant of the conductivity sensor for the chemistry box has already been set to 0.58 in CASSY Lab.

If another conductivity sensor is used, its cell constant has to be entered as a factor in Settings Conductivity CA1 under **Correct**. Then the **Correct Factor** button has to be pressed.

For a more precise determination of the cell constant, calibration solutions can be used:

- Rinse the 100 ml beaker and the conductivity sensor first with distilled water and then with approx. 30-40 ml of calibration solution.
- Immerse the conductivity sensor in another 50 ml of calibration solution as if it was for a conductivity measurement (pay attention to the distances from the walls of the beaker), enter the target value in the second line in Settings CA1 under **Correct**, and press the **Correct Factor** button when a stable measured value is reached.

### Preparing the experiment (see drawing)

Plug the chemistry box with the conductivity sensor into input A of the Sensor-CASSY.

Rinse the 100 ml beaker and the conductivity sensor with approx. 30 ml of ammonium carbonate solution. Dispose of the rinsing solution, fill the remainder of the ammonium carbonate solution into the beaker, and measure the conductivity of this solution. See to it that the conductivity sensor is immersed to a depth of at least 2 cm and that its distance from the walls of the vessel is at least 1 cm (see instruction sheet).

Enter the measured value in Settings ϑ1 in the field Formula instead of the default value. This value is required for calculating the concentration of urea since it is assumed that after complete hydrolysis of the urea a 0.1 M solution of ammonium carbonate is obtained.

Setup an assembly for measuring the conductivity using the magnetic stirrer, the stand material, the conductivity sensor, and the second beaker. Again see to it that the distance of the conductivity sensor from the walls of the vessel and from the stirrer bar is sufficient.

Fill exactly 80 ml of distilled water into the beaker (use the graduated pipette), add the urea solution, and switch the magnetic stirrer on. The conductivity indicated in the display instrument $C_{A1}$ should not exceed 0.02 mS/cm in the case of pure chemicals.

### Carrying out the experiment

■ Load settings
- Start the measurement with ⏱.
- Pour the urease solution into the beaker with the urea solution.
- After 2 to 3 minutes, add some crystals of copper sulphate to the solution using the spatula. Mark the time of injection by Diagram → Set Marker → Vertical Line.
- Wait until the shape of the conductivity curve becomes linear again. Then stop the measurement with ⏱.

### Evaluation

For the purpose of evaluation, several diagrams have been prepared:

1. In the diagram **Specific Conductivity**, the measured values of the conductivity are plotted against the time. It is clearly seen that the conductivity increases almost linearly before the addition of copper sulphate, whereas the curve is almost horizontal after the copper sulphate has completely dissolved. This demonstrates the toxic action of the heavy metal on the enzyme.

2. The diagram **Urea Concentration** shows the course of the urea concentration as calculated from the specific conductivity. The applied formula reads:

$$[NH_2CONH_2] = \frac{\kappa_1 - C_{A1}}{\kappa_1 - \kappa_0} \cdot 100 \quad mmol/l$$

Here $\theta_1$ is the conductivity of the ammonium carbonate solution measured before the experiment (conductivity at the end of the reaction), $C_{A1}$ the conductivity measured at the time t, $\theta_0$ the conductivity of the solution at the beginning of the reaction, and 100 mmol/l the concentration of urea at the beginning of the reaction. In order to calculate the urea concentration, the first value of the conductivity has to be entered in Settings θ0 in the field Formula instead of the default value.

This calculation is correct until copper sulphate is added (range A in the diagram); afterwards $C_{A1}$ is also influenced by the copper and sulphate ions present in the solution (ranges B and C). However, after the copper sulphate has completely dissolved, the relative change of the conductivity only depends on the proceeding hydrolysis of the urea (C). Therefore the reaction rate after the poisoning of the urease can also be determined.

The slope of the resulting straight line in the plot of the urea concentration against the time gives the value of $k_2 \cdot [ES]$. As [ES] is almost constant in the steady state (see theoretical background), the curve obtained for the reaction rate r is approximately a straight line. In order to calculate the initial reaction rate, fit a straight line to the curve range up to t ≈ 60 s. Click the diagram with the right mouse button, select Fit function → Best-fit straight line , and mark the corresponding curve range. The slope of the straight line is displayed as parameter A below on the left in the status line, and can be inserted in the diagram with Set Marker → Text. The slope of the second linear curve range after the addition of copper sulphate is determined in the same way. From a comparison of the two slopes it becomes obvious that the reaction has almost been stopped.

3. In the diagram **Reaction Rate**, the derivative of the urea concentration with respect to the time is plotted. It is clearly seen that the reaction rate is constant before the addition of $CuSO_4$ and approximately 0 afterwards. By inserting a horizontal line at the value for $k_2 \cdot [ES]$ obtained via the diagram **Urea Concentration**, this difference can be emphasized. A comparison with the diagram **Reaction Rate** of the experiment Reaction of marble with hydrochloric acid (determining the reaction order) reveals the differences between a first-order reaction and the zero-order reaction observed in this experiment.

### Theoretical background

The reaction rate r is defined as the change of the concentration of one of the parent substances or one of the products per unit time, i.e. it always refers to one of the substances that participate in the reaction. The change of the concentration of the reactants enters the calculation with a negative sign and that of the products with a positive sign. In the enzymatic splitting of urea, the reaction rate with reference to the urea concentration thus is:

$$r_{H_2NCONH_2} = -\frac{d\,[H_2NCONH_2]}{dt}$$

The reaction takes place through catalysis by the enzyme urease. The mechanism can be described as follows (E: enzyme urease, S: substrate urea, ES: enzyme-substrate complex, P: products):

$$E + S \underset{k_1'}{\overset{k_1}{\rightleftharpoons}} ES \overset{k_2}{\rightarrow} P$$

The reaction rate of the splitting of urea is also given by the rate equation:

$$r_{H_2NCONH_2} = -\frac{d\left[H_2NCONH_2\right]}{dt} = k_2 \cdot \frac{k_1}{k_1'} \cdot [E] \cdot [S] = k_2 \cdot [ES]$$

That means, with reference to [ES] it is a first-order reaction.

As the enzyme E acts as a catalyst, its total concentration remains constant in the course of the reaction. If the substrate concentration is sufficient, a stationary state arises, where the rates of formation and decomposition of the enzyme-substrate complex are equal:

$$k_1 \cdot [E] \cdot [S] = (k_1' + k_2) \cdot [ES]$$

For this reason, the concentration [ES] is constant during the reaction, its magnitude being controlled by the magnitude of the rate coefficient. Such a case is called a steady state. For the formation of the reaction products P this results in a constant reaction rate, and therefore the curve of the urea concentration has a linear shape. All together this leads to a zero-order rate equation for the splitting of urea by urease:

$$r_{H_2NCONH_2} = k_2 \cdot [ES] = k_3$$

As the reaction rate actually depends on [ES], this dependence being hidden by the constancy of [ES], this case is also called a pseudo-zero-order reaction.

For determining the rate coefficient of a reaction of this type, you only have to determine the slope of the straight line in the concentration-time diagram of the urea.

The fact that urease is not stable at room temperature is also obvious from the drop of the reaction rate when the experiment is continued for a long time. Only in the beginning of the reaction is the curve for the urea concentration linear.

### Further experiment options

The enzymatic reaction kinetics can be studied more thoroughly if an experiment series with different initial concentrations of urea (e.g. 0.005 mol/l, 0.01 mol/l, 0.025 mol/l, 0.05 mol/l, 0.075 mol/l, 0.1 mol/l, 0.2 mol/l) is carried out. Plot the reaction rate as a function of the initial concentration in a new diagram.

From the maximum reaction rate $r_{max}$ obtained in the experiment series, the Michaelis constant $K_m$ can be determined. $K_m$ is defined as

$$K_m = \frac{k_1' + k_2}{k_1} = \frac{[E] \cdot [S]}{[ES]} \qquad (1)$$

and is related with the reaction rate via

$$r = k_2 \cdot ([E] + [ES]) \cdot \frac{[S]}{K_m + [S]} \qquad (2)$$

Given that $r_{max}$ is reached when the enzyme is saturated with substrate, half the enzyme has to be complexed in the enzyme-substrate complex at ½ $r_{max}$. Then [E] = [ES], and from (1) it follows that

$K_m$ = [S] at ½ $r_{max}$.

As, in addition, for high concentrations

$$r_{max} = k_2 \cdot ([E] + [ES]) \qquad (3)$$

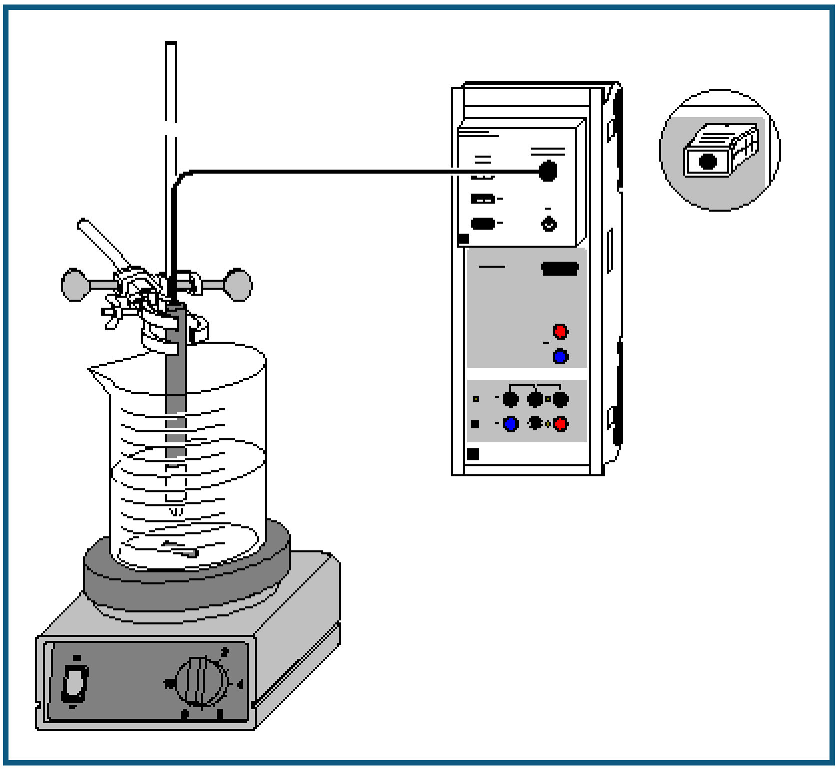
the reaction rate of an enzyme-substrate mixture can easily be calculated according to (2) and (3) with the Michaelis constant and the maximum reaction rate.

The Michaelis constant is to be determined from the substrate concentration at ½ $r_{max}$. $K_m$ is determined more precisely if 1/r is plotted against 1/[S] following Lineweaver-Burk. The plot is based on a transformation of (2) and (3):

$$\frac{1}{r} = \frac{K_m}{r_{max} \cdot [S]} + \frac{1}{r_{max}}$$

The slope of the straight line gives just the term $K_m/r_{max}$, and the cut off from the 1/r axis is $1/r_{max}$.

## Hydrolysis of tertiary butyl chloride (determining the reaction order)



can also be carried out with Pocket-CASSY and Mobile-CASSY

### Experiment description

Hydrolysis of tertiary butyl chloride (2-chloro-2-methylpropane) results in the formation of tertiary butanol and hydrogen chloride (through protolysis of oxonium and chloride ions), which lead to a sharp increase in conductivity:

$(CH_3)_3C - Cl + 2\ H_2O \longrightarrow (CH_3)_3C - OH + H_3O^+ + Cl^-$

### Equipment list

| | | |
|---|---|---|
| 1 | Sensor-CASSY | 524 010 or 524 013 |
| 1 | CASSY Lab 2 | 524 220 |
| 1 | Chemistry box or conductivity adapter S | 524 067(1) |
| 1 | Conductivity sensor | 529 670 |
| 1 | Magnetic stirrer | 666 8451 |
| 1 | Beaker, 250 ml, ts | 664 113 |
| 1 | Stand tube | 666 607 |
| 1 | Double bosshead | 301 09 |
| 1 | Universal clamp, 0...25 mm | 666 551 |
| 1 | Graduated cylinder, 100 ml | 665 754 |
| 1 | Measuring pipette, 1 ml | 665 994 |
| 1 | Pipetting ball | 666 003 |
| 1 | PC with Windows XP/Vista/7 | |

### Chemicals

0.8 ml solution of tertiary butyl chloride
(c=0.1 mol/l) in acetone

### Danger

Acetone is readily flammable. Keep away from ignition sources.

### Experiment setup (see drawing)

- Set up the magnetic stirrer on the stand.
- In the graduated cylinder, measure off 90 ml distilled water and 10 ml acetone and pour these into the beaker.
- Add a magnetic stirrer bar and place the beaker on the magnetic stirrer. Mount the conductivity measuring cell on the stand so that it is immersed to a level just below the air opening. Switch on the magnetic stirrer.
- Plug in the conductivity box at input A of Sensor-CASSY and connect the conductivity measuring cell to the conductivity box using the banana plug.

### Carrying out the experiment

■ Load settings

Notes on the displayed conductivity value

The initial conductivity value should not exceed 10 κS/cm for this experiment. If this occurs, clean the measuring cell thoroughly with distilled water.

Alternatively, you can **Correct** the offset in Settings Conductivity (click on the display with the right mouse button) to set the initial value to zero.

- Calibrate the measuring cell. To do this, open Settings Conductivity (click on the display with the right mouse button), select **Correct**, and enter the factor stamped on the cell and select **Correct Factor**.
- Measure off 0.8 ml of the tertiary butyl chloride solution (c = 0.1 mol/l) with the measuring pipette.
- Start the measurement with ⏱.
- Quickly dissolve the measured quantity of tertiary butyl chloride in the beaker. Mark the time of injection by Diagram → Set Marker → Vertical Line.
- After about 8 minutes, terminate the measurement with ⏱; at this point the conductivity should scarcely change. If necessary, you can increase the measuring range in Settings CA1.

### Evaluation

This experiment is provided with four evaluation procedures already prepared:

Display of change in concentration

Click the **Concentration** tab. You can now follow the change in the concentration c of tertiary butyl chloride. The calculation of the concentration in mmol/l is performed using the amount of the substance (0.8 ml 0.1 mol solution), the present conductivity $C_{A1}$ and the final conductivity (here: 198.9 κS/cm; this value can be changed in accordance with the conductivity value read from the table).

You can view the conversion formula **(1-CA1/198.9)*0.8**, and alter it if desired, in the Settings c; the same is true for the display range.

Test for 1st-order reaction

Select the tab **Test for 1st Order**. This shows $\ln(c_A/c)$ as a function of t ($c_A$ = initial concentration, c quantity of tertiary butyl chloride used). To determine the velocity constant k of the reaction, apply a best-fit straight line to the beginning linear section of the curve (click the right mouse button to fit the line in the diagram) and determine the slope. Using Set Marker → Text, you can label the line with the value for the slope (A).

Test for 2nd-order reaction

Select the tab **Test for 2nd Order**. This shows $1/c - 1/c_A$ as a function of t ($c_A$ = initial concentration, c quantity of tertiary butyl chloride used). This diagram does not show a linear relationship. Thus, no second-order reaction occurs here.

Method of half-times

In the diagram **Half-time**: as this is a first-order reaction, the rate constant can also be determined via the method of half-times. Insert horizontal lines at 0.4 mmol, 0.2 mmol, and 0.1 mmol; mark the points of intersection of these lines with the concentration curve by vertical lines. The average time difference between all vertical lines is thehalf-time $t_{1/2}$, which in this example is 63 s.

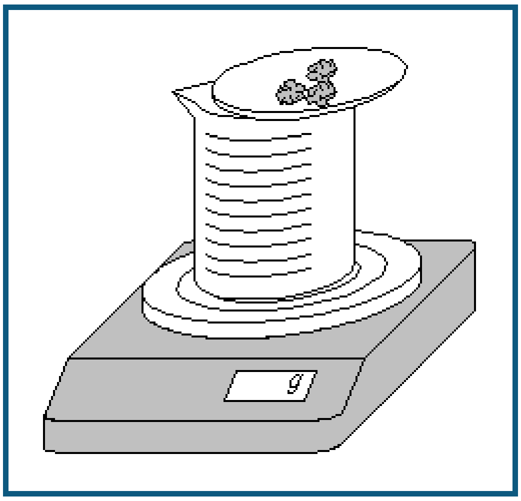
Enter the half-time determined in the experiment in Settings k in the formula **ln 2/63** as denominator. The result is displayed in the display instrument k.

### Further experiment options

- Performance and recording of hydrolysis at different temperatures. The curves are superimposed for comparison when the measurement is repeated. The effect on the progress and speed of the reaction can be clearly seen. The activation energy of the reaction can be calculated from the different velocity constants and the corresponding temperatures.

- Use of different solvents to investigate how the solvent affects the order and speed of the reaction.
- Investigation of enzymatic reactions, e.g. breakdown of urea by urease.

## Reaction of marble with hydrochloric acid (determining the reaction order)



**Safety note**

Hydrochloric acid is caustic. Wear protective goggles, gloves and clothing.

### Experiment description

If an excess amount of marble (lime, $CaCO_3$) reacts with a defined amount of hydrochloric acid, the reaction order can be determined from the mass balance. The reaction takes place according to the following equation:

$$CaCO_3 + 2H_3O^+ \xrightarrow[aq]{} Ca^{2+} + CO_2 \uparrow + 3H_2O$$

As carbon dioxide escapes, the mass of the reaction mixture decreases continuously. This decrease can be measured by means of a balance and enables the evolution of the concentration of hydrochloric acid to be determined.

### Equipment list

| | | |
|---|---|---|
| 1 | CASSY Lab 2 | 524 220 |
| 1 | Electronic balance | SATE412 |
| 1 | Interface cable | 667 7800 |
| 1 | Beaker, squat shape, 250 ml | 664 130 |
| 1 | Watch glass, ∅ = 80 mm | 664 154 |
| 1 | Bulb pipette, 25 ml | 665 976 |
| 1 | Pipetting ball | 666 003 |
| 1 | PC with Windows XP/Vista/7 | |

### Chemicals

| | |
|---|---|
| Marble, chips, 250 g | 673 2500 |
| Hydrochloric acid, c = 2 mol/l, 500 ml | 674 6920 |

### Experiment setup (see drawing)

The program supports the Sartorius, Mettler and Ohaus balances with a serial data output available from LD Didactic.

Connect the balance to a USB port of the computer via the connecting cable. As the cables of different manufacturers differ from each other, use the interface cable provided by the respective manufacturer to ensure that the computer connection works correctly.

Use the pipette to put exactly 75 ml of hydrochloric acid into the beaker. Put the watch glass dish on the beaker, set the balance to 0, and weigh in exactly 30 g of marble chips on the watch glass dish. Reset the balance to 0.

### Carrying out the experiment

☐ Load settings
- Adjust the serial port of the USB cable, baud rate and the mode of the balance in Settings mass m:
  Factory settings of Sartorius balances:
  Mode: 7O1
  Baud rate: 1200

Factory settings of Mettler balances:
Mode: 8N1
Baud rate: 9600

- In one respect the factory settings of the balance have to be changed. Read the instruction sheet of the balance:
  Sartorius: data transfer as "Auto print regardless of stability" instead of "Print on request after stability"
  Mettler: continuous data transfer ("S.Cont")
- All transferred measured values are displayed (Troubleshooting)
- Start the measurement with ⏱.
- Initiate the reaction by pouring the marble chips from the watch glass dish into the beaker. Leave the watch glass dish on the beaker.
- When the reaction has almost come to a standstill (approx. 10 minutes), stop the data logging with ⏱.

### Evaluation

The fluctuations at the beginning of the measurement, which are caused by moving the watch glass dish, can be corrected by clicking the respective value with the mouse and entering "0".

1. In the diagram **Standard**: the measuring data give the mass m of the carbon dioxide that has escaped during the reaction (see reaction equation). Calculate the amount $n(CO_2)$ that has escaped from these data points and from this the concentration of the remaining acid $[H_3O^+]$:

$$n(CO_2) = -\frac{m}{44\,g/mol}$$

$$\left[H_3O^+\right] = \frac{2\,mol/l \cdot 0{,}075\,l - 2 \cdot n(CO_2)}{0{,}075\,l + 3 \cdot n(CO_2) \cdot 0{,}018\,l}$$

In the second equation, the numerator corresponds to the overall balance with respect to the amount of acid and the denominator to the overall volume balance.

2. In the diagram **1st order**: as a test for a first-order reaction with respect to the hydrochloric acid, the natural logarithm of the concentration of hydrochloric acid is plotted against the time t. In the case of a first order reaction, this plot leads to a straight line with the slope -k.

In order to determine the rate coefficient k, click the diagram with the right mouse button, select Fit function → Best-fit straight line, and mark the linear curve range, where a linear fit is reasonable. The slope of the straight line obtained in the fit is displayed in the status line below on the left and can be dragged into the diagram using the mouse. In the present experiment example, a rate coefficient of 0.01541/s is obtained.

In the experiment example, the plot for the first-order rate equation does not result in a straight line over the whole range because, after part of the hydrochloric acid has reacted, the rate is governed by diffusion: when the concentration of hydrochloric acid decreases, the acid reacts at a faster rate than new $H_3O^+$ ions are transported to the surface of the marble. Therefore the rate coefficient drops, and a deviation from the rate equation is observed. However, the reaction is well described by the first-order rate equation until 80 % of the acid are consumed in the reaction.

3. In the diagram **2nd order**: as a test for a second-order reaction with respect to the hydrochloric acid, the term $1/[H_3O^+]$ is plotted against the time t. If the reaction was of second order, this plot would result in a straight line with the slope k.

In the experiment example, the $H_3O^+$ concentration used for the calculations is averaged over 10 seconds in order to smooth the jumps that occur after 95 % of the acid have been consumed. These jumps are due to the finite resolution of the balance.

As there is no clearly linear region in this plot, you can assume that at no time a second-order reaction occurs in the experiment.

4. The evolution of the reaction rate r following from the reaction order is illustrated in the diagram **Reaction rate**. As the resolution of the measured values output by the balance would have to be greater by one order of magnitude - which would make the demonstration experiment much more difficult- in order to obtain optimum results in this diagram, the reaction rate $r_m$, which is averaged over 10 seconds, is plotted instead of r.

### Theoretical background

The reaction rate r is defined as the change of the concentration of one of the parent substances or one of the products per unit time, i.e. it always refers to one of the substances that participate in the reaction. The change of the concentration of the reactants enters the calculation with a negative sign and that of the products with a positive sign. For the reaction

$$CaCO_3 + 2H_3O^+ \xrightarrow[aq.]{} Ca^{2+} + CO_2 \uparrow + 3H_2O$$

the reaction rate r with respect to the concentration of $H_3O^+$ ions thus is:

$$r_{H_3O^+} = -\frac{d[H_3O^+]}{dt}$$

It is double the reaction rate with respect to the concentration of calcium ions because two $H_3O^+$ ions are required to create one calcium ion:

$$r_{Ca^{2+}} = \frac{1}{2} r_{H_3O^+} = \frac{d[Ca^{2+}]}{dt}$$

In order to find the dependence of the reaction rate on the concentration of the participating substances, the rate equation that governs the reaction is determined experimentally. The reaction order with respect to a particular substance is given by the exponent carried by this substance in the rate equation. The overall reaction order is formed from the sum of the exponents. In the reaction

$$CaCO_3 + 2H_3O^+ \xrightarrow[aq]{} Ca^{2+} + CO_2 \uparrow + 3H_2O$$

the reaction order can only be determined easily for the ions in the solution. For a first-order reaction the rate equation would read:

$$r_{H_3O^+} = 2 \cdot \frac{d[Ca^{2+}]}{dt} = -\frac{d[H_3O^+]}{dt} = k \cdot [H_3O^+]$$

After integration, the straight-line equation

$$\ln[H_3O^+] = -k \cdot t + \ln[H_3O^+]_0$$

with the slope -k and the cut off $\ln[H_3O^+]_0$ is obtained. $[H_3O^+]_0$ is the initial concentration of the acid.

For a second-order reaction with respect to the $H_3O^+$ concentration, the rate equation would read:

$$r = -\frac{d[H_3O^+]}{dt} = k \cdot [H_3O^+]^2$$

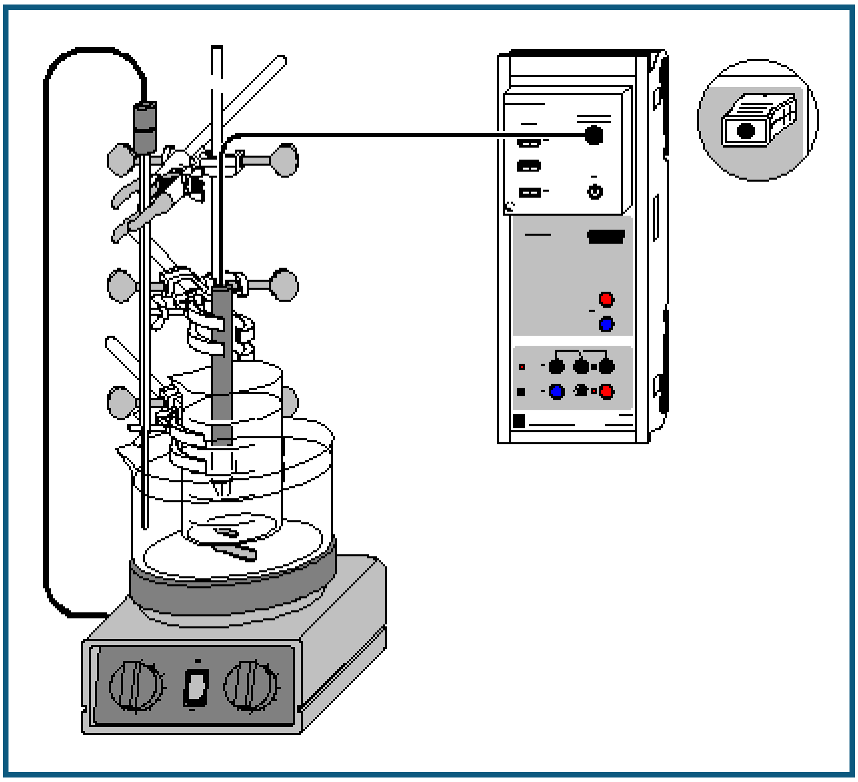
After integration, the straight-line equation

$$\frac{1}{[H_3O^+]} = k \cdot t + \frac{1}{[H_3O^+]_0}$$

with the slope k and the cut off $1/[H_3O^+]_0$ is obtained.

By plotting these two straight lines, it can be examined to what extent a reaction obeys the rate equations of first order or second order, respectively.

## Alkaline hydrolysis of ethyl acetate (determining the reaction order)



can also be carried out with Pocket-CASSY and Mobile-CASSY

### Safety notes

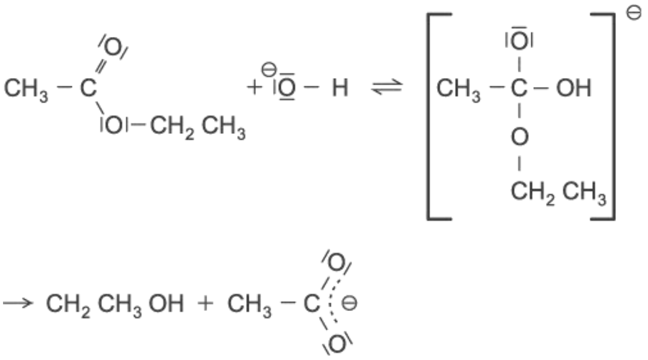
Ethyl acetate is highly flammable. Keep away from ignition sources.

Ethyl acetate irritates the eyes. Wear protective goggles while working with ethyl acetate. When it gets into contact with your eyes, immediately rinse your eyes with water, and consult a doctor.

The vapour of the ester can cause a dazed feeling; do not breathe in the vapour.

### Experiment description

Alkaline hydrolysis of esters proceeds in two steps:



As in the course of the reaction acetate ions go into solution instead of the hydroxide ions, the reaction can be followed via measurements of the conductivity. From the time dependence of the hydroxide ion concentration obtained from these measurements the reaction order and the rate coefficient of the alkaline ester hydrolysis can be determined. As the rate coefficient depends on the temperature, it is recommendable to carry out the experiment in a thermostated water bath.

### Equipment list

| | | |
|---|---|---|
| 1 | Sensor-CASSY | 524 010 or 524 013 |
| 1 | CASSY Lab 2 | 524 220 |

| | | |
|---|---|---|
| 1 | Chemistry box or conductivity adapter S | 524 067(1) |
| 1 | Conductivity sensor | 529 670 |
| 1 | Magnetic stirrer with hot plate | 666 839 |
| 1 | Contact thermometer | 666 8392 |
| 1 | Stirrer bar, 50 mm | 666 854 |
| 1 | Stirrer bar, 15 mm | 666 850 |
| 1 | Stand rod, 500 mm, ∅ = 10 mm | 301 27 |
| 3 | Crossed bossheads | 666 543 |
| 2 | Universal clamps, 0...25 mm | 666 551 |
| 1 | Universal clamp, 0...80 mm | 666 555 |
| 1 | Beaker, 100 ml, tall shape | 664 137 |
| 1 | Crystallization dish, 900 ml | 664 177 |
| 1 | Syringe, 2 ml | 665 963 |
| 1 | Disposable needle, 40 mm | 665 960 |
| 1 | Bulb pipette, 25 ml | 665 976 |
| 1 | Pipetting ball | 666 003 |
| 1 | Balance, resolution 0.01 g | |
| 1 | PC with Windows XP/Vista/7 | |

### Chemicals

| | |
|---|---|
| Ethyl acetate, e.g. 250 ml | 671 9630 |
| Caustic soda solution, c = 0.1 mol/l, e.g. 500 ml | 673 8410 |
| If necessary: calibration solution,12.88 mS/cm | 667 4640 |

### Calibration

■ Load settings

- The cell constant of the conductivity sensor for the chemistry box has already been set to 0.58 in CASSY Lab. If another conductivity sensor is used, its cell constant has to be entered as a factor in Settings Conductivity CA1 under **Correct**. Then the **Correct Factor** button has to be pressed.
- For a more precise determination of the cell constant, calibration solutions can be used: rinse the beaker and the conductivity sensor first with distilled water and then with approx. 30-40 ml of calibration solution. Immerse the conductivity sensor in another 50 ml of calibration solution as if it was for a conductivity measurement (see to it that the distance from the walls of the beaker is at least 1 cm), enter the target value in the second line in Settings CA1 under Correct, and press the **Correct Factor** button when a stable measured value is reached.
- Mark the sensor used, the chemistry box, and the Sensor-CASSY as the calibration is only valid for this combination.

### Experiment setup (see drawing)

Fill tap water into the crystallization dish almost up to the brim, and put the dish with the bigger stirrer bar onto the magnetic stirrer. Attach the beaker with the other stirrer bar to the stand rod with the aid of the universal clamp so that the beaker hangs in the crystallization dish. The beaker should be immersed as deeply as possible in the centre of the water bath over the stirring magnet. Use the pipette to put exactly 75 ml of caustic soda solution (0.0075 mol) into the beaker.

Immerse the contact thermometer in the water bath and the conductivity sensor in the beaker, each with one of the small universal clamps. See to it that the distance between the conductivity sensor and both the glass wall and the stirrer bar is at least 1 cm. Set the heat controller of the magnetic stirrer to 80 °C at maximum. Set the contact thermometer, which has to be connected to the magnetic stirrer, to approx. 40 to 45 °C. Set the speed of the stirrer so that vortex formation is just avoided.

Wait until the temperature of the caustic soda solution has reached a constant value. This can be checked at the display instrument for the temperature $\vartheta_{A1}$ (access via the corresponding button in the upper line on the screen) or, even more comfortable, starting a measurement by pressing ⏱.

Put the empty syringe with the needle on the balance, and set the balance to 0. Weigh in exactly 1.32 g of ethyl acetate (0.015 mol) into the syringe.

### Carrying out the experiment

■ Load settings

- The conductivity $C_{A1}$ for 0.1 molar caustic soda solution is at the upper limit of the selected measuring range. If required, change to the next higher measuring range in the settings CA1.
- Start a new measurement with ⏱.

- Firmly inject the ethyl acetate in order to achieve a good distribution. Mark the time of injection by Diagram → Set Marker → Vertical Line.
- Depending on the reaction temperature, allow the reaction to proceed for approx. 8 to 12 minutes until the value of the conductivity has become constant.
- Stop the measurement with ⏱. Switch the hot plate off.

### Evaluation

1. In the diagram **Specific Conductivity**, the measured values of the specific conductivity and the temperature are plotted against the reaction time. In order to determine the reaction temperature exactly, click the diagram with the right mouse button, select Draw Mean, and obtain the average temperature at which the experiment has been carried out by marking the curve section between the initial and the final temperature. The mean value is drawn in the diagram automatically and can be read in the status line below on the left. The numerical value can be inserted in the diagram with Set Marker → Text.

2. The diagram **Hydroxide Concentration** shows the course of the concentration of hydroxide ions as calculated from the specific conductivity. The [OH$^-$] concentration is calculated according to the formula:

$$\left[OH^-\right] = \frac{C_{A1} - \kappa_1}{\kappa_0 - \kappa_1} \cdot 0{,}1 \ \text{mol/l}$$

Here $C_{A1}$ is the measured conductivity, $\theta_0$ the conductivity before the ester has been added, $\theta_1$ the conductivity at the end of the reaction, and 0.1 mol/l the concentration of the caustic soda solution at the beginning of the reaction. In order that the concentration of hydroxide ions is calculated correctly, enter the respective measured values in Settings θ1 and θ0 in the field formula instead of the default values.

3. The diagrams **1st Order** and **2nd Order** have been prepared for determining the reaction order: for fitting a straight line to the curve in each case, click the diagram with the right mouse button, select Fit Function Best-fit Straight Line, and, starting from the beginning of the reaction, mark the curve range where a fit to a straight line is reasonable. The great deviation from a straight line in the **1st Order** diagram and the fair agreement with a straight line up to a consumption of approx. 90 % of the reactants in the **2nd Order** diagram indicate that this is a second-order reaction. The slope of the straight line in the **2nd Order** plot is the rate coefficient k of the reaction. It is found as parameter A of the straight-line equation A*x+B in the status line and can be dragged from there into the diagram using the mouse.

4. The diagrams **Arrhenius / Eyring 1** and **2** have been prepared for determining the activation parameters. For details see the experiment Alkaline hydrolysis of ethyl acetate - determining the activation parameters.

### Theoretical background

The reaction rate r is defined as the change of the concentration of one of the parent substances or one of the products per unit time, i.e. it always refers to one of the substances that participate in the reaction. The change of the concentration of the reactants enters the calculation with a negative sign and that of the products with a positive sign. For the alkaline ester hydrolysis, the reaction rate with respect to the ester concentration equals that with respect to the hydroxide concentration as the two substances react with each other in the ratio 1:1:

$$r_{OH^-} = r_{CH_3COOAc} = -\frac{d\left[OH^-\right]}{dt} = -\frac{d\left[CH_3COOAc\right]}{dt}$$

In order to find the dependence of the reaction rate on the concentration of the participating substances, the rate equation that governs the reaction is determined experimentally. The reaction order with respect to a particular substance is given by the exponent carried by this substance in the rate equation. The overall reaction order is formed from the sum of the exponents.

In the experiment example, the reaction is tested for two reaction orders: if the reaction was of first order with respect to the hydroxide concentration and independent of the ester concentration, the overall rate equation would be of first order:

$$r_{OH^-} = -\frac{d\left[OH^-\right]}{dt} = k \cdot \left[OH^-\right]$$

The same rate equation would result if the reaction exhibited a first order dependence on the ester concentration and independence of the hydroxide concentration because:

$$\frac{d\left[OH^-\right]}{dt} = \frac{d\left[CH_3COOAc\right]}{dt}$$

In order to check the validity of this rate equation, its integrated form is used:

$$\ln[OH^-] = -k \cdot t + \ln[OH^-]_0$$

If $\ln[OH^-]$ is plotted against the time t, the result is a straight line with slope -k and cut off $\ln[OH^-]_0$ in the case of a first-order reaction. $[OH^-]_0$ is the initial concentration on hydroxide ions.

In the case of a first-order reaction with respect to both components, the result is a second-order rate equation:

$$-\frac{d[OH^-]}{dt} = -\frac{d[CH_3COOAc]}{dt} = k \cdot [OH^-] \cdot [CH_3COOAc]$$

The integrated form of the rate equation reads:

$$\ln\frac{[OH^-]_0 \cdot ([CH_3COOAc]_0 - ([OH^-]_0 - [OH^-]))}{[CH_3COOAc]_0 \cdot [OH^-]} \cdot \frac{1}{[CH_3COOAc]_0 - [OH^-]_0} = k \cdot t$$

A plot of the expression on the left hand side against t is already arranged in the **2nd Order** diagram. The slope of the function, which is a straight line until approx. 90 % of the reactants have been consumed, is the rate coefficient of the reaction.

If the initial concentrations of the two substances are equal, the rate equation takes the simpler form:

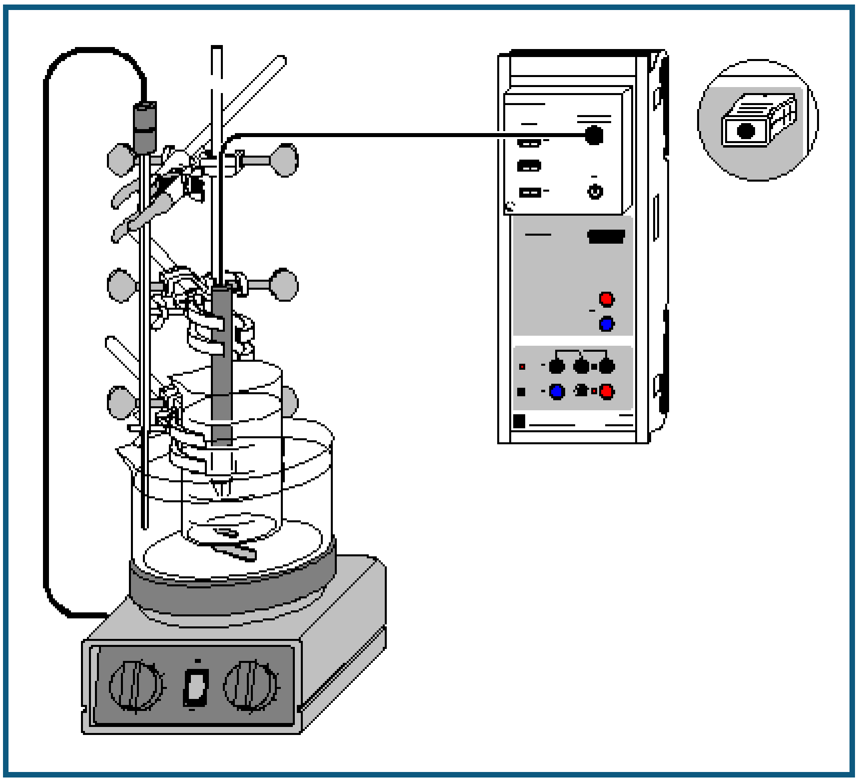
$$-\frac{d[OH^-]}{dt} = -\frac{d[CH_3COOAc]}{dt} = k \cdot [OH^-]^2$$

Its integrated form

$$\frac{1}{[OH^-]} = k \cdot t + \frac{1}{[OH^-]_0}$$

leads to a plot of $1/[OH^-]$ against t, which, in the case of a second-order reaction, is a straight line with slope k and cut off $1/[OH^-]_0$. However, as equimolar use of ester and caustic soda solution leads to a much longer duration of the reaction, double the amount of ester was used in this experiment example, and the determination of the rate equation via more complicated expressions was accepted.

# Alkaline hydrolysis of ethyl acetate (determining the activation parameters)



✓ ✓ can also be carried out with Pocket-CASSY and Mobile-CASSY

**Safety notes**

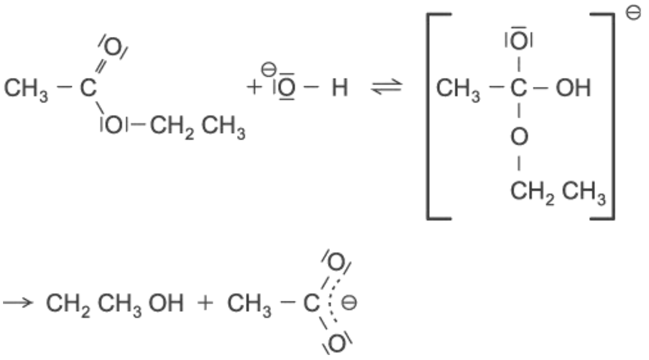
Ethyl acetate is highly flammable. Keep away from ignition sources.

Ethyl acetate irritates the eyes. Wear protective goggles while working with ethyl acetate. When it gets into contact with your eyes, immediately rinse your eyes with water, and consult a doctor.

The vapour of the ester can cause a dazed feeling; Do not breathe in the vapour.

### Experiment description

Alkaline hydrolysis of esters proceeds in two steps:



As in the course of the reaction acetate ions go into solution instead of the hydroxide ions, the reaction can be followed via measurements of the conductivity. From the time dependence of the hydroxide ion concentration obtained from these measurements the reaction order and the rate coefficient k of the alkaline ester hydrolysis can be determined.

The temperature dependence of the rate coefficient can be determined by carrying out the ester hydrolysis several times at different temperatures in a water bath. From the temperature dependence of k, the activation parameters can be calculated: the activation energy $E_a$ according to Arrhenius and the free energy of activation $\Gamma G^{\#}$ after Eyring, respectively, which is a function of the activation enthalpy $\Gamma H^{\#}$ and the activation entropy $\Gamma S^{\#}$.

## Equipment list

| | | |
|---|---|---|
| 1 | Sensor-CASSY | 524 010 or 524 013 |
| 1 | CASSY Lab 2 | 524 220 |
| 1 | Chemistry box or conductivity adapter S | 524 067(1) |
| 1 | Conductivity sensor | 529 670 |
| 1 | Magnetic stirrer with hot plate | 666 839 |
| 1 | Contact thermometer | 666 8392 |
| 1 | Stirrer bar, 50 mm | 666 854 |
| 1 | Stirrer bar, 15 mm | 666 850 |
| 1 | Stand rod, 500 mm, ∅ = 10 mm | 301 27 |
| 3 | Crossed bossheads | 666 543 |
| 2 | Universal clamps, 0...25 mm | 666 551 |
| 1 | Universal clamp, 0...80 mm | 666 555 |
| 1 | Beaker, 100 ml, tall shape | 664 137 |
| 1 | Crystallization dish, 900 ml | 664 177 |
| 1 | Syringe, 2 ml | 665 963 |
| 1 | Disposable needle, 40 mm | 665 960 |
| 1 | Bulb pipette, 25 ml | 665 976 |
| 1 | Pipetting ball | 666 003 |
| 1 | Balance, resolution 0.01 g | |
| 1 | PC with Windows XP/Vista/7 | |

## Chemicals

| | |
|---|---|
| Ethyl acetate, e.g. 250 ml | 671 9630 |
| Caustic soda solution, c = 0.1 mol/l, e.g. 500 ml | 673 8410 |
| If necessary: calibration solution,12.88 mS/cm | 667 4640 |

## Calibration

■ Load settings

- The cell constant of the conductivity sensor for the chemistry box has already been set to 0.58 in CASSY Lab. If another conductivity sensor is used, its cell constant has to be entered as a factor in Settings Conductivity CA1 under **Correct**. Then the **Correct Factor** button has to be pressed.
- For a more precise determination of the cell constant, calibration solutions can be used: rinse the beaker and the conductivity sensor first with distilled water and then with approx. 30-40 ml of calibration solution. Immerse the conductivity sensor in another 50 ml of calibration solution as if it was for a conductivity measurement (see to it that the distance from the walls of the beaker is at least 1 cm), enter the target value in the second line under **Correct**, and press the **Correct Factor** button when a stable measured value is reached.
- Mark the sensor used, the chemistry box, and the Sensor-CASSY as the calibration is only valid for this combination.

## Experiment setup (see drawing)

Fill tap water into the crystallization dish almost up to the brim, and put the dish with the bigger stirrer bar onto the magnetic stirrer. Attach the beaker with the other stirrer bar to the stand rod with the aid of the universal clamp so that the beaker hangs in the crystallization dish. The beaker should be immersed as deeply as possible in the centre of the water bath over the stirring magnet.

Immerse the contact thermometer in the water bath and the conductivity sensor in the beaker, each with one of the small universal clamps. See to it that the distance between the conductivity sensor and both the glass wall and the stirrer bar is at least 1 cm. Set the heat controller of the magnetic stirrer to 80 °C at maximum. Set the contact thermometer, which has to be connected to the magnetic stirrer, to approx. 35 °C for the first measurement series, to 45 °C for the second, and to approx. 55 °C for the third measurement series. If desired, further measurement series can be recorded, e.g., at 50 or 60 °C. Set the speed of the stirrer so that vortex formation is just avoided.

## Carrying out the experiment

■ Load settings

- Use the pipette to put exactly 75 ml of 0.1 M caustic soda solution (0.0075 mol) into the beaker.
- Wait until the temperature of the caustic soda solution has reached a constant value. This can be checked at the display instrument for the temperature $\vartheta_{A1}$ (access via the corresponding button in the upper line on the screen) or, even more comfortable, starting a measurement with ⏱.
- In the meantime, put the empty syringe with the needle on the balance, and set the balance to 0. Weigh in exactly 1.32 g of ethyl acetate (0,015 mol) into the syringe.

- If you have checked the constancy of the temperature by means of a measurement, stop this measurement series with ⏱ and delete it with 🗋.
- Start a new measurement with ⏱.
- Firmly inject the ethyl acetate in order to achieve a good distribution. Mark the time of injection by Diagram → Set Marker → Vertical Line.
- Depending on the reaction temperature, allow the reaction to proceed for approx. 7 to 15 minutes until the value of the conductivity has become constant.
- Stop the measurement with ⏱, and store the measured values with 💾, adding a note on the reaction temperature.
- Having stored the measurement series, delete it with 🗋 to make way for recording the next measurement series.
- Set the contact thermometer to the new reaction temperature, put the reaction mixture into a container, and rinse the beaker.
- Repeat the experiment at the next temperature.
- Record and store at least three measurement series.

### Evaluation

1. In the diagram **Specific Conductivity**, the measured values of the specific conductivity $C_{A1}$ and the temperature $\vartheta_{A1}$ are plotted against the reaction time.

2. From $C_{A1}$ the concentration of hydroxide ions is calculated according to the formula

$$[OH^-] = \frac{C_{A1} - \kappa_1}{\kappa_0 - \kappa_1} \cdot 0{,}1 \ \text{mol/l}$$

In this equation, $\theta_0$ is the conductivity before the ester has been added, $\theta_1$ the conductivity at the end of the reaction, and 0.1 mol/l the concentration of the caustic soda solution at the beginning of the reaction. In order that the concentration of hydroxide ions is calculated correctly, enter the respective measured values in Settings θ1 and θ0 in the field formula instead of the default values for each measurement series. The evolution of the concentration of hydroxide ions calculated form the above equation is shown in the diagram **Hydroxide concentration**.

3. Next the measurement series are united into a single file by loading the other recorded measurement series with 📂 in addition to the measurement series which is just open.

4. In order to determine the reaction temperatures exactly, click the diagram **Specific Conductivity** with the right mouse button, select Draw Mean, and obtain the average temperature $\vartheta_m$ at which the respective measurement has been carried out by marking one of the temperature curves between the initial and the final temperature. The mean value is drawn in the diagram automatically and can be read in the status line below on the left. The numerical value can be inserted in the diagram with Set Marker → Text.

5. The rate coefficients k associated with the different temperatures are determined in the diagram **2nd Order**. Click the diagram with the right mouse button, select Fit Function → Best-fit Straight Line, and, starting from the beginning of the reaction, mark for each of the curves the curve range where a fit to a straight line is reasonable. The slope of the resulting straight line is the rate coefficient k of the reaction at the average temperature $\vartheta_m$ just determined. It is found as parameter A of the straight-line equation A*x+B in the status line and can be inserted in the diagram with Set Marker → Text.

6. Now enter the previously obtained rate coefficients and the associated absolute temperatures T in K ($T = \vartheta_m + 273.15$) into the table**Arrhenius / Eyring 1** by clicking the corresponding line of the table with the left mouse button and typing the values. In the diagram **Arrhenius / Eyring 2**, the plots according to Arrhenius and Eyring are calculated automatically.

7. In order to determine the activation energy $E_a$ according to Arrhenius, apply a Best-fit straight line to the data points of ln k in the diagram **Arrhenius / Eyring 2**. The resulting slope of this straight line is equal to $-E_a/R$. The Best-fit straight line applied to the data points of ln (k/T) has the slope $-\Gamma H^{\#}/R$ and the cut off ln $(k_b/h)$ $+\Gamma S^{\#}/R$ (see Theoretical background). The slopes of the straight lines can again be read below in the status line as parameters A. The cut offs are given by the parameters B. These parameters, too, can be transferred into the diagram.

### Theoretical background

Arrhenius gave an explanation of the exponential relation between the temperature and the reaction rate, which had already known for some time, by identifying the two parameters a and b in the empirical formula

$$k = a \cdot e^{-b/T}$$

as the frequency factor A and the activation energy in units of the general gas constant $E_a/R$, whereby the activation energy $E_a$ is the energy required by two colliding molecules in order to be able to react; the factor A contains the number of molecule collisions per second and a steric factor, which takes into account the fact that colliding molecules must have a certain mutual orientation in order to react with each other.

According to Arrhenius, the temperature dependence of the rate coefficient can also be written in the following form:

$$k = A \cdot e^{-Ea/RT}$$

A plot of ln k against 1/T leads to a straight line with the slope $-E_a/R$ and the cut off ln A.

A more precise form was given to Arrhenius' equation by the "Theory of the transition state" of Eyring, which gives a more accurate definition of the parameters A and $E_a$.

Eyring's starting point was the consideration that for all elementary reactions to occur between two substances A and B an activated complex has to be reached as a transition state; this state is in chemical equilibrium with the initial substances:

$$A + B \rightleftharpoons AB^\#$$

$$K^\# = \frac{\left[AB^\#\right]}{[A] \cdot [B]}$$

Eyring's decisive achievement was to prove that the activated complexes of any elementary chemical reaction are converted into the products with the same rate coefficient:

$$\frac{d[C]}{dt} = \frac{k_b \cdot T}{h} \cdot \left[AB^\#\right]$$

Here C is the product of the elementary reaction, $k_b$ the Boltzmann constant, h the Planck constant, and T the absolute temperature. The rate of the entire reaction is therefore

$$\frac{d[C]}{dt} = \frac{k_b \cdot T}{h} \cdot K^\# \cdot [A] \cdot [B]$$

with the rate coefficient:

$$k = \frac{k_b \cdot T}{h} \cdot K^\#$$

From thermodynamics it is known that any equilibrium constant K can be determined from the differences between the free enthalpies of the products and the parent substances. Thus:

$$\Delta G^\# = -RT \cdot \ln K^\# ; \qquad \Delta G^\# = \Delta H^\# - T\Delta S^\#$$

If these two expressions are inserted in the equation of the rate coefficient, Eyring's equation is obtained:

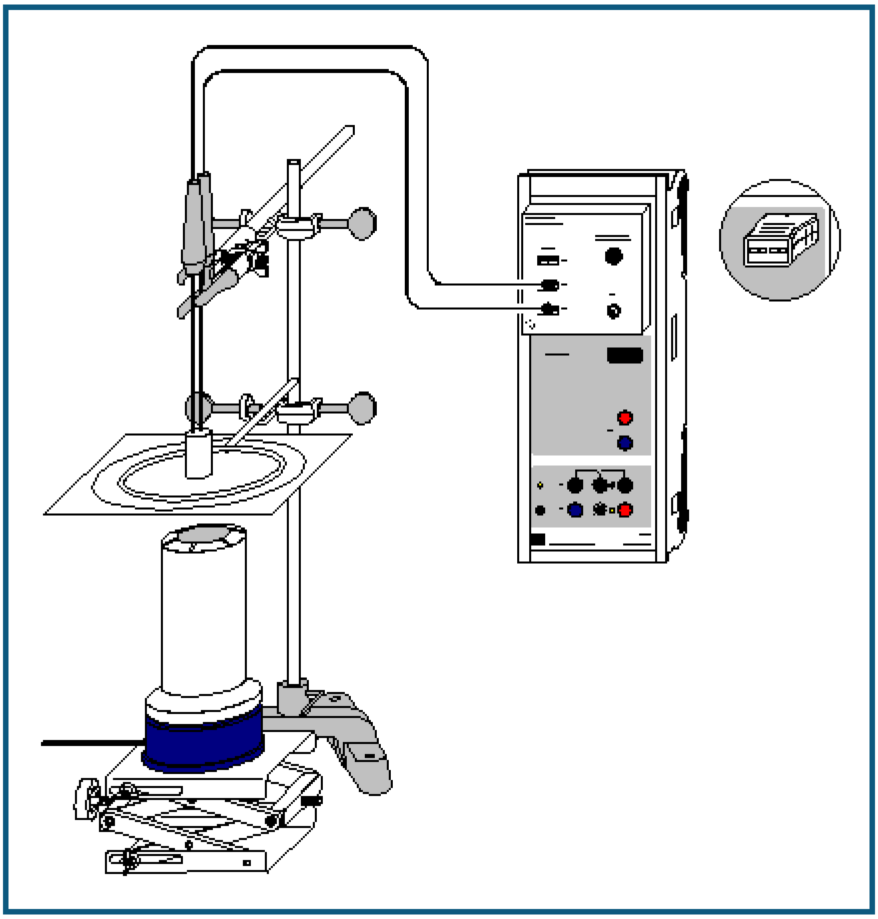
$$k = \frac{k_b \cdot T}{h} \cdot e^{\Delta S^\# / R} \cdot e^{-\Delta H^\# / RT}$$

$\Gamma S^\#$ is called the activation entropy and $\Gamma H^\#$ the activation enthalpy. From these two parameters conclusions can be drawn regarding the transition state of a reaction: a negative activation entropy such as in this experiment example indicates a higher-order transition state with respect to the initial state, i.e., in order that the activated complex can form, bonds have to form or the particles must have a certain position relative to each other. If $\Gamma S^\#$ is negative, the entry has a retarding effect on the reaction as the temperature rises. A positive activation entropy, on the other hand, indicates the breakage of bonds in the activated complex or an increase in rotational degrees of freedom around one or more bonds. This leads to an enhancing effect on the reaction when the temperature rises.

The free energy of activation $\Gamma G^\#$ of a reaction, which results from the activation entropy and the activation enthalpy, is always positive. Its temperature dependent magnitude determines the magnitude of the rate coefficient and is thus related to the reaction rate. In the experiment example, the averaged values of $\Gamma S^\#$ and $\Gamma H^\#$ at 298 K (25 °C) lead to a free energy of activation of

$$\Gamma G^\# = 68200\ \text{J / mol} + 50\ \text{J/(mol} \cdot \text{K)} \cdot 298\ \text{K} = 83.1\ \text{kJ / mol.}$$

## Differential thermal analysis of copper sulphate



can also be carried out with Pocket-CASSY and Mobile-CASSY

**Danger**

Copper sulphate is dangerous to health and environmentally hazardous. Wear protective goggles and gloves. Do not allow copper sulphate to get into the environment.

Danger of burn. Before touching the apparatus, allow it to cool down to room temperature.

### Experiment description

On the one hand, differential thermal analysis (DTA) enables important quantities of physical chemistry to be measured, e.g., latent heats or enthalpies of transition. On the other hand, DTA is well suited as an introduction into analytical chemistry because it is quite easy to grasp.

In DTA, two substances are heated in an adjustable oven: a chemically inert reference substance (e.g. aluminum oxide, $Al_2O_3$) and the sample substance, which is examined for phase transitions and/or chemical reactions in the entire temperature range. The substances are in symmetric places in the oven, each provided with a temperature sensor.

If an endothermic (e.g. evaporation) or an exothermic (e.g. combustion reaction) process takes place in the sample, a temperature difference ΓT arises between the reference substance and the sample. In the case of endothermic reactions, the sample substance warms up at a slower rate than the reference substance, in the case of exothermic reactions at a faster rate. By plotting ΓT against the reference temperature $\vartheta$, a characteristic DTA curve is obtained for every substance. From this curve the transition temperatures and enthalpies of transition of the occurring processes can be determined.

In order to make the experiment easier to understand, an open measuring assembly, which gives a good illustration of the principle of measurement, is used in the present experiment example. However, for an accurate determination of enthalpies of transition, a closed oven is required.

In this example, the temperatures at which water of crystallization bonded in copper sulphate is split off are determined up to 150 °C. For this the opportunity of directly measuring the differential temperature provided by the chemistry box is taken advantage of as it is more precise than computing the difference between two individual temperatures.

### Equipment list

| | | |
|---|---|---|
| 1 | Sensor-CASSY | 524 010 or 524 013 |
| 1 | CASSY Lab 2 | 524 220 |
| 1 | Chemistry box or NiCr-Ni adapter S | 524 067(3) |
| 2 | Temperature sensors NiCr-Ni, type K, ∅ 1.5 mm | 529 676 |
| 1 | Heating block with two holes | 666 202 |
| 1 | Set of 20 glass tubes | 666 203 |
| 1 | Electric burner | 666 776 |
| 1 | Stand base, V-shape, 20 cm | 300 02 |
| 1 | Stand rod, 47 cm | 300 42 |
| 2 | Crossed bossheads | 666 543 |
| 1 | Universal clamp, 0...25 mm | 666 551 |
| 1 | Stand ring with stem, ∅ 100 mm | 666 573 |
| 1 | Wire gauze, 160*160 mm | 666 685 |
| 1 | Laboratory stand 3 | 666 583 |
| 2 | Mortars, 50 ml | 608 350 |
| 2 | Pistille | 608 360 |
| 1 | PC with Windows XP/Vista/7 | |

### Chemicals

| | |
|---|---|
| Aluminum oxide ($Al_2O_3$), e.g. 250 g | 670 2900 |
| Copper(II) sulphate pentahydrate, e.g. 100 g | 672 9600 |

### Experiment setup (see drawing)

Connect the chemistry box to input A of the Sensor-CASSY with the temperature sensors being connected to inputs $T_2$ and $T_3$.

Set up an assembly for heating the heating block using the stand material, the wire gauze, the electric burner, and the laboratory stand 3. Put the heating block onto the wire gauze exactly over the heating aperture of the electric burner. At the beginning of the measurement, the distance between the heating aperture of the burner and the wire gauze should be approx. 5 cm.

Triturate a spatula-tipfull of copper sulphate in one of the mortars, and fill it into one of the glass tubes up to approx. two-thirds of its height. Do the same with another glass tube and a spatula-tipfull of aluminum oxide.

Turn the temperature sensor connected to $T_2$ as deeply as possible into the aluminum oxide and that connected to $T_3$ into the copper sulphate.

Fix both temperature sensors together with a miniature clamp below the handle so that the glass tubes rest on the bottom of the two holes of the heating block. See to it that the entire base of the heating block has contact with the wire gauze.

### Carrying out the experiment

■ Load settings

- Switch the electric burner on.
- Wait about one minute. Then start the measurement with ⏱.
- When the temperature curve becomes horizontal, enhance the height of the laboratory stand 3 somewhat to reduce the distance between the burner and the wire gauze.
- Stop the measurement with ⏱ when the temperature is approx. 150°C. Switch the electric burner off.

### Evaluation

1. In the diagram **Standard**, the temperature value and the temperature difference ΓT are plotted against the time.

2. In the diagram **dT(T)**, the temperature difference is plotted against the reference temperature (temperature of the aluminum oxide).

In order to determine the transition temperature, apply inflectional tangents to the left edges of each peak. To do this, click the diagram with the right mouse button, select Fit Function → Best-fit Straight Line, and then mark a narrow curve range around the inflection point of the left edge of the peak. After that the associated base line is determined for each peak. The base lines are also constructed as Best-fit straight lines, whereby the curve range to be marked is the range just before the respective peak. In the experiment example, the peaks are very close to each other so that the first base line can be used for the second peak as well. The base line of the third peak has to be constructed as a horizontal line through the preceding minimum. However, the resulting errors remain small (± 0.3 °C).

In differential thermal analysis, the point of intersection of the inflectional tangent of every peak and the associated base line is given as the temperature value for the phase transition or the start of a reaction. As DTA is a dynamic method of analysis, these temperatures can slightly deviate from the thermodynamic equilibrium temperatures depending on the ambient conditions.

In order to determine the point of intersection, switch the coordinate display on by pressing **Alt+K**, position the mouse pointer on the point of intersection, and enter the indicated temperature in the diagram with **Alt+T**. In addition, you can mark the transitions by a vertical line and insert an explanatory text.

Up to 150 °C, the DTA of copper sulphate exhibits three peaks. The first one (approx. 96 °C) is associated with the spitting-off of the first two bonded water molecules, the second corresponds to the evaporation of these water molecules and the third one to the splitting-off and evaporization of two more water molecules:

1. $CuSO_4 \cdot 5H_2O \xrightarrow{96\,°C} CuSO_4 \cdot 3H_2O + 2H_2O(l)$
2. $2H_2O(l) \xrightarrow{103\,°C} 2H_2O(g)$
3. $CuSO_4 \cdot 3H_2O \xrightarrow{118\,°C} CuSO_4 \cdot H_2O + 2H_2O(g)$

The last bonded water molecule is only split off at 250 °C; recording this peak was renounced in favour of a shorter duration of the experiment.

### Further experiment options

In order to obtain a clearer separation of the peaks, you can slow down the rate of heating or reduce the amount of substance significantly. Regarding the practicability of the experiment as a demonstration experiment, these possibilities were renounced in the example measurement.

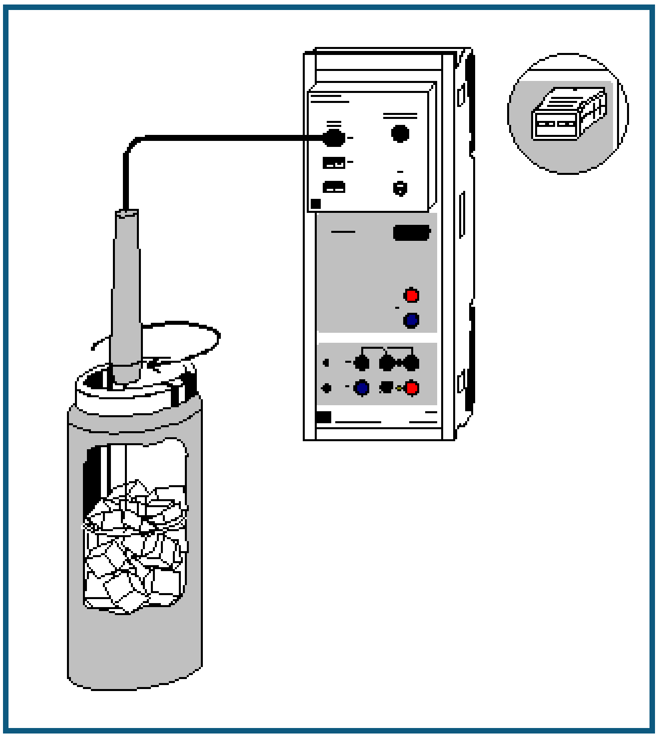
If you weigh the copper sulphate exactly before and after each peak, you can determine the amount of evaporated crystallization water. To do this, first stop heating at approx. 100 °C, then at approx. 115 °C and at 150 °C. When the substance has cooled down, you can determine the mass difference relative to the initial mass.

In the described experiment setup, many other determinations can be carried out. It is suitable for, e.g.:

- a consideration of the phase transitions of sulphur (transition between the α and β modification at approx. 100 °C, melting point at 119 °C, transition between the ι and κ melt starting from 159 °C),
- the determination of the triggering temperature of strongly exothermic reactions (e.g. ignition of black powder), which is relatively harmless due to the small amount of substance,
- setting up state diagrams of mixtures (e.g. tin and lead).

A more precise adjustment for a continuous rise in temperature is possible by means of a power controller (667 823) that is suitable for use in conjunction with the burner.

## Preparing a freezing mixture



can also be carried out with Pocket-CASSY and Mobile-CASSY

### Experiment description

If ice is mixed with a salt, part of the ice melts, and the salt dissolves in the water from the melted ice. The energy required for melting the water and dissolving the salt is taken from the environment so that the entire mixture cools down. Depending on the kind of salt, temperatures of down to -60 °C are reached. Water soluble liquids (e.g. ethanol) can also create such effects.

The melting of ice when a salt is added is due to the freezing-point depression of a solution as compared with the pure solvent. Thereby the water-ice equilibrium is shifted towards the liquid state, and heat is taken from the environment until a new equilibrium is established at a lower temperature.

In this experiment, a simple freezing mixture is prepared from common salt and ice in a Dewar flask. Even with this cheap mixture temperatures of below -20 °C can be reached.

### Equipment list

| | | |
|---|---|---|
| 1 | Sensor-CASSY | 524 010 or 524 013 |
| 1 | CASSY Lab 2 | 524 220 |
| 1 | Chemistry box or NiCr-Ni adapter S | 524 067(3) |
| 1 | Temperature sensor NiCr-Ni, type K | 529 676 |
| 1 | Dewar flask, 0.5 l | 667 320 |
| 8 | Watch glass dishes, ∅ = 8 cm | 664 154 |
| 1 | Laboratory balance | |
| 1 | PC with Windows XP/Vista/7 | |

### Required substances

| | |
|---|---|
| Sodium chloride, e.g. 250 g | 673 5700 |
| Ice, approx. 200 g | |
| Distilled water | |

### Experiment preparation

- Plug the chemistry box with the temperature sensor being connected to $T_1$ into input A of the Sensor-CASSY.
- Weigh in 10 g of sodium chloride on each of the watch glass dishes.
- Crush the ice as fine as possible in order that it can well be mixed with the salt.

## Calibration

In order to obtain accurate measuring results, calibrate the temperature sensors when using it for the first time. Afterwards the calibration should be repeated from time to time.

■ Load settings

- Immerse the temperature sensor in ice water (mixture of ice and a small amount of water), stir with the temperature sensor, and wait until the display instrument shows a measured value that is stable up to ± 0.1 °C.
- Enter the target value "0" in the first line in Settings ϑA11 under **Correct**, and press the **Correct Offset** button.
- Store the calibrated settings with 💾 under a new name.
- Mark the Sensor-CASSY, the chemistry box, and the temperature sensor in order that they can be used again in the same combination (otherwise the stored calibration will not be applicable).

## Carrying out the experiment

- Use or load the calibrated settings.
- Fill crushed ice into the Dewar flask, and add a small amount of water.
- Immerse the temperature sensor in the ice and stir.
- Record the first measured value with ⏱, and enter "0" as the first value in the table column $m_{NaCl}$, by clicking the table line with the left mouse button and typing the number.

Keep to the following procedure until all of the salt has been added to the ice:

- Put 10 g of common salt into the Dewar flask.
- Thoroughly stir with the temperature sensor until a uniform temperature is measured everywhere in the freezing mixture (check with the aid of the display instrument $\vartheta_{A11}$).
- Record the measured value with ⏱.
- Enter the total mass of common salt added up to that moment into the appropriate table cell for $m_{NaCl}$.

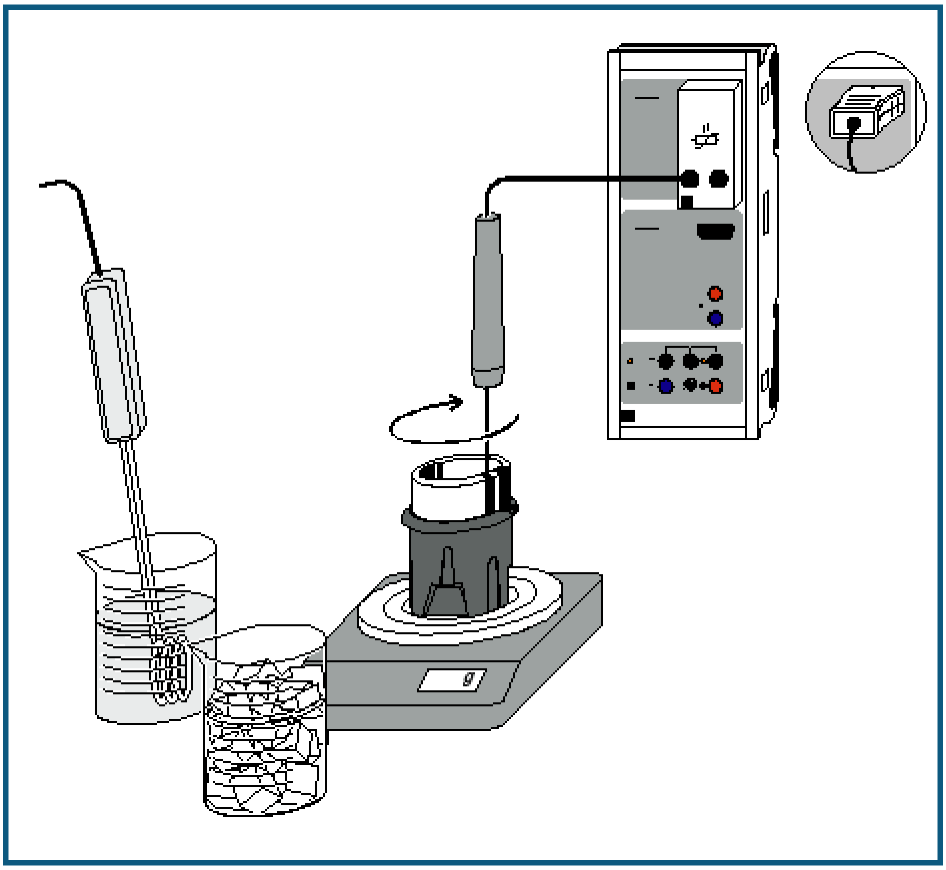
## Evaluation

The measuring curve shows the temperature in the freezing mixture as a function of the mass of sodium chloride added. It is clearly seen that addition of 10 g of NaCl to pure ice leads to a significantly stronger decrease in temperature than addition to a freezing mixture that already contains a great amount of salt. After 60 g of NaCl has been added, saturation is reached. Further addition of common salt does not lower the temperature of the mixture as the limit of the solubility of common salt in water is reached.

The saturation temperature can be marked by a horizontal line through the temperature minimum with Diagram → Set Marker → Horizontal Line. The temperature value is displayed in the status line and can be inserted in the diagram with Diagram → Set Marker → Text.

The diagram generated can be printed via the printer symbol in the upper line on the screen.

## Determining the melting enthalpy of ice



✓ ✓ can also be carried out with Pocket-CASSY and Mobile-CASSY

### Experiment description

If a certain amount of ice is put into the warm water contained in a calorimeter, a mixing temperature $\vartheta_m$ can be determined after the ice has melted and completely mixed with the water. The mixing temperature depends on the masses of the water ($m_1$) and the ice ($m_2$) as well as on the corresponding temperatures $\vartheta_1$ and $\vartheta_2$. In order to simplify the evaluation, ice of $\vartheta_2$ = 0 °C is used for the measurement.

Quick recording of the measured values with CASSY Lab enables a temperature curve to be determined, which can be used to calculate the melting enthalpy of ice. With the same setup other calorimetric measurements can be carried out as well, e.g., mixing experiments or the determination of heat capacities.

### Equipment list

| | | |
|---|---|---|
| 1 | Sensor-CASSY | 524 010 or 524 013 |
| 1 | CASSY Lab 2 | 524 220 |
| | | |
| 1 | Temperature box | 524 045 |
| 1 | Temperature sensor NTC | 666 212 |
| | or | |
| 1 | Temperature sensor S | 524 044 |
| | | |
| 1 | Dewar flask | 386 48 |
| 1 | Safety immersion heater | 303 25 |
| 1 | Beaker, squat shape, 250 ml | 664 130 |
| 1 | Beaker, squat shape, 600 ml | 664 132 |
| 1 | Balance, measuring range up to 500 g,resolution 0.01 g | |
| 1 | Absorbent cloth | |
| 1 | PC with Windows 98/2000/XP/Vista | |

### Required substances

Ice, approx. 100 g
Distilled water

### Experiment setup (see drawing)

Plug the temperature box with the temperature sensor being connected into input A of the Sensor-CASSY. Alternatively, connect the temperature sensor S to input A.

Heat distilled water in the bigger beaker up to a temperature of about 80 °C. Put the dry Dewar flask on the balance and set the display of the balance to 0.

### Calibration

Calibrate the temperature sensor while the water is heated:

▢ Load settings
- Crush the ice, and put it into the other beaker.
- Add a small amount of water. After a short time, the ice-water equilibrium with a temperature of 0 °C should be established.
- Immerse the temperature sensor in the ice water mixture and stir.
- Enter the target value "0" in the first line in Settings ϑA11 under **Correct**, and press the **Correct Offset** button.

### Carrying out the experiment

- Pour about 120 g of hot water into the Dewar flask.
- Pour the water from the ice water mixture away, pour the ice on the cloth, and dry it thoroughly.
- Read the mass of the hot water, and take it down.
- Immerse the temperature sensor in the flask.
- Start the measurement with ⏱.
- Having waited for approx. 30 to 60 seconds, pour the ice from the cloth into the Dewar flask. While doing so, permanently stir with the temperature sensor.
- Continue stirring until all of the ice has dissolved.
- After another 30 to 60 seconds, stop the measurement with ⏱.
- Remove the temperature sensor from the Dewar flask, and drain it well over the flask. Read the total mass at the balance, and take it down.

### Evaluation

In the diagram, the measured values of the temperature $\vartheta$ are plotted against the time t.

1. In order to determine the calorimeter and the mixing temperature, carry out a triangular interpolation. To do this click in the diagram using the right-hand mouse button, select Other Evaluations → Carry out Triangular Interpolation and mark the two straight curve sections.

2. The point of intersection of the vertical line of the triangular interpolation with the upper best-fit straight line corresponds to the initial temperature $\vartheta_1$ of the calorimeter, whereas the lower point of intersection corresponds to the mixing temperature $\vartheta_m$. As the straight lines are almost horizontal, only a small error has to be expected (± 0.1 °C).

3. The points of intersection are displayed in the status line below on the left and can be inserted in the diagram with Set Marker → Text.

The calculation of the melting enthalpy $\Gamma H_f$ can be derived in the following way:

I) Quantity of heat given off by the calorimeter and the hot water:

$$\Gamma Q_1 = c_w \cdot (m_1 + m_0) \cdot (\vartheta_1 - \vartheta_m)$$

II) Quantity of heat taken up by the ice ($\vartheta_2 = 0$ °C) from the calorimeter:

$$\Gamma Q_2 = m_2 \cdot \Gamma H_f + m_2 \cdot c_w \cdot (\vartheta_m - 0)$$

Here $c_w$ is the heat capacity of water, $m_1$ the mass of the hot water, $m_2$ the mass of the ice and $m_0$ the water equivalent of the calorimeter. As there is almost no heat exchanged with the environment, we have

$$\Gamma Q_1 = \Gamma Q_2.$$

Consequently the melting enthalpy $\Gamma H_f$ is calculated according to:

$$\Delta H_f = \left( \frac{m_1 + m_0}{m_2} \cdot (\vartheta_1 - \vartheta_m) - \vartheta_m \right) \cdot c_w$$

With the water equivalent $m_0$ = 24 g of the Dewar flask used, the measured values of the experiment example lead to the following calculation:

$$\Delta H_f = \left( \frac{121 + 24}{75{,}6} \cdot (73{,}5 - 21{,}5\ ^\circ\mathrm{C}) - 21{,}5\ ^\circ\mathrm{C} \right) \cdot 4{,}19\ \mathrm{J}/^\circ\mathrm{C} \cdot \mathrm{g} = 327{,}8\ \mathrm{J}/\mathrm{g}$$

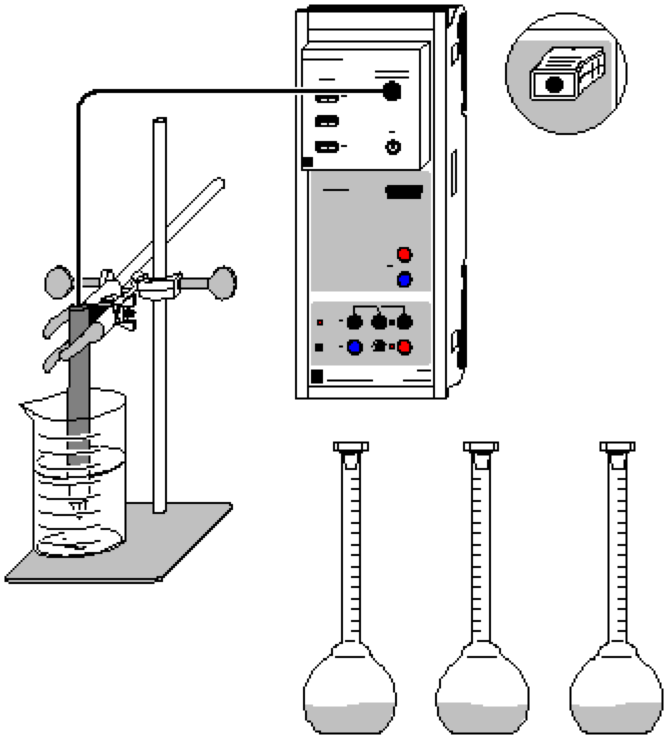
This result is very close to the value of 334 J/g quoted in the literature.

ΓH f is significantly greater than the heat capacity of 1 g of water:

$$\frac{\Delta H_f}{c_w \cdot 1\,\mathrm{g}} = \frac{334}{4{,}19} = 79{,}7$$

That means: with the energy required to melt 1 g of ice having a temperature of 0 °C, 1 g of water can be heated from 0 °C to approx. 80 °C.

## Determining the conductivity of different solutions



✓ ✓ can also be carried out with Pocket-CASSY and Mobile-CASSY

### Experiment description

The electric conductivity of aqueous solutions depends on several parameters:

a) concentration of the solution, b) degree of dissociation of the substance, c) mobility of the ions, and d) charge of the ions.

From a comparison of conductivities measured on different solutions, conclusions can be drawn regarding these parameters.

The values obtained are displayed by CASSY Lab in easy to read large characters and in clearly arranged diagrams.

### Equipment list

| | | |
|---|---|---|
| 1 | Sensor-CASSY | 524 010 or 524 013 |
| 1 | CASSY Lab 2 | 524 220 |
| 1 | Chemistry box or conductivity adapter S | 524 067(1) |
| 1 | Conductivity sensor | 529 670 |
| 1 | Bunsen burner stand, 450 mm | 666 502 |
| 1 | Crossed bosshead | 666 543 |
| 1 | Universal clamp, 0...25 mm | 666 551 |
| 1 | Beaker, 100 ml, tall shape | 664 137 |
| 15 | Volumetric flasks, 100 ml | 665 793 |
| 1 | Bulb pipette, 50 ml | 665 977 |
| 1 | Bulb pipette, 10 ml | 665 975 |
| 2 | Pipetting balls | 666 003 |
| 1 | Spatula | 666 962 |
| 1 | Watch glass dish, e.g. 80 mm | 664 154 |
| 1 | Powder funnel, e.g. 60 mm | 602 681 |
| 1 | Balance (at least up to 100 g, resolution 0.01 g) | |
| 1 | PC with Windows XP/Vista/7 | |

### Chemicals

| | |
|---|---|
| D(+)-glucose, e.g. 100 g | 672 1100 |
| Acetic acid, c = 1 mol/l, e.g. 1000 ml | 671 9590 |
| Magnesium sulphate 7-hydrate, e.g. 100 g | 673 1600 |
| Sodium chloride, e.g. 250 g | 673 5700 |
| Hydrochloric acid, c = 1 mol/l, 500 ml | 674 6900 |
| Distilled water | |
| If necessary: | |
| Calibration solution, 111.8 mS/cm | 667 4644 |
| Calibration solution, 12.88 mS/cm | 667 4640 |

### Preparing the solutions

For preparing the solutions, the balance, the pipettes, the volumetric flasks, the spatula, the watch glass dish, and the funnel are required. From each substance three solutions of different concentrations are prepared. Of course, other concentrations can be used in addition or some of the measuring values can be omitted.

1) Glucose solutions (1 mol/l, 0.5 mol/l, 0.1 mol/l)
One after another weigh in exactly 19.82 g (1 mol/l), 9.91 g (0.5 mol/l) and 1.98 g (0.1 mol/l) of glucose on the watch glass dish, which is lying on the balance, and rinse it with distilled water through the funnel into a 100 ml flask. Then clean the watch glass dish, the spatula and the funnel.

2) Acetic acid solutions (0.5 mol/l, 0.1 mol/l, 0.01 mol/l)
Using the pipette, put 50 ml (0.5 mol/l) and 10 ml (0.1 mol/l) of 1 M acetic acid in a 100 ml volumetric flask each, and fill the flasks with distilled water up to the calibration mark. Prepare the 0.01 M acetic acid from 10 ml of 0.1 M solution in a new flask.

3) Magnesium sulphate solutions (0.5 mol/l, 0.1 mol/l, 0.01 mol/l)
One after another weigh in exactly 12.32 g (0.5 mol/l) and 2.46 g (0.1 mol/l) of magnesium sulphate on the watch glass dish, which is lying on the balance, and rinse it with distilled water through the funnel into a 100 ml flask. Using the cleaned pipette, prepare the 0.01 M solution from 10 ml of 0.1 M magnesium sulphate solution in a new flask. Then clean the watch glass dish, the spatula, the funnel and the pipette.

4) NaCl solutions (0.5 mol/l, 0.1 mol/l, 0.01 mol/l)
Weigh in exactly 2.92 g (0.5 mol/l) of sodium chloride on the watch glass dish, which is lying on the balance, and rinse it with distilled water through the funnel into a 100 ml flask. Using the pipette, prepare the 0.1 M solution from 20 ml of 0.5 M solution in a new volumetric flask and the 0.01 M solution from 10 ml of the 0.1 M solution.

5) Hydrochloric acid solution (0.5 mol/l, 0.1 mol/l, 0.01 mol/l)
Using cleaned pipettes, put 50 ml (0.5 mol/l) and 10 ml (0.1 mol/l) of 1 M hydrochloric acid into a 100 ml volumetric flask each, and fill the flask with distilled water up to the calibration mark. Prepare the 0.01 M acetic acid from 10 ml of 0.1 M solution in a new flask.

### Experiment setup (see drawing)

Plug the chemistry box with the conductivity sensor being connected into input A of the Sensor-CASSY. After thoroughly rinsing the conductivity sensor with distilled water, fix it in the clamp, so that its height can be adjusted with the crossed bosshead according to the requirements.

### Calibration

☐ Load settings

The cell constant of the conductivity sensor for the chemistry box has already been set to 0.58 in CASSY Lab. If another conductivity sensor is used, its cell constant has to be entered as a factor in Settings Conductivity CA1 under **Correct**. Then the **Correct Factor** button has to be pressed.

For a more precise determination of the cell constant, calibration solutions can be used: rinse the beaker and the conductivity sensor first with distilled water and then with approx. 30-40 ml of calibration solution. Immerse the conductivity sensor in another 50 ml of calibration solution as if it was for a conductivity measurement (pay attention to the distances from the walls of the beaker), enter the target value in the second line in Settings CA1 under Correct, and press the **Correct Factor** button when a stable measured value is reached.

### Carrying out the experiment

☐ Load settings

One after another measure the conductivity of distilled water, the solutions of glucose, acetic acid, magnesium sulphate, sodium chloride, and hydrochloric acid, starting with the lowest concentration and keeping to the following order:

- Rinse the electrode and the beaker thoroughly with 30-40 ml of the solution.
- Fill another 60 ml of the solution into the beaker.
- Adjust the height of the conductivity sensor so that its immersion depth in the liquid is 2 cm and its distance from every wall at least 1 cm.
- If necessary, change the measuring range in Settings Conductivity CA1. Always select the lowest possible measuring range.
- When the displayed value is stable, record the measured value with ⏱.
- Enter the concentration and the substance associated with the measured value in the diagram. To do this, select Set Marker → Text in the context menu of the diagram (right mouse button), type the substance and the value of the concentration and position the text at the desired place in the diagram with the mouse.
- In order to simplify the evaluation, select **Measurement** → **Append new Measurement Series** before measuring the conductivity of a new substance.
- Before measuring the conductivity of a new substance, thoroughly rinse the beaker and the conductivity sensor with distilled water.

### Evaluation

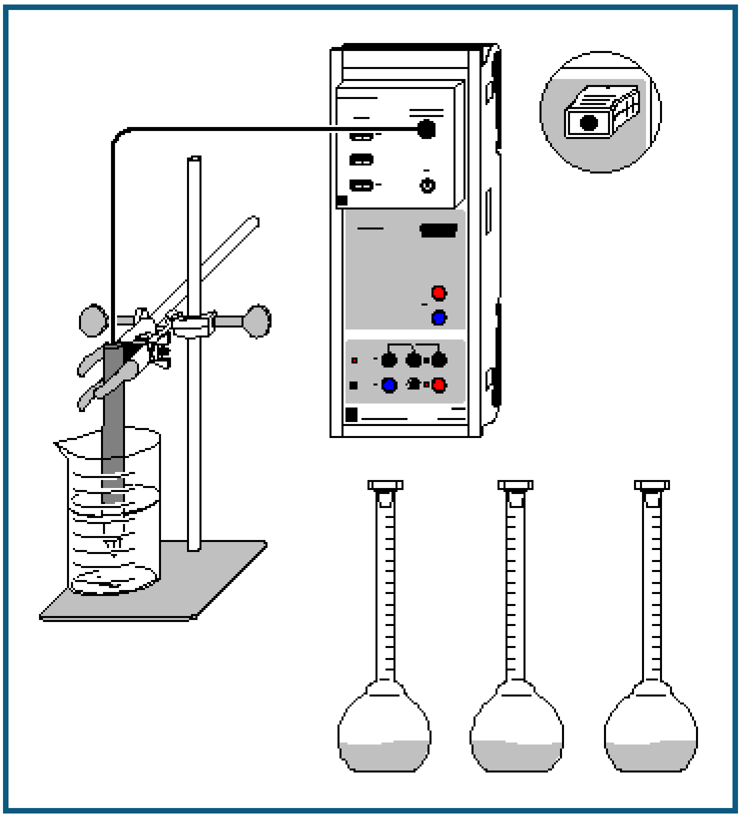
When the large representation of the display instrument is selected, the measured values can also be read by persons who are at some distance from the screen. The values are automatically entered in the diagrams as bars so that the differences between the conductivities are visualized.

This experiment demonstrates clearly that the conductivity depends strongly on the concentration. Moreover it can be seen from the measuring results that strong electrolytes having a high degree of dissociation conduct much better than substances that do not or only to a small proportion dissociate. From the higher conductivity of hydrochloric acid as compared with the common salt solutions it can be concluded that the mobility of hydronium ions is greater than that of sodium ions.

Despite the higher ion charge, the magnesium sulphate solutions of higher concentration do not exhibit a greater conductivity than the corresponding NaCl solutions because the ions exert strong electrostatic forces on each other due to their charges, which are twice the charges of the ions of sodium and chloride ions. However, at lower concentrations (great distances between the ions), e.g. 0.01 mol/l, the conductivity is higher as compared with NaCl.

The diagrams generated can be printed via the printer symbol in the upper line on the screen.

## Determining the limiting equivalent conductivity of sodium chloride



can also be carried out with Pocket-CASSY and Mobile-CASSY

### Experiment description

Measurement of the conductivities of the same electrolyte at different concentrations enables several important characteristic data of the substance to be determined. In this experiment, the measured specific conductivity $C_{A1}$ of sodium chloride is used to calculate its equivalent conductivity $\Lambda_{eq}$, which is defined as the ratio of the specific conductivity and the equivalent concentration:

$$\Lambda_{eq} = \frac{C_{A1}}{c_0 \cdot n}$$

Here $c_0$ is the concentration of the solution and n the number of released positive and negative charges. In the case of NaCl, n is 1 as NaCl dissociates according to the equation:

$$\mathrm{NaCl} \xrightarrow{H_2O} \mathrm{Na}^+ + \mathrm{Cl}^-$$

As dissolved ions are subject to mutual electrostatic interactions, the equivalent conductivity depends on the concentration. Only at infinite dilution are the interactions equal to zero as the distances between the ions become too large. Therefore the equivalent conductivity at infinite dilution $\Lambda_0$ (limiting equivalent conductivity) gives the equivalent conductivity of the completely dissociated substance without interionic interactions. $\Lambda_0$ can be determined graphically according to Kohlrausch's square-root law

$$\Lambda_{eq} = \Lambda_0 - k\sqrt{c_0}$$

The ratio of the equivalent conductivity and the limiting equivalent conductivity $\Lambda_{eq}/\Lambda_0$ corresponds to the degree of dissociation α of sodium chloride. In strong electrolytes such as NaCl, α is almost 1 in solutions of low concentration.

### Equipment list

| | | |
|---|---|---|
| 1 | Sensor-CASSY | 524 010 or 524 013 |
| 1 | CASSY Lab 2 | 524 220 |
| 1 | Chemistry box or conductivity adapter S | 524 067(1) |
| 1 | Conductivity sensor | 529 670 |
| 1 | Bunsen burner stand, 450 mm | 666 502 |

| | | |
|---|---|---|
| 1 | Crossed bosshead | 666 543 |
| 1 | Universal clamp, 0...25 mm | 666 551 |
| 1 | Beaker, 100 ml, tall shape | 664 137 |
| 1 | Volumetric flask, 250 ml | 665 794 |
| 6 | Volumetric flasks, 100 ml | 665 793 |
| 1 | Bulb pipette, 10 ml | 665 975 |
| 1 | Bulb pipette, 25 ml | 665 976 |
| 2 | Pipetting balls | 666 003 |
| 1 | Spatula | 666 962 |
| 1 | Watch glass dish, e.g. 80 mm | 664 154 |
| 1 | Powder funnel, e.g. 60 mm | 602 681 |
| 1 | Balance (at least up to 100 g, resolution 0.01 g) | |
| 1 | PC with Windows XP/Vista/7 | |

## Chemicals

| | |
|---|---|
| Sodium chloride, e.g. 250 g | 673 5700 |
| Distilled water | |
| If necessary: | |
| Calibration solution, 111.8 mS/cm | 667 4644 |
| Calibration solution, 12.88 mS/cm | 667 4640 |

## Preparing the solutions

For preparing the solutions, the balance, the pipettes, the volumetric flasks, the spatula, the watch glass dish, and the funnel are required.

Weigh in exactly 29.22 g of sodium chloride (0.5 mol) on the watch glass dish, which is lying on the balance, and rinse the salt through the funnel into the 250 ml flask with distilled water. After dissolving the salt completely and filling the flask up to the calibration mark, use the 2 M NaCl solution for preparing the other solutions. For 100 ml of the respective solution you need:

for 1 mol/l: 50 ml
for 0.8 mol/l: 40 ml
for 0.5 mol/l: 25 ml
for 0.2 mol/l: 10 ml
for 0.1 mol/l: of the solution with c = 1 mol/l: 10 ml
for 0.01 mol/l: of the solution with c = 0.1 mol/l: 10 ml

If you intend to investigate the specific conductivity of NaCl over the total range of concentrations, it is recommendable to prepare some additional solutions of higher concentration, e.g. 1.5 mol/l, 3 mol/l, 4 mol/l, 5 mol/l, and 6 mol/l.

## Experiment setup (see drawing)

Plug the chemistry box with the conductivity sensor being connected into input A of the Sensor-CASSY. After thoroughly rinsing the conductivity sensor with distilled water, fix it in the clamp, so that its height can be adjusted with the crossed bosshead according to the requirements.

## Calibration

☐ Load settings

The cell constant of the conductivity sensor for the chemistry box has already been set to 0.58 in CASSY Lab. If another conductivity sensor is used, its cell constant has to be entered as a factor in Settings Conductivity CA1 under **Correct**. Then the **Correct Factor** button has to be pressed.

For a more precise determination of the cell constant, calibration solutions can be used: rinse the beaker and the conductivity sensor first with distilled water and then with approx. 30-40 ml of calibration solution. Immerse the conductivity sensor in another 50 ml of calibration solution as if it was for a conductivity measurement (pay attention to the distances from the walls of the beaker), enter the target value in the second line in Settings CA1 under Correct, and press the **Correct Factor** button when a stable measured value is reached.

Such a correction with calibration solutions is also necessary for the conductivity sensor used in this experiment if you intend measurements on highly concentrated NaCl solutions whose specific conductivity exceeds 100 mS/cm. This is the case for concentrations over 1.5 mol/l.

## Carrying out the experiment

■ Load settings

Starting with the solution of the lowest concentration (0.01 mol/l) and following the order up to the 2 M solution, keep to the following procedure:

- Rinse the electrode and the beaker thoroughly with 30-40 ml of the solution.
- Pour this portion of the solution away.
- Fill the remaining solution (approx. 60 ml) into the beaker.
- Adjust the height of the conductivity sensor so that its immersion depth in the liquid is 2 cm and its distance from every wall at least 1 cm.
- If necessary, change the measuring range in Settings Conductivity CA1. Always select the lowest possible measuring range.
- When the displayed value is stable, record the measured value with ⏱.
- Enter the concentration associated with the measured value into the table. To do this, click the corresponding line of the table with the left mouse button, and type the value of the concentration.
- Pour the solution away.

## Evaluation

The values obtained for $C_{A1}$ give the specific conductivity of the solution. This quantity is not substance specific, but depends on the concentration and the temperature. The temperature compensation for the sensor programmed in CASSY Lab determines the data automatically with respect to the standard temperature of 25 °C.

For the evaluation of the data, 4 diagrams have been prepared in CASSY Lab:

1. In the first diagram, the **Specific conductivity** $C_{A1}$ is plotted against the concentration $c_0$.

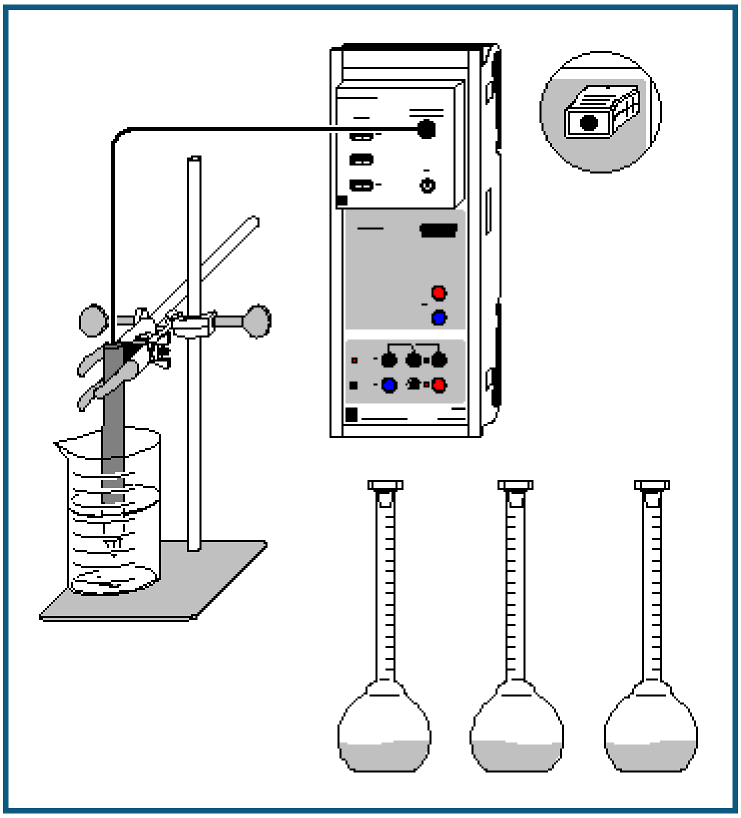
2. The second diagram displays the concentration dependence of the **Equivalent conductivity** $\Lambda_{eq}$.

3. According to Kohlrausch's square-root law, the plot of the equivalent conductivity against the square root of the molar concentration is approximately a straight line in the range of low concentrations, the cut off being the limiting equivalent conductivity. This behavior can be seen in the diagram **Kohlrausch plot**. The slope k depends on the number of ions that result form dissociation (i.e., this slope is smaller in the case of NaCl than, e.g., in the case of $H_2SO_4$).

For fitting a straight line, click the diagram with the right mouse button, select Fit function → Best-fit straight line. After marking the curve range between 0 and 0.5 mol/l you obtain a straight line whose slope A and cut off B are displayed in the status line below on the left.These values can be inserted in the diagram with Set Marker → Text. The parameter A corresponds to -k in the Kohlrausch law, and B is the value of the limiting equivalent conductivity $\Lambda_0$. Enter this value in Settings Λ0 in the field Formula to calculate α.

4. Finally, the diagram **Degree of dissociation** shows the calculated data for α. It is clearly seen that even in the case of strong electrolytes the degree of dissociation is only approximately 1 for very low concentrations. This deviation from the ideal behavior of a strong electrolyte can be explained by the interactions between the ions (ionic association due to Coulomb forces, impediment to the migration of ions in the solution).

## Determining the dissociation constant of acetic acid



can also be carried out with Pocket-CASSY and Mobile-CASSY

**Danger**

Highly concentrated acetic acid is caustic. Wear protective goggles, gloves and clothing. Do not breathe in the vapour of concentrated acetic acid.

Concentrated acetic acid is flammable. Avoid free flames, and do not smoke.

### Experiment description

The specific conductivity of acetic acid in various concentrations is measured. From the data acquired, the equivalent conductivity $\Lambda_{eq}$ is calculated. The values obtained show that Kohlrausch's square-root law for determining the limiting equivalent conductivity does not apply to weak electrolytes. With the aid of the limiting equivalent conductivity determined via the individual ionic limiting equivalent conductivities and by applying Ostwald's dilution law, the degree of dissociation $\alpha$ and the equilibrium constant $K_{Diss}$ of the dissociation equilibrium of acetic acid can be calculated.

### Equipment list

| | | |
|---|---|---|
| 1 | Sensor-CASSY | 524 010 or 524 013 |
| 1 | CASSY Lab 2 | 524 220 |
| 1 | Chemistry box or conductivity adapter S | 524 067(1) |
| 1 | Conductivity sensor | 529 670 |
| 1 | Bunsen burner stand, 450 mm | 666 502 |
| 1 | Crossed bosshead | 666 543 |
| 1 | Universal clamp, 0...25 mm | 666 551 |
| 1 | Beaker, 100 ml, tall shape | 664 137 |
| 9 | Volumetric flasks, 100 ml | 665 793 |
| 1 | Bulb pipette, 10 ml | 665 975 |
| 1 | Bulb pipette, 50 ml | 665 977 |
| 2 | Pipetting balls | 666 003 |
| 1 | Collection container, approx. 1.5 l capacity | |
| 1 | PC with Windows XP/Vista/7 | |

## Chemicals

| | |
|---|---|
| Acetic acid, 99-100 % (approx. 17.5 mol/l), 500 ml | 671 9510 |
| Acetic acid, c = 1 mol/l, 1000 ml | 671 9590 |
| Distilled water | |

## Preparing the solutions

For preparing the acetic acid solutions, the pipettes and the volumetric flasks are required.

Quantities of pure acetic acid required for 100 ml of solution:

- for HAc 50 % (8.75 mol/l): 50 ml
- for HAc 20 % (3.5 mol/l) and 10 % (1.75 mol/l), respectively: 20 ml and 10 ml, respectively

For preparing other solutions, use 1 M acetic acid:

- for HAc, c = 0.5 mol/l: 50 ml
- for HAc, c = 0.1 mol/l: 10 ml

Fill distilled water into the volumetric flasks containing the above mentioned amounts of acetic acid up to the calibration mark. Now use the acetic acid solutions just prepared to prepare further solutions. For this purpose put 10 ml of the HAc solution that has ten times the concentration of the solution to be prepared into a new flask, and add distilled water up to the calibration mark. In this way you obtain the following concentrations:

c = 0.05 mol/l, c = 0.01 mol/l, c = 0.005 mol/l, c = 0.001 mol/l

Now you have eleven acetic acid solutions available for measuring the conductivity at different concentrations. If you intend to perform detailed investigations of the total range of the specific conductivity, it is recommendable to prepare additional solutions of higher concentration (e.g. 30 %, 40 %, 60 %, 70 %, 80 %, 90 %).

## Experiment setup (see drawing)

Plug the chemistry box with the conductivity sensor being connected into input A of the Sensor-CASSY. After thoroughly rinsing the conductivity sensor with distilled water, fix it in the clamp, so that its height can be adjusted by loosening and fastening the screw of the crossed bosshead at the stand.

## Calibration

☐ Load settings

The cell constant of the conductivity sensor for the chemistry box has already been set to 0.58 in CASSY Lab. If another conductivity sensor is used, its cell constant has to be entered as a factor in Settings Conductivity CA1 under **Correct**. Then the **Correct Factor** button has to be pressed.

For a more precise determination of the cell constant, calibration solutions can be used: rinse the beaker and the conductivity sensor first with distilled water and then with approx. 30-40 ml of calibration solution. Immerse the conductivity sensor in another 50 ml of calibration solution as if it was for a conductivity measurement (pay attention to the distances from the walls of the beaker), enter the target value in the second line in Settings CA1 under Correct, and press the **Correct Factor** button when a stable measured value is reached.

## Carrying out the experiment

☐ Load settings

Starting with the solution of the lowest concentration (0.001 mol/l) and following the order up to concentrated acetic acid, keep to the following procedure:

- Rinse the electrode and the 100 ml beaker thoroughly with 30-40 ml of the solution.
- Pour this portion of the solution into a collection container.
- Fill the remaining solution (approx. 60 ml) into the 100 ml beaker.
- Fix the conductivity sensor at the stand so that its immersion depth in the liquid is 2 cm and its distance from every wall at least 1 cm.
- When the displayed value is stable, record the measured value with ⏱.
- Enter the concentration associated with the measured value into the table by clicking the corresponding place of the table with the left mouse button and typing the value of the concentration.
- Pour the solution into the collection container.

## Evaluation

The values obtained for $C_{A1}$ give the specific conductivity of the solution. This quantity is not substance specific, but depends on the concentration and the temperature. The temperature compensation for the sensor integrated in CASSY Lab determines the data automatically with respect to the standard temperature of 25 °C.

For the evaluation of the data, several diagrams have been prepared in CASSY Lab:

1+2) In the first two diagrams, the specific conductivity $C_{A1}$ is plotted against the molar concentration and the percentage by volume, respectively, of the acetic acid.

3) The third diagram shows the **Equivalent conductivity** $\Lambda_{eq}$ as a function of the concentration.

4) If acetic acid was a strong electrolyte, a plot of the equivalent conductivity against the square root of the molar concentration would yield a straight line (see below: Kohlrausch's square-root law). The strong deviation from this law is seen in the diagram **Kohlrausch**.

5) In the diagram **Dissociation**, the values of the negative decimal logarithm of the dissociation constant $pK_{Diss}$ and the degree of dissociation α as calculated from the measuring data are plotted. One reason for the decrease of $K_{Diss}$ towards higher concentrations is the fact that in this region the concentration of water can no longer be considered to be constant; a further reason is given by the formation of ion agglomerates which occurs when the distances between ions become small.

6) In the diagram **Ostwald**, you can check the agreement between the measured values and the values quoted in the literature. For this purpose, plot the reciprocal of the equivalent conductivity (in mol/(S*cm$^2$)) against the specific conductivity up to concentrations of 1 mol/l. From the cut off and the slope of the resulting straight line, $K_{Diss}$ and $\Lambda_0$ can be calculated (see last equation in the section Theoretical background). As small errors in the measured values lead to big errors in this plot, this calculation has been renounced. Instead, the literature values for $K_{Diss}$ and $\Lambda_0$ are used to check the measured values:

Calculate the corresponding straight line with the parameters A for $pK_{Diss}$ and B for $\Lambda_0$ in the menu item Diagram → Fit Function → Free Fit. Enter "1/B + x/(B^2 * 10^-A)" in the field intended for the formula; enter the literature values "4.76" for $pK_{Diss}$ (parameter A) and "390.6" for $\Lambda_0$ (parameter B) and set the associated switch to **constant**. After clicking **Continue with Range Marking**, select an arbitrary range of the plotted measured values to obtain the calculated straight line.

## Theoretical background

The equivalent conductivity $\Lambda_{eq}$ is a substance specific quantity. It is given by the ratio of the specific conductivity $C_{A1}$ and the equivalent concentration:

$$\Lambda_{eq} = \frac{C_{A1}}{c_0 \cdot n}$$

where $c_0$ is the molar concentration of the dissolved substance and n the number of positive or negative charges arising from the dissociation of one molecule. In the case of acetic acid we have n = 1:

$$HAc + H_2O \rightleftharpoons Ac^- + H_3O^+$$

The equilibrium is described by two characteristic parameters: the degree of dissociation α and the equilibrium constant (acidity constant) $K_{Diss}$.

α is defined as

$$\alpha = \frac{[Ac^-]}{c_0}$$

with the initial concentration $c_0$ of acetic acid and the concentration of acetate ions $[Ac^-]$ in the solution.

$K_{Diss}$ and the acidity constant of acetic acid are identical:

$$K_{Diss} = \frac{[Ac^-] \cdot [H_3O^+]}{[HAc]}$$

By inserting

$[Ac^-] = [H_3O^+] = \alpha \cdot c_0$

and

$[HAc] = (1 - \alpha) \cdot c_0$

in the equation for $K_{Diss}$, "Oswald's dilution law" can be derived. For monovalent electrolytes it reads:

$$K_{Diss} = \frac{\alpha^2 \cdot c_0}{1 - \alpha}$$

For weak electrolytes with a small value of $K_{Diss}$, it follows that α increases as the concentration $c_0$ decreases until α = 1 in the case of infinite dilution. Even weak electrolytes dissociate completely when infinitely dilute because recombination does not take place due to the infinite distances between cations and anions.

That means, for the limiting equivalent conductivity, i.e., the equivalent conductivity for infinite dilution $\Lambda_0$, we have α = 1. As the equivalent conductivity is proportional to the proportion of dissociated molecules, the degree of dissociation can also be determined via

$$\alpha = \frac{\Lambda_{eq}}{\Lambda_0}$$

For strong electrolytes, Kohlrausch's "square-root law" holds:

$$\Lambda_{eq} = \Lambda_0 - k\sqrt{c_0}$$

From this, $\Lambda_0$ can be determined graphically. For weak electrolytes, $\Lambda_0$ has to be determined in a roundabout way via the "law of independent migration of ions", which states that ions of opposite charges move independently from each other in the case of infinite dilution. For monovalent compounds it reads:

$\Lambda_0 = \Lambda_+ + \Lambda_-$

$\imath_+$ and $\imath_-$ are the equivalent conductivities of the individual kinds of cations and anions at infinite dilution. However, as they cannot be measured individually, sums are formed of known limiting equivalent conductivities of strong electrolytes. The equivalent conductivity of acetic acid at infinite dilution is calculated in the following way:

$\Lambda_0(HAc) = \Lambda_0(HCl) + \Lambda_0(NaAc) - \Lambda_0(NaCl)$

$= \Lambda(H^+) + \Lambda(Cl^-) + \Lambda(Na^+) + \Lambda(Ac^-) - \Lambda(Na^+) - \Lambda(Cl^-) = \Lambda(H^+) + \Lambda(Ac^-)$

Inserting the literature values, you obtain $\Lambda_0(HAc) = 390.6$ S*cm$^2$/mol.

This value is used in the experiment example for calculating α, which eventually is needed for determining the dissociation constant $K_{Diss}$ according to "Ostwald's dilution law".

Another possibility of determining the limiting equivalent conductivity is given by inserting

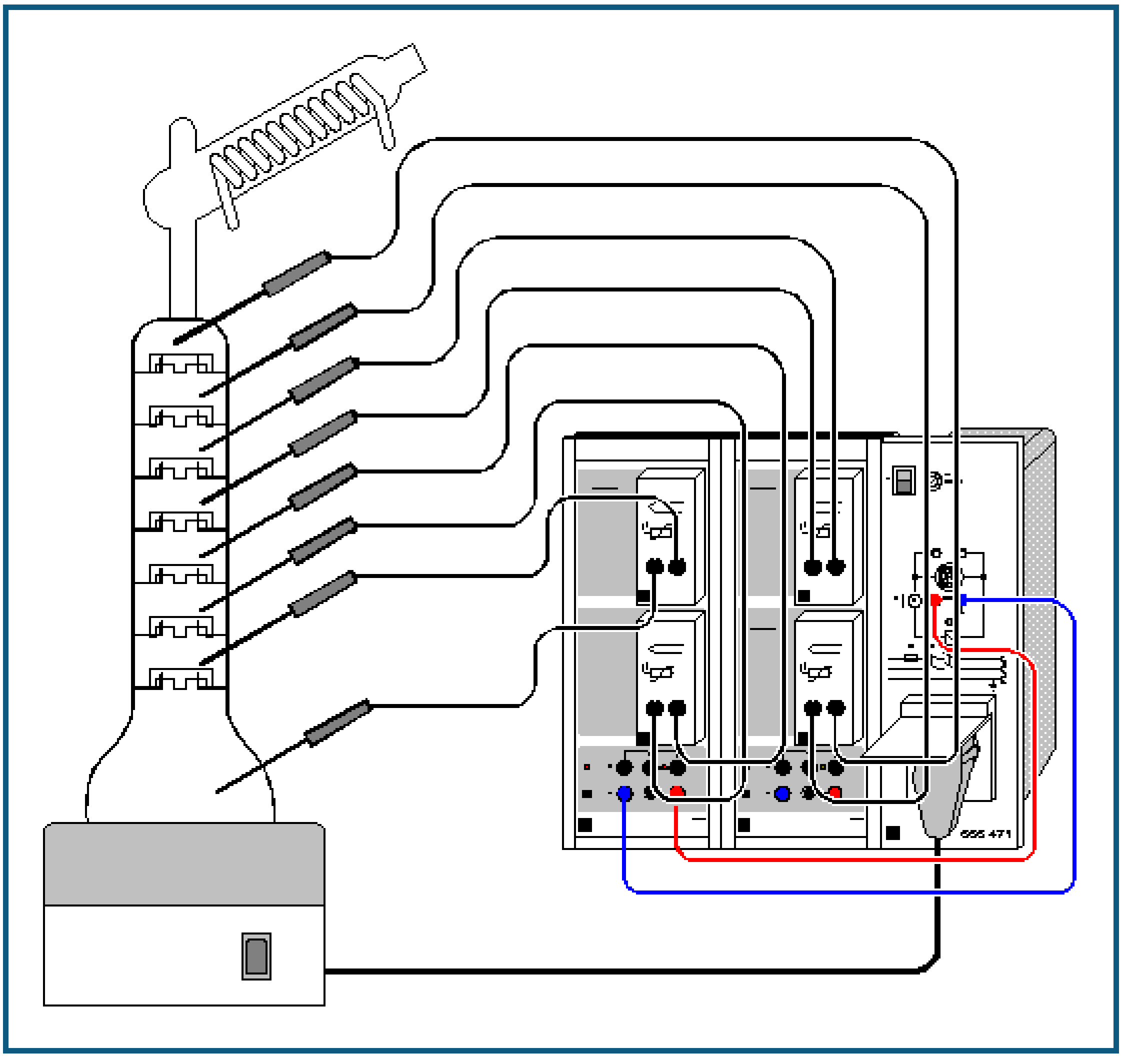
$$\alpha = \frac{\Lambda_{eq}}{\Lambda_0}$$

in Ostwald's dilution law. A transformation leads to the equation

$$\frac{1}{\Lambda_{eq}} = \frac{1}{\Lambda_0} + \frac{\Lambda_{eq} \cdot c_0}{K_{Diss} \cdot \Lambda_0^2}$$

If you plot $1/\Lambda_{eq}$ against $\Lambda_{eq}$*$c_0$, you obtain a straight line with the cut off $1/\Lambda_0$ and the slope $1/(K_{Diss}$*$\Lambda_0)$, whereby $\Lambda_{eq}$*$c_0$ = $C_A$1 for acetic acid. However, as even very small inaccuracies of the measurement lead to big errors, this method it only suited for high-precision measurements. Here the equation is used to check the accuracy of the measurement in the low concentration range.

## Separation of a two-component mixture using the rectification apparatus CE2



### Experiment description

The rectification apparatus CE2 enables separation of organic material systems, e.g. a 1:1 mixture of methanol and ethanol, and determination of the theoretical separation stages with total material reflux.

In this experiment, up to eight temperatures can be measured and recorded by the computer, with simultaneous heating control.

### Equipment list

| | | |
|---|---|---|
| 2 | Sensor-CASSYs | 524 010 or 524 013 |
| 1 | CASSY Lab 2 | 524 220 |
| 4 | Temperature boxes | 524 045 |
| 8 | Temperature sensors NiCr-Ni | 666 193 |
| 1 | CPS-voltage supply, switchable | 666 471 |
| 1 | Rectification apparatus CE2 | 661 311 |
| 1 | Stand system CE2 | 661 301 |
| 1 | CPS mains distributor | 665 497 |
| 1 | Panel frame | 666 425 |
| 1 | Pair of cables, 50 cm, red and blue | 501 45 |
| 1 | PC with Windows XP/Vista/7 | |

### Experiment setup (see drawing)

For information on setting up the apparatus for experiments (see drawing), refer to the experiment manual (668 922) and the Instruction Sheet of the rectification apparatus.**Observe all safety notes given in the Instruction Sheet!**

Place the two Sensor-CASSY units in the top level of the CPS panel frame and cascade them.

Attach temperature boxes at **Analog inputs** $A_1$, $B_1$, $A_2$ **and** $B_2$. Connect two NiCr-Ni temperature sensors to each temperature box. The temperature sensors have the following order in the rectification apparatus, beginning from the sump of the column:

$\vartheta_{A11}$ (sump); $\vartheta_{A12}$; $\vartheta_{B11}$; $\vartheta_{B12}$; $\vartheta_{A21}$; $\vartheta_{A22}$; $\vartheta_{B21}$; $\vartheta_{B22}$ (column head)

The **Voltage Output** $S_1$ is connected to the CPS voltage supply and the knob on CASSY set to about the middle. The CPS-voltage supply is used to connect the heating device. This should be controlled so that it switches off at a specific temperature $\vartheta_{A11}$ in the column sump and after a specified time t. You can set these parameters by defining a formula. Open the formula dialog in Settings Relay/Voltage Source (click the right mouse button over $S_1$).

The default activation condition is **&JA11 < 120 and t > 0 and t < 2:00:00**. This means that the heating device is on when the temperature $\vartheta_{A11}$ (&JA11) is less than 120 °C, the measurement has been started and the time of two hours has not yet elapsed. You can change the defaults to match your application. Note that this formula increases the experimenter's safety.

**Relay output** $R_1$ is still available. This can be used for vacuum rectification CE 4/1 (661 332) to increase the controlling accuracy.

## Calibration

For precise measurements, you should calibrate the temperature sensors before first use as well as later at longer intervals.

■ Load settings

- In Settings ϑA11 select **Correct**.
- Immerse temperature sensor $\vartheta_{A11}$ in ice water (0 °C).
- Enter 0 as the first target and click **Correct Offset**.
- Immerse the temperature sensor in boiling water (100 °C).
- Enter 100 as the second target value and click **Correct Factor**.
- Calibrate the other seven temperature sensors in the same way.
- You can save your calibrated settings under a new name for later use with 💾.
- Mark the Sensor-CASSY units, the temperature sensors and temperature boxes so that they can be used subsequently in the same configuration (this is the only way that the stored calibration will remain applicable).

## Carrying out the experiment

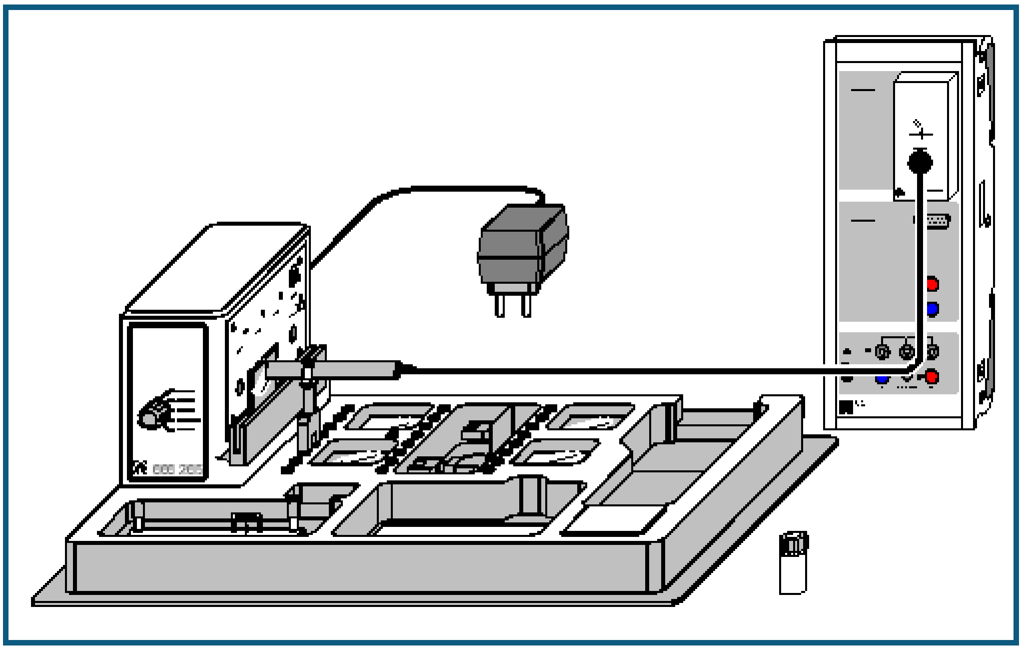
- Switch on the cooling water (cryostat or other).
- Switch on the heating apparatus with the switch on the device.
- Check the system for tightness.
- Start automatic measurement with ⏱ (the heating device is started automatically).
- Wait until a constant temperature is reached.
- Stop automatic measurement with ⏱.
- Turn the switch on the heating device off and lower the heater.
- Switch off the cooling water after the column sump has cooled down.

Sampling and evaluation are described in the manual: Thermal Separation Methods, Part 2: Rectification (668 922).

## Experiment results

It is important that a constant temperature is reached over the entire column. Once this is achieved, the apparatus is in equilibrium and sampling can begin. We can observe that different temperatures are measured in the individual trays due to the different composition of the phase mixtures. As we can see in the example, the temperature decreases in the bottom tray with respect to the higher ones. As the vapor phase is measured in the top tray, this temperature is naturally greater than in the next lower tray.

## Absorption of UV radiation



can also be carried out with Pocket-CASSY and Mobile-CASSY

**Safety note**

Do not look directly into the ray.

### Experiment description

The transmission of several materials for UV-A, UV-B, and UV-C radiation is determined and the effect of sunscreens is tested by measuring the transmitted illuminance.

### Equipment list

| | | |
|---|---|---|
| 1 | Sensor-CASSY | 524 010 or 524 013 |
| 1 | CASSY Lab 2 | 524 220 |
| 1 | Lux box | 524 051 |
| 1 | UV-A sensor<br>and/or | 666 244 |
| 1 | UV-B sensor<br>and/or | 666 245 |
| 1 | UV-C sensor | 666 246 |
| 1 | UV-IR-VIS experiment kit | 666 265 |
| 1 | PC with Windows XP/Vista/7 | |

### Experiment setup (see drawing)

Connect the lux box together with the selected UV sensor (A, B, or C) to the Sensor-CASSY. Using a clamp, fix the UV sensor as close as possible to the appropriate exit aperture of the UV-IR-VIS experiment kit. However, see to it that the holding rail remains free for material samples to be inserted. Connect the experiment kit via the plug-in power supply.

Read the instruction sheets of the UV-IR-VIS experiment kit and the sensors carefully.

### Calibration

Before using a UV sensor for the first time, you have to calibrate it.

Load settings

- Select the **Correct** button in Settings Illuminance EA1, enter the factor printed on the sensor, and click **Correct Factor**.
- The calibration is only valid for the particular corrected sensor.

## Carrying out the experiment

■ Load settings

- Switch the desired UV lamp on, and wait approx. 5 minutes until a stable final value has been reached in the display window for the **Illuminance** $E_{A1}$. You may have to select another measuring range in Settings Illuminance EA1, if the preset range is exceeded.
- Record the first measured value (without absorber) with ⏱.
- One after another insert the following absorbers in the holding rail between the UV lamp and the sensor:
  - quartz glass,
  - window glass,
  - acrylic glass,
  - PVC,
  - quartz glass with a thin film of sunscreen filter (Parsol),
  - optionally: quartz glass with a thin film of cooking oil, spectacle lens

  and record a further measured value for each item.

## Evaluation

The values are displayed in two diagrams: in the bar chart **Illuminance**, the absolute measured values are shown. With Diagram → Set Marker → Text explanatory text can be assigned to the bars.

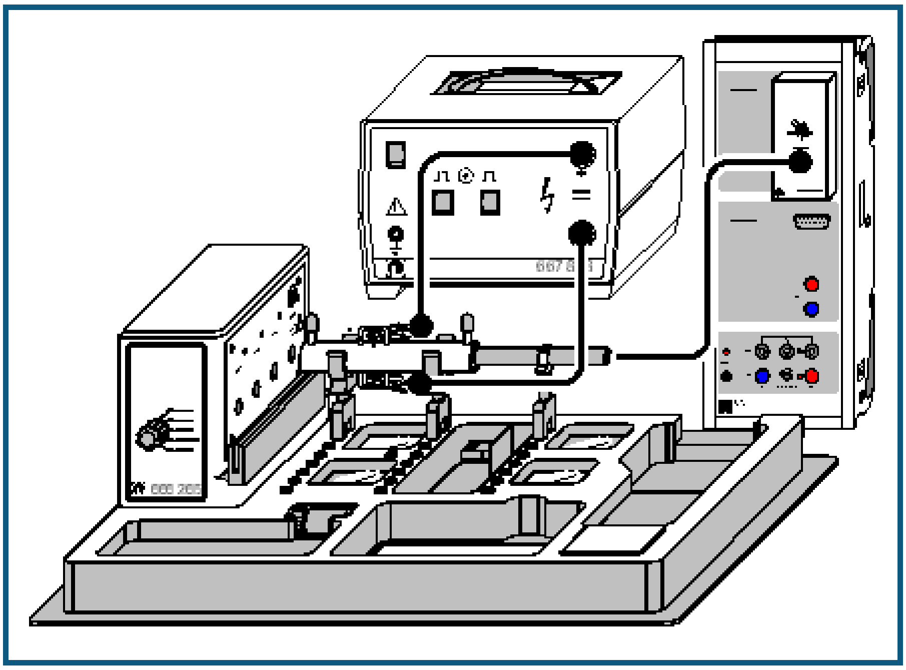
The second diagram, **Transmission**, shows the percentage of the examined radiation that has passed through the respective material.

The specific filtering effect of some materials on UV-B and UV-C radiation and their transmission of UV-A radiation is of particular interest with regard to danger to humans:

In the case of the quartz glass which has been covered with sunscreen filter, the transmission of UV-A radiation, which gives rise to the suntan, is significantly higher than the transmission of the dangerous UV-B and UV-C radiation. In the past decades, the UV-B irradiation on the surface of the earth has increased because the ozone layer has continuously become thinner and thinner. This effect is considered to be the cause of damage of hereditary substance, skin cancer, and blindness. The agent Parsol protects the skin with its UV-B and UV-C filtering effect and passes a great proportion of the tanning UV-A radiation.

As UV-C radiation is even more aggressive than UV-B radiation, the UV-C filtering effect of many materials and particularly of the atmosphere is a prerequisite for life on earth to be possible.

## Simulation of the ozone hole



can also be carried out with Pocket-CASSY and Mobile-CASSY

### Safety notes

Never look directly into the UV-C ray.

Use only non-hazardous contact high-voltage power supplies with direct currents I < 2 mA.

Keep to the current regulations concerning the handling of chemicals.

Do not breathe in the vapour of dichloromethane.

### Experiment description

By means of silent discharge initiated by a high voltage, ozone is produced in a closed cuvette. The absorption of UV-C radiation by the ozone formed in the cuvette is determined as a function of time via a measurement of the illuminance E with a UV-C sensor.

After addition of a small amount of dichloromethane ($CH_2Cl_2$, as a surrogate of CFC), a marked increase of the illuminance (i.e. decrease of the absorption) is observed, from which it can be concluded that the ozone in the cuvette is degraded by dichloromethane.

### Equipment list

| | | |
|---|---|---|
| 1 | Sensor-CASSY | 524 010 or 524 013 |
| 1 | CASSY Lab 2 | 524 220 |
| 1 | Lux box | 524 051 |
| 1 | UV-C sensor | 666 246 |
| 1 | UV-IR-VIS experiment kit | 666 265 |
| 1 | Rubber bulb | 667 241 |
| 1 | Syringe, 1 ml | 665 957 |
| 1 | Spark-gap supply unit | 667 818 |
| 1 | PC with Windows XP/Vista/7 | |

### Chemical

| | |
|---|---|
| Dichloromethane, e.g. 250 ml | 671 6600 |

### Experiment setup (see drawing)

Connect the lux box together with the UV-C sensor to the Sensor-CASSY.

Set up the UV-IR-VIS experiment kit so that nobody can be blinded by the UV-C radiation. Mount the round cuvette from the UV-IR-VIS experiment kit with two holders immediately in front of the exit aperture of the UV-C radiation, and connect the metal contacts to the spark-gap supply unit via two tapping clamps and the connecting leads. As the electric field is very strong, see to it that the connecting leads do not lie one on top of the other or too close to the sensor, the Sensor-CASSY or their cabling. Using a holder, insert the UV sensor immediately in front of the cuvette window. Connect the UV-IR-VIS experiment kit via the plug-in power supply.

Read the instruction sheets of the UV-IR-VIS experiment kit and of the spark-gap supply unit carefully.

### Calibration

Before using the UV sensor, you have to calibrate it.

☐ Load settings

- Select the **Correct** button in Settings Illuminance EA1, enter the factor printed on the sensor, and click **Correct Factor**.
- The calibration is only valid for the particular corrected sensor.

### Carrying out the experiment

☐ Load settings

- Using the rubber bulb, remove residual gas that may be left in the round cuvette, and close the openings of the cuvette with the two black caps.
- Switch the UV-C lamp on, and wait approx. 5 minutes until a stable final value has been reached in the display window for the Illuminance $E_{A1}$.
- You may have to select another measuring range in Settings Illuminance EA1, if the preset range is exceeded.
- Switch the spark-gap supply unit on, and set it to the mode "continuous operation" (red LED shines).
- Immediately start recording the measuring data with ⏱.
- During the entire measurement do not move the cuvette and the sensor as this would distort the measurement.
- Switch the spark-gap supply unit off after 5 to 10 minutes and mark this moment in the diagram with Diagram → Set Marker → Vertical Line.
- Switch the supply unit on again after approx. 3 to 5 minutes, and set another mark with Diagram → Set Marker → Vertical Line at the corresponding position.
- After another 3 to 5 minutes, shake the closed bottle containing dichloromethane briefly, and, using the syringe, take 1 ml of the vapour from the gas space over the liquid. Close the bottle. Do not breathe in the vapour.
- Open one of the caps of the round cuvette, inject the content of the syringe, and, having closed the cuvette, set another mark with Diagram → Set Marker → Vertical Line at the moment of injection.
- Stop the data logging with ⏱ after another 3 to 5 minutes has elapsed, and switch the high voltage off.

### Remarks

The formation and degradation of ozone in the stratosphere (10 to 35 km altitude) is governed by several reactions:

1. $O_2 \xrightarrow{h\cdot\nu} \dot{O} + \dot{O}$ $\lambda < 240\ \text{nm}$
2. $\dot{O} + O_2 + M \rightarrow O_3 + M$
3. $O_3 \xrightarrow{h\cdot\nu} O_2 + \dot{O}$ $\lambda < 310\ \text{nm}$
4. $\dot{O} + O_3 \rightarrow 2O_2$

These reactions keep the ozone concentration in a stationary equilibrium.

If UV-C radiation with wavelengths below 240 nm acts on oxygen, this leads to ozone formation (reactions 1 and 2) because the oxygen radicals formed in this process react with other oxygen molecules to ozone giving off their kinetic energy to a third inert reactant M (e.g. a nitrogen molecule). As the mercury lamp used in the UV-IR-VIS experiment kit generates UV-C radiation of 254 nm wavelength, which is not able to split oxygen molecules, the reaction 1 is initiated by a high voltage of 10 kV in this experiment.

The degradation of ozone, too, takes place with the aid of UV radiation: however, for the splitting (reaction 3), radiation with wavelengths below 310 nm is sufficient. This UV dependence of the ozone formation and degradation leads to a complete absorption of UV-C radiation (220-280 nm, initiation of the reactions 1 and 3) and to a partial absorption of UV-B radiation (280-320 nm, initiation of the reaction 3) by the ozone layer in the stratosphere.

The degradation of ozone by CFC is also initiated by UV-C radiation:

5. $R_3CCl \xrightarrow{h\cdot\nu} R_3\dot{C} + \dot{Cl}$

6. $\dot{Cl} + O_3 \rightarrow O_2 + Cl\dot{O}$

7. $Cl\dot{O} + \dot{O} \rightarrow O_2 + \dot{Cl}$

The chlorine radical created in reaction 5 by absorption of UV-C radiation is set free again and again in a continuous repetition of the reactions 6 and 7, whereby the oxygen radical in reaction 7 comes from the natural degeneration of ozone (reaction 3) or from the natural splitting of oxygen (reaction 1). Therefore a few chlorine radicals suffice to initiate a ozone degenerating chain reaction.

In contrast to completely halogenated CFC, dichloromethane, which is used in this experiment, is already degenerated in the troposhere and does not damage the ozone layer.

### Evaluation

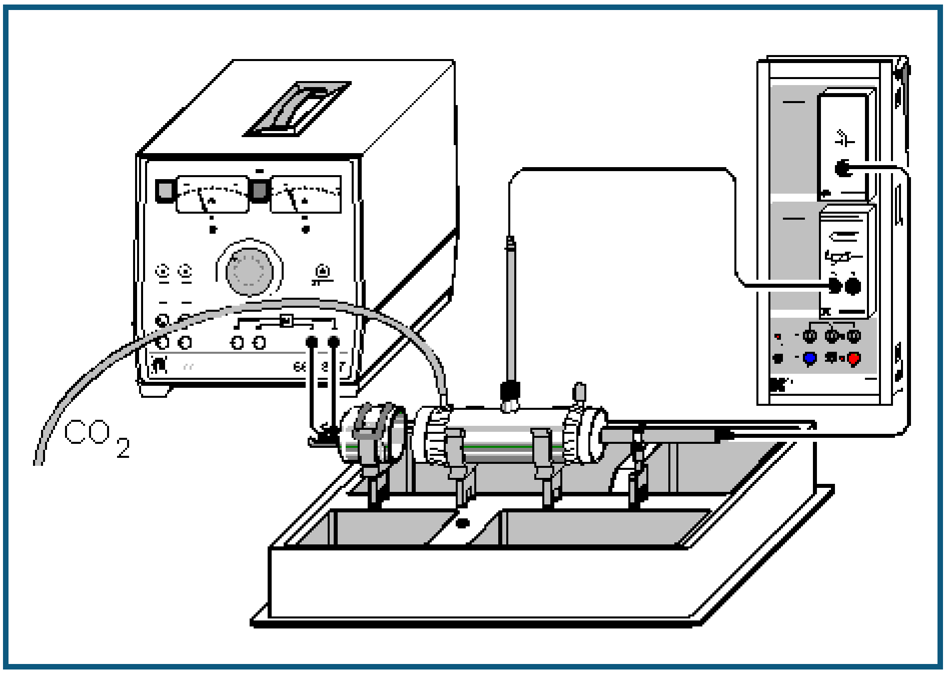
In order to get a clearer display, you can remove the values corresponding to short-term fluctuations in the illuminance caused by switching on and off the high voltage by double-clicking these values in the table and pressing the blank key.

To start the evaluation, enter the first value of the measurements series for the illuminance $E_{A1}$ instead of the default value of "0.290" in the field Formula of Settings Absorption A. An explanatory text can be inserted with Diagram → Set Marker → Text to label the sections separated by the vertical lines.

After switching the high voltage on, the reactions 1 and 2 (ozone formation) predominate over the degeneration reactions 3 and 4. This is seen from the decrease in illuminance or from the increasing absorption of UV-C radiation (range **A** in the diagrams), respectively. When the high voltage is switched off, the ozone concentration is reduced as oxygen radicals from reaction 1 are no longer available for ozone formation, and therefore the degeneration reactions 3 and 4 predominate. As a consequence, the illuminance rises quickly and the absorption of UV-C radiation is reduced (range **B**) indicating a drop of the ozone concentration.

In range **C**, the illuminance decreases again due to another production of ozone by the high voltage. Addition of a small amount of dichloromethane again results in an increasing illuminance despite the high voltage, which is still applied (range **D** in the diagrams).Even a very small amount of $CH_2Cl_2$ vapour leads to a strong decrease in ozone concentration accompanied by a reduction of the UV-C absorption.

## Greenhouse effect of $CO_2$



can also be carried out with Pocket-CASSY and Mobile-CASSY

### Safety notes

The IR radiator becomes very hot. Do not touch the filament. Do not operate the IR radiator with currents over 6 A.

Keep to the current regulations concerning the handling of gases.

### Experiment description

In general, the warming of the atmosphere known as "greenhouse effect" is, among other things, attributed to the rising concentration of carbon dioxide in the air. The experiment described in this example with the IR-$CO_2$ experiment kit clearly shows the effect of $CO_2$: if the $CO_2$ concentration is enhanced, an absorption of infrared radiation and an increase in temperature are measured.

### Equipment list

| | | |
|---|---|---|
| 1 | Sensor-CASSY | 524 010 or 524 013 |
| 1 | CASSY Lab 2 | 524 220 |
| 1 | Lux box | 524 051 |
| 1 | IR-$CO_2$ sensor | 666 248 |
| 1 | Temperature box | 524 045 |
| 1 | Temperature sensor NiCr-Ni | 666 216 |
| 1 | IR-$CO_2$ experiment kit | 666 2651 |
| 1 | Variable extra low voltage transformer D | 667 827 |
| 1 | Silicone tubing, internal diameter 5 mm | 604 431 |
| 1 | Connecting lead, 50 cm, red | 501 25 |
| 1 | Connecting lead, 50 cm, blue | 501 26 |
| 2 | Crocodile-clips | 501 83 |
| 1 | Rubber bulb | 667 241 |
| 1 | PC with Windows XP/Vista/7 | |

### Chemicals

| | |
|---|---|
| Carbon dioxide, compressed gas bottle | 661 0082 |
| with pressure reducing valve according to DIN | 661 017 |

### Experiment setup (see drawing)

Read the instruction sheets of the IR-$CO_2$ experiment kit, the variable extra low voltage transformer and the IR-$CO_2$ sensor carefully.

Connect the lux box with the IR-$CO_2$ sensor to input A and the temperature box with the temperature sensor being plugged in $T_1$ to input B of the Sensor-CASSY.

Insert the IR radiator in the holding clamp on the tray, clamp the measuring cuvette which is covered with two plastic foils in the holders on the tray so that its distance from the radiator is at least 5 mm, and insert the temperature sensor in the GL14 thread so that the tip of the sensing element in positioned in the centre of the cuvette.

Using the holding clamp, mount the IR-$CO_2$ sensor immediately behind the measuring cuvette, and connect the direct current output of the variable extra low voltage transformer (0...20 V) to the contacts of the radiator via the connecting leads.

Close the other inlet with a black plastic cap.

### Calibration

Before using the IR-$CO_2$ sensor, you have to calibrate it.

▨ Load settings

- Select the **Correct** button in Settings Illuminance EA1, enter the factor printed on the sensor, and click **Correct Factor**.
- The calibration is only valid for the particular corrected sensor.

### Carrying out the experiment

▨ Load settings

- Adjust a current of at most 6 A so that the filament only glows very weakly. The measured temperature should not exceed 80 °C.
- When the temperature and the illuminance are virtually constant (observe the display windows in CASSY Lab), start the measurement with ⏱.
- After approx. one minute, remove the black cover cap and allow carbon dioxide to flow through the cuvette for about one minute. Mark the moment when you switch the carbon dioxide flow on by Diagram → Set Marker → Vertical Line.
- Set another vertical line with Diagram → Set Marker → Vertical Line when you switch the carbon dioxide current off, and close the cuvette with the black cap.
- Wait another 3 to 5 minutes until the temperature is constant again. Then stop the measurement with ⏱, and switch the variable extra low voltage transformer off.

### Evaluation

In the two diagrams, the relation between the temperature (first diagram) / illuminance (second diagram) and the absorption by carbon dioxide is illustrated.

For the evaluation, the stationary states before and after the introduction of carbon dioxide are relevant.

1. A comparison of the temperatures and the illuminances before and after the cuvette was filled with carbon dioxide shows a marked rise in temperature accompanied by a reduction of the illuminance.

For comparing the initial values with the values at the end of the measurement, first enter the mean values in the diagram. To do this, select Diagram → Draw Mean, and mark the respective stationary curve range at the beginning and at the end of the measurement series. The mean value calculated by CASSY Lab is displayed by a horizontal line. The corresponding value can be dragged with the mouse from the status line into the diagram.

Hint: if the scale of the Y axis relevant for the respective measured values is activated via the diagram buttons $\mathbf{E}_{A1}$ and $\boldsymbol{\vartheta}_{B11}$, the mean values and labels are displayed in the same color as the corresponding curve.

The exact difference between the two mean values of the temperature and the illuminance is output in the status line when Diagram → Set Marker → Measure Difference is selected and subsequently the two mean value straight lines are clicked. This value, too, can be dragged into the diagram with the mouse.

2. For determining the absorption, enter the first mean value $E_0$ (initial value) in Settings illuminance E0 in the field formula. For the calculation of the absorption A, the formula

$$A = 100 - \left( \frac{E_{A1}}{E_0} \cdot 100 \right)$$

is preset. Mean values and differences are entered in the same way as in the case of the first diagram.

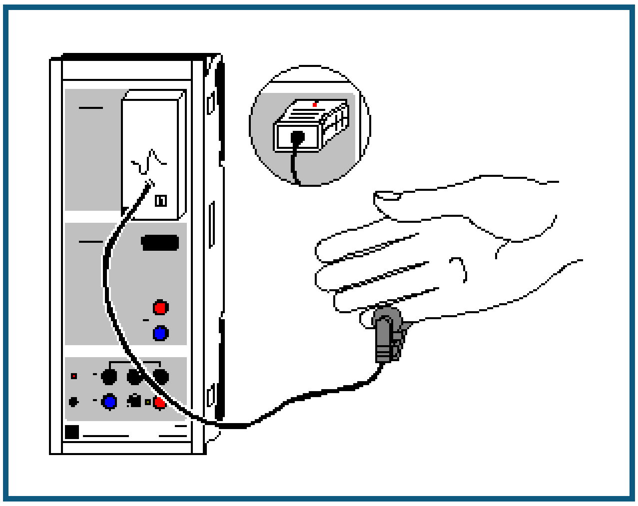
The results make it clear that carbon dioxide absorbs a great proportion of the infrared radiation. The rise of the temperature in the cuvette can be attributed to this absorption.

## Experiment examples biology

These experiment examples support you in using CASSY Lab. The measurement data or settings for the examples can be loaded directly into CASSY Lab. Simply click the symbols ☐ in the descriptions. New examples are labeled with a red •.

- Pulse
- Skin resistance
- Electrocardiogram
- Electromyogram
- Blood pressure
- Reaction time
- Lung volume (spirometry)
- Long-term measurement of climate data

## Pulse



can also be carried out with Pocket-CASSY

**Safety note**

The values and curves measured in this experiment have no medical significance and are not suitable for monitoring human health.

Use the pulse box only as described in the Instruction Sheet.

### Experiment description

The pulsing flow of blood changes the optical properties of the human body. CASSY determines the pulse frequency via the pulse box. The software records the change in the pulse frequency (e.g. during physical exertion) or the resting pulse frequency of athletic and nonathletic test subjects.

### Equipment list

| | | |
|---|---|---|
| 1 | Sensor-CASSY | 524 010 or 524 013 |
| 1 | CASSY Lab 2 | 524 220 |
| 1 | Pulse box or Pulse sensor S | 524 047(1) |
| 1 | PC with Windows XP/Vista/7 | |

### Experiment setup (see drawing)

The pulse sensor of the pulse box at Sensor-CASSY input A is placed at a point on the body with a strong flow of blood, e.g. at the root of the nail on the little finger. Make sure that the sensor is not moved during the measurement, as this can falsify the results.

### Carrying out the experiment

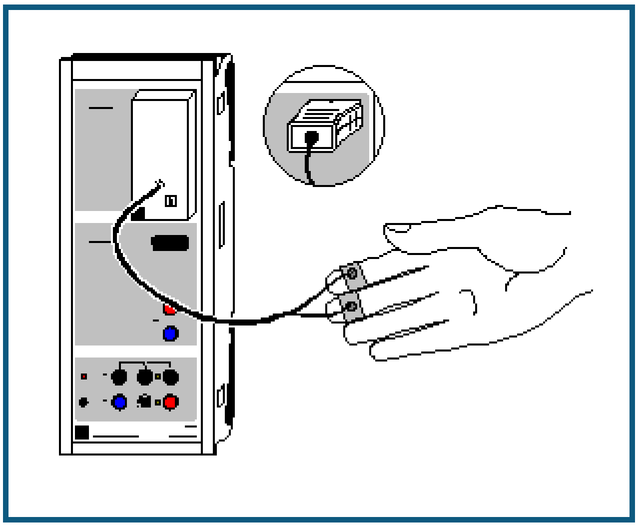
Load settings

- Wait until instrument $P_{A1}$ shows stable pulse values (box adapts to the signal strength).
- Start the measurement with .
- If desired, investigate how the pulse curve depends on physical exertion (knee bends).
- Stop the measurement with .
- You can repeat the measurement with altered factors or different test subjects. Once again, wait for the pulse values to stabilize before pressing .

### Evaluation

You can find the average pulse frequency by finding the mean value from the measuring curve. Simply click the right mouse button over the diagram, select Draw Mean and mark the desired curve range. The value appears in the status line at the bottom left and can be inserted anywhere in the diagram as text.

## Skin resistance



can also be carried out with Pocket-CASSY and Mobile-CASSY

**Safety note**

The values and curves measured in this experiment have no medical significance and are not suitable for monitoring human health.

Use the skin resistance box only as described in the Instruction Sheet.

### Experiment description

The resistance of the skin R changes in response to external factors. This setup can be used e.g. to investigate the effects of autogenous training or a startling event. The measurement always shows the conductance of the skin G=1/R (greater values mean lower resistance).

### Equipment list

| | | |
|---|---|---|
| 1 | Sensor-CASSY | 524 010 or 524 013 |
| 1 | CASSY Lab 2 | 524 220 |
| 1 | Skin resistance box or Skin resistance sensor S | 524 048(1) |
| 1 | PC with Windows XP/Vista/7 | |

### Experiment setup (see drawing)

Plug in the skin resistance box at Sensor-CASSY input A and attach the electrodes securely to the tips of the test subject's index and middle fingers using the Velcro strips. The hand should rest on a support.

### Carrying out the experiment

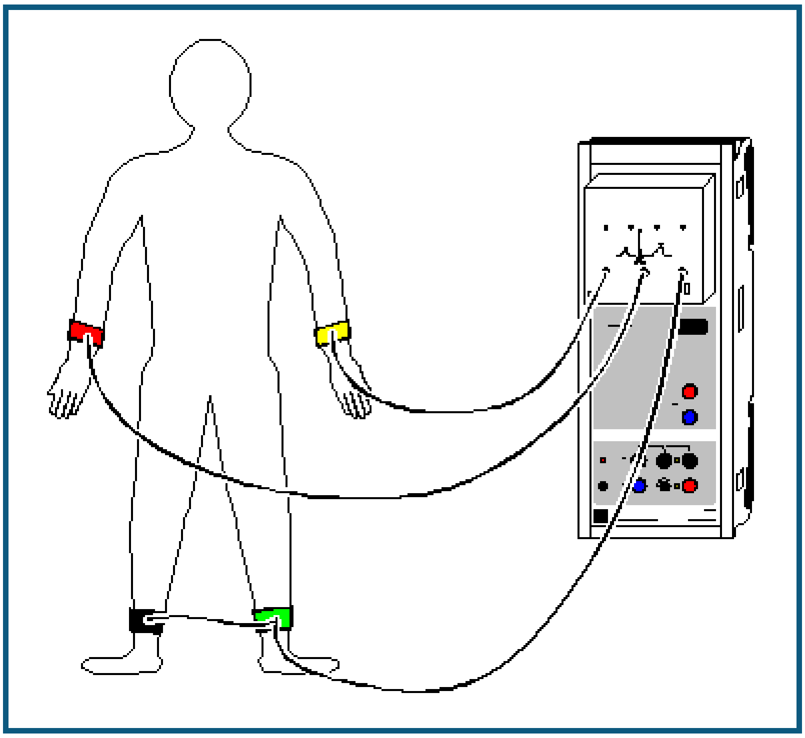
☐ Load settings
- Adjust the measuring range in Settings Skin Conductance GA1 or drag the y-axis of the diagram so that the displayed skin conductance value $G_{A1}$ is about in the middle (if necessary, enter the values via the keyboard after clicking on the y-axis).
- Start the measurement with ⏱.
- If desired, investigate the effects of autogenous training or a startling event (e.g. a loud hand clap) followed by conscious relaxation.
- Stop the measurement with ⏱.
- You can repeat the measurement with altered factors or different test subjects. Once again, adjust the y-axis before pressing ⏱ to restart the measurement.

### Evaluation

The diagram reveals how the skin conductance changes in response to external factors.

You can determine the average skin conductance by finding the mean value from the measuring curve. Simply click the right mouse button over the diagram, select Draw Mean and mark the desired curve range. The value appears in the status line at the bottom left and can be inserted anywhere in the diagram as text.

## Electrocardiogram (ECG)



can also be carried out with Pocket-CASSY

**Safety note**

The values and diagrams obtained in this experiment have no medical significance and are not suitable for monitoring human health.

Use the ECG/EMG box only as described in the Instruction Sheet.

### Experiment description

Every stimulation of the cardiac muscle is accompanied by electric voltage changes, which propagate from one cardiac muscle cell to the other. Due to the large number of cells, the generated voltages can be tapped with electrodes attached to the body and, after amplification, made visible in the form of diagrams. For the electrocardiogram the Einthoven limb leads are used (I, II, III).

The electrodes measure potential changes (voltage changes) when the different heart chambers contract. At rest the cardiac muscle cells are polarized, i.e. there is a slight potential difference between the inside of the cell membrane and the outside. The cardiac muscle cells can depolarize without any influence from outside, i.e. spontaneously. The group of cells which are the first to depolarize constitute the so-called "pacemaker" (sinoatrial node). This node is located in the right atrium of the heart. The two atria contract almost at the same time due to the high-speed conduction of stimulus between the cells.

The ventricles of the heart are electrically insulated from the atria. Only at one place there is a group of cells (atrioventricular node) which transmit the electric signal of the atrium contraction to the ventricles. A slight delay of the transmission of excitation ensures that the ventricles do not contract simultaneously with the atria so that the blood has enough time to flow from the atria into the ventricles.

The atrioventricular node transmits the depolarization over special fibres (His bundles) to the ventricles. In the muscular wall of the ventricles there are other fibres (Purkinje fibres) that provide quick conduction of stimulus. So simultaneous and complete contraction of the ventricles is ensured.

The depolarization, contraction and subsequent repolarization is a continuously repeated process which make small currents flow due to the close neighbourhood of polarized a unpolarized cells. The changes of the currents can be measured from outside, amplified and plotted as a function of time. The ECG is the graphic representation of the measured electric currents.

### Equipment list

| | | |
|---|---|---|
| 1 | Sensor-CASSY | 524 010 or 524 013 |

| | | |
|---|---|---|
| 1 | CASSY Lab 2 | 524 220 |
| 1 | ECG/EMG box | 524 049 |
| 1 | Electrode gel | 662 112 |
| 1 | Disinfectant spray | 662 113 |
| 1 | PC with Windows XP/Vista/7 | |

### Experiment setup (see drawing)

The test subject should be relaxed and in a resting posture, as otherwise the ECG signal can be overlaid by the electrical potentials of the skeletal musculature, falsifying the measurement. To reduce the skin resistance, spread electrode gel (662 112) on the electrodes and attach them to the appropriate points in the body using the rubber straps. Then attach the leads to the electrodes as follows:

| | |
|---|---|
| red | right arm |
| yellow | left arm |
| green | left calf |
| black | right calf |

### Important

Clean the electrodes after each use with a paper towel or similar to prevent a salt layer from forming when the gel dries. Then spray the electrodes and the corresponding skin sites with disinfectant (662 113) to ensure maximum hygiene.

### Carrying out the experiment

■ Load settings
- Start the measurement with ⏱.
- The three leads according to Einthoven are recorded simultaneously.
- Stop the measurement with ⏱.

### Evaluation

For the sake of clarity, part of the display should be enlarged with the Zoom function before evaluation

A typical part of an ECG is given by a flat line, the isoelectric line. Deviations from this line are due to the electric activity of the cardiac muscle.

In a typical ECG, the first deviation from this line is a small upward deflection. The P-wave last approx. 0.05 seconds. For the evaluation a vertical line can be set at the beginning and the end of the P-wave. The duration can be determined by a differential measurement between the two lines. The P-wave is based on the depolarization and contraction of the atria.

Next the ECG returns to the isoelectric line. During this time, the atrioventricular node transmits the excitation via the His bundle and the Purkinje fibres to the ventricles. The depolarization of the AV node leads to a slight downward pulse, the Q-wave. Immediately afterwards a quick rise (R-wave) and a subsequent drop below the isoelectric line (S-wave) occur. Then the ECG returns to the initial value. These three waves are called the QRS complex, which is brought about by the depolarization and contraction of the ventricles.

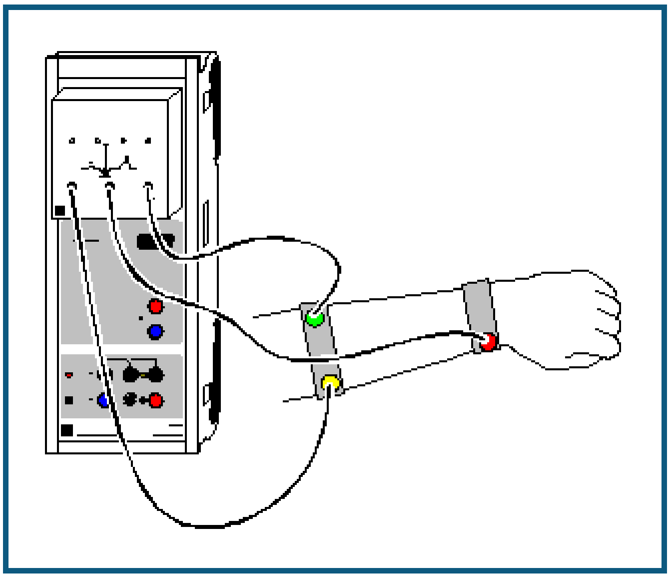
After a further break the cell repolarize. The corresponding current causes an upward wave, the T-wave.

The sequence from P over QRS to T is one cycle of the heart. The number of cycles per minute corresponds to the pulse beat.

### Further experiment proposals

- Recording an ECG before and after exertion (e.g. knee-bends)
- Statistics of the duration of the individual sections for all students in the class
- Differences between women and men

## Electromyogram (EMG)



can also be carried out with Pocket-CASSY

**Safety note**

The values and diagrams obtained in this experiment have no medical significance and are not suitable for monitoring human health.

Use the ECG/EMG box only as described in the Instruction Sheet.

### Experiment description

This experiment measures the electrical potentials of activated muscles by attaching surface electrodes in the area of the muscles.

### Equipment list

| | | |
|---|---|---|
| 1 | Sensor-CASSY | 524 010 or 524 013 |
| 1 | CASSY Lab 2 | 524 220 |
| 1 | ECG/EMG box | 524 049 |
| 1 | Electrode gel | 662 112 |
| 1 | Disinfectant spray | 662 113 |
| 1 | PC with Windows XP/Vista/7 | |

### Experiment setup (see drawing)

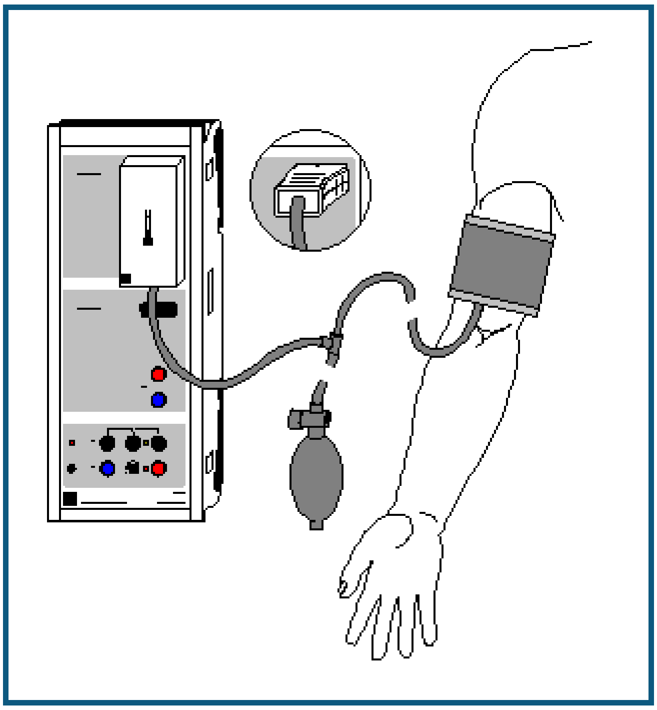
To record an EMG curve of the finger musculature, attach the electrodes at the beginning and end of the muscle on the underside of the forearm and the reference electrode on the opposite side of the muscle group, i.e. on the outside of the forearm. Connect the electrodes as follows:

| | |
|---|---|
| red | start of muscle on underside of forearm |
| yellow | end of muscle on underside of forearm |
| green | reference electrode on outside of forearm |

### Carrying out the experiment

☐ Load settings
- Start the measurement with ⏱.
- When recording the EMG curve, the test subject makes a fist and then opens it. This should be repeated several times.
- Stop the measurement with ⏱.

## Blood pressure



can also be carried out with Pocket-CASSY

**Safety note**

The values and curves measured in this experiment have no medical significance and are not suitable for monitoring human health.

Use the blood pressure box only as described in the Instruction Sheet.

### Experiment description

The blood pressure box is used to measure the pressure at the cuff as pressure variations in the cuff (oscillometric blood pressure measurement). These can be used to calculate the diastole and systole.

### Equipment list

| | | |
|---|---|---|
| 1 | Sensor-CASSY | 524 010 or 524 013 |
| 1 | CASSY Lab 2 | 524 220 |
| 1 | Blood pressure box or Blood pressure sensor S | 524 050(1) |
| 1 | PC with Windows XP/Vista/7 | |

### Experiment setup (see drawing)

Connect the cuff with valve and pumping bulb to the blood pressure box at Sensor-CASSY input A. The valve on the pumping bulb should be about halfway open (in the middle between the two stops of the valve screw). The release rate of the valve should be set to 2-3 mm Hg per pulse beat. Higher release rates make for less accurate evaluations as fewer significant maxima are recorded. A measurement with the valve all the way open will serve to demonstrate this error.

Slide the cuff over the test subject's uncovered left upper arm until the lower edge of the cuff is approx. 2-3 cm above the elbow. Make sure that the cuff hose emerges from the cuff on the inside of the upper arm in the area of the artery (in the direction of the hand). The metal support must not lie against the artery, as this will falsify the blood pressure curve. After wrapping the free end of the cuff around the arm, secure the cuff using the Velcro strips. The cuff should lie snugly on the upper arm, but should not exert any pressure on the artery before it is pumped up. During the measurement the arm should be relaxed and rest on the table slightly bent.

## Carrying out the experiment

☐ Load settings

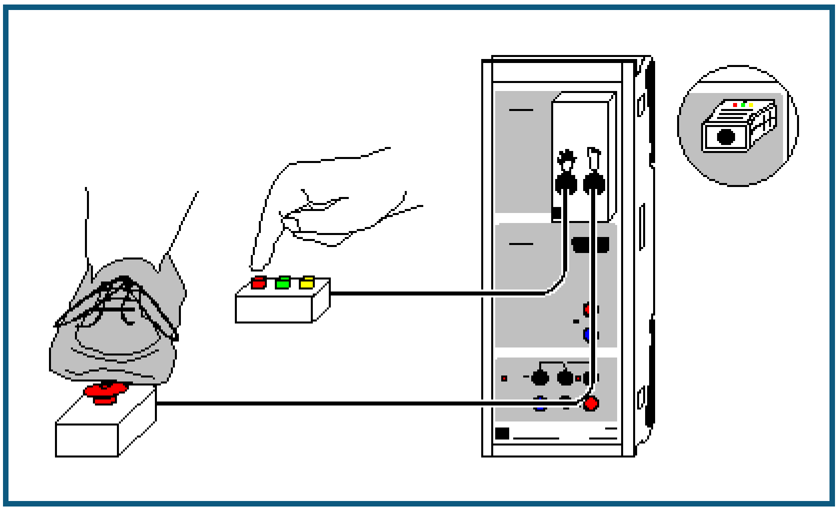
- Correct the zero point of the pressure display if necessary. To do this, open Settings Blood Pressure pA1 and select → **0** ←.
- Using the bulb, pump up the cuff to about 180 $mm_{Hg}$ (depending on the expected systolic pressure). The display shows how the cuff pressure increases.
- Start the measurement with ⏱.
- The arm must not move during the experiment. The amplitude of the oscillations increases during the measurement (once the pressure drops below the systolic threshold) and then decreases (once the pressure drops below the diastolic threshold).
- When the amplitude of the oscillations remains constant several times in a row, stop the measurement with ⏱.
- Vent the cuff completely by pressing the red button on the hand valve.
- Wait at least two minutes before repeating measurements on the same test subject.

## Evaluation

The pressure varies only slightly at supersystolic cuff pressures, due to pulse beats in the compressed arterial section. At the moment in which the cuff pressure falls below the systolic pressure and a brief systolic opening occurs in the artery, the oscillations increase and reach a maximum at the mean arterial blood pressure (which corresponds to the arithmetic mean of the pressure). The diastolic blood pressure corresponds to the point at which the oscillations stop decreasing, i.e. when the blood vessels are open during the entire diastole. The remaining pressure variations are caused by pulse beats transmitted to the cuff.

To calculate the systole and diastole, press the right mouse button in the diagram, select Other Evaluations → Determine Systole and Diastole and mark the entire curve range. The systole and diastole values appear in the status line at the bottom left and can be inserted anywhere in the diagram as text.

## Reaction time



can also be carried out with Pocket-CASSY

### Experiment description

The reaction time is determined using the reaction test box and the pushbutton and/or foot switch. The measured times can be used to calculate the conduction velocity of nerve pulses.

### Equipment list

| | | |
|---|---|---|
| 1 | Sensor-CASSY | 524 010 or 524 013 |
| 1 | CASSY Lab 2 | 524 220 |
| 1 | Reaction test box or Reaction test adapter S | 524 046(1) |
| 1 | Pushbutton<br>and/or | 662 148 |
| 1 | Foot switch | 662 149 |
| 1 | PC with Windows XP/Vista/7 | |

### Experiment setup (see drawing)

Connect the pushbutton or foot switch to the reaction test box at Sensor-CASSY input A. The test subject should be relaxed and at rest. To determine the reaction time with the hand, the subject's hand should rest on the table next to the pushbutton. When determining the reaction time with the foot, the foot should be next to the foot switch on the floor.

### Carrying out the experiment

■ Load settings
- Start the measurement series with ⏱.
- After a random interval following pressing of any element of the pushbutton or foot switch, the pointer appears in the color red, green or yellow (foot switch is always red). The test subject must now react by pressing the same color button as the pointer as quickly as possible. The measured reaction time appears in the display instrument, the table and the diagram.
- Record the desired number of reaction times (10 to 20) in the same way.
- Stop the measurement series with ⏱.
- You can record additional measurement series with other subjects or reactions (e.g. with hand on foot switch instead of foot to determine the nerve conduction speed) with ⏱.

### Evaluation

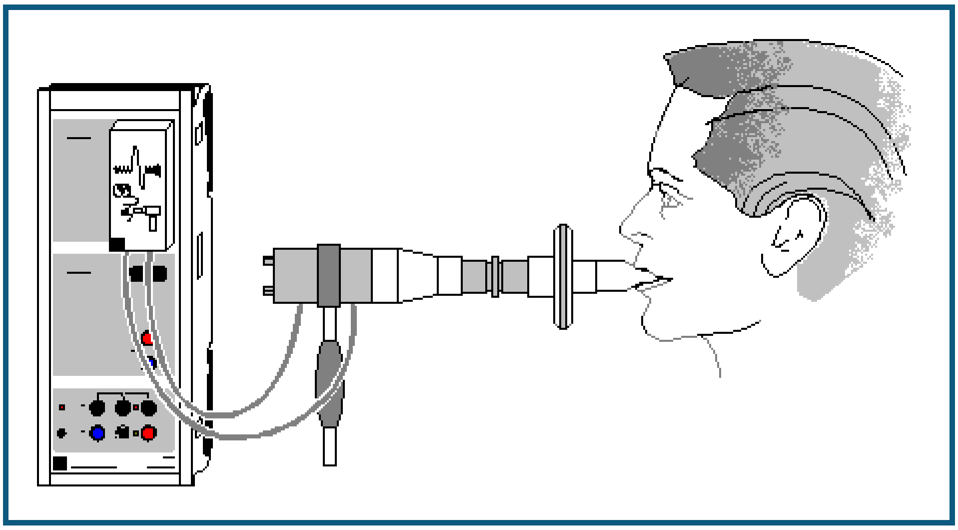
You can find the average reaction time by determining the mean value from the measuring curve. Simply click the right mouse button over the diagram, select Draw Mean and mark the desired curve range. The value appears in the status line at the bottom left and can be inserted anywhere in the diagram as text.

To determine the nerve conduction velocity you need to determine the difference in the lengths of the conducting nerve paths by first measuring the length from the spine at the level of the shoulder joint to the middle of the upper arm. Then measure from the same point to the middle of the thigh.

The mean nerve conduction velocity v is calculated as the quotient of the length difference (foot – hand) and the time difference (reaction time foot – reaction time hand) as

$v = ( l(\text{foot}) – l/(\text{hand}) ) / ( t(\text{foot}) – t(\text{hand}) )$.

## Lung volume (spirometry)



✓ can also be carried out with Pocket-CASSY

### Safety note

Never use the spirometer without a bacteria filter.

The values and curves measured in this experiment have no medical significance and are not suitable for monitoring human health.

Use the spirometer box only as described in the Instruction Sheet.

### Experiment description

The spirometer is used to determine the respiratory volume. The device operates according to the pneumotachographic principle and measures the volume flux. CASSY Lab then determines the respiratory volume through integration.

### Equipment list

| | | |
|---|---|---|
| 1 | Sensor-CASSY | 524 010 or 524 013 |
| 1 | CASSY Lab 2 | 524 220 |
| 1 | Spirometer box | 524 056 |
| 1 | Mouthpiece for the spirometer, 30 items | 662 3812 |
| 1 | Bacteria filter for spirometer, 30 items | 662 3813 |
| 1 | PC with Windows XP/Vista/7 | |

### Experiment setup (see drawing)

Connect the spirometer box to Sensor-CASSY input A about 10 seconds before the measurement (warm-up phase). Use a new mouthpiece and a new bacteria filter for every test person, and disinfect the sieves regularly with a disinfectant.

### Carrying out the experiment

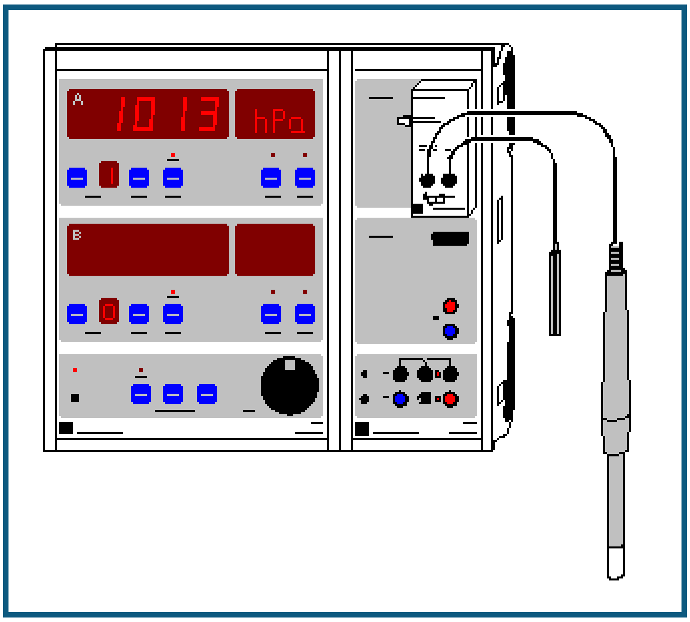
- ▢ Load settings
- Compensate the zero point off the displayed volume flux $dV_{A1}$. Open the window Settings Volume Flux dVA1, select → **0** ← and make sure that no air is flowing through the spirometer during this procedure.
- Start the measurement as soon as possible afterwards with ⏱ (as long as the thermal error in volume flux $dV_{A1}$ is still negligible).
- Breathe evenly through the spirometer three or four times. Then inhale and exhale as much air as possible through the spirometer. Then breathe evenly again.
- Stop the measurement with ⏱.

## Evaluation

The tidal volume $V_1$ is the difference between the maximum and minimum for normal breathing. You can determine this e.g. by setting horizontal lines or directly by measuring the difference. You can insert this value at any point in the diagram as text.

The vital capacity $V_2$ is calculated as the sum of the inspiratory and expiratory reserve volume and the tidal volume. It can be determined from the minimum and maximum at maximum inspiration and expiration analogously to the tidal volume.

## Long-term measurement of climate data



### Experiment description

Measuring values related to climate, namely the humidity $rH_{A1}$, the temperature of the air $T_{A11}$ (integrated in the humidity sensor), the air pressure $p_{A1}$ (integrated in the climate box) and the illuminance $E_{A1}$ (light intensity) are measured over a long time interval with CASSY-Display and Sensor-CASSY (i.e. without computer). The table with measured values can be read and evaluated during the measurement or at the end of it with a computer and the CASSY Lab program.

### Equipment list

| | | |
|---|---|---|
| 1 | CASSY-Display | 524 020 |
| 1 | Sensor-CASSY | 524 010 or 524 013 |
| 1 | CASSY Lab 2 | 524 220 |
| 1 | Climate box | 524 057 |
| 1 | Humidity sensor | 529 057 |
| 1 | Lux sensor | 666 243 |
| 1 | PC with Windows XP/Vista/7 | |

### Experiment setup (see drawing)

The apparatus is set up at a protected location where there is a power supply. Alternatively, a 12 V accumulator with a sufficient capacity (> 6 Ah) may be used as a power supply.

### Carrying out the experiment

- Calibrate the **humidity sensor** (only required for the first measurement).
  For this connect the Sensor-CASSY with the climate box directly to the PC, activate the climate box in CASSY Lab, select **Correct**, enter the four imprinted numbers C1 to C4 and confirm with **OK**.. Then connect the Sensor-CASSY again to the CASSY-Display.
- **Setting and starting the data logger**
  If the key **START/STOP** is pressed, "CLR?" (new values can be appended) or "CLR!" (new values cannot be appended) appears in the upper display and the default "NO" appears in the lower display. By rotating **ADJUST** you can change from "NO" to "YES" and vice-versa and confirm by pressing **START/STOP**. Afterwards you can set the time interval of data logging with **ADJUST** and confirm again with **START/STOP**. Then the data logger starts running (the LED over **START/STOP** now shines continuously).
- **Looking at the measured values in the data logger**
  If **SHOW** is selected, all stored measured values can be looked at in the display with **ADJUST**. While this is done, data logger operation is temporarily switched off (the LED over **START/STOP** blinks). The measurement is continued by pressing **SHOW** once more.
- **Activating economy operation of the CASSY-Display**

It is possible to activate economy operation during the measurement by switching off the display of the CASSY-Display for long measuring times. For this the CASSY with number 0 is selected in both displays with the key **NEXT**. The displays go out and the Sensor-CASSY is switched off. For every new measurement the instruments are switched on for a short time interval.

### Evaluation

For the data readout connect the CASSY-Display to a computer with CASSY Lab. The CASSY-Display can be transported to the computer without power supply (the measured values remain stored). The start of the measurement is entered in the comment field automatically.

In the example, a measurement series of the climate at Hanover from December 15, 2000 to February 23, 2001 is shown. The measuring interval was half an hour.

The maximum number of measured values depends on the number of measured quantities. In this example a total of approx. 5000 lines of measured values is possible. This corresponds to a maximum measuring period of 100 days.

### Remark

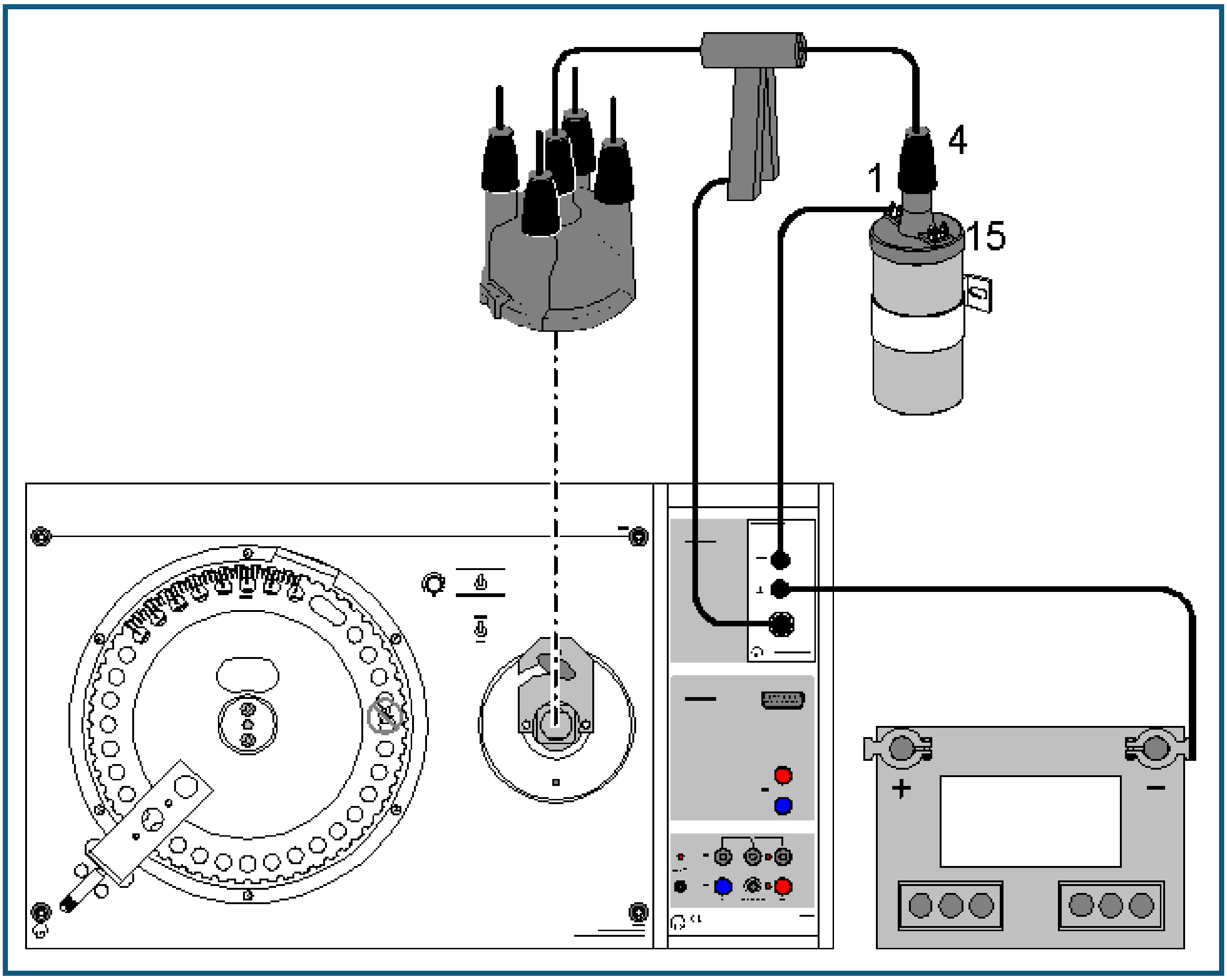
In order that faultless operation of the CASSY-Display is ensured, the version of its firmware should be 1.08 or higher. If necessary, the CASSY-Display can be updated by CASSY Lab. When this is done, all measured data that might be stored in the CASSY-Display are deleted.

## Experiment examples technology

These experiment examples support you in using CASSY Lab. If available, the corresponding label is given. The measurement data or settings for the examples can be loaded directly into CASSY Lab. Simply click the symbols ☐ in the descriptions. New examples are labeled with a red •.

- T 3.2.4 Motor vehicle – ignition systems
- T 3.2.5 Motor vehicle – mixture formation systems
- T 3.2.7.1 Motor vehicle – on-board computer with radio
- T 3.2.7.5 Motor vehicle – comfort system with CAN bus
- T 3.2.7.5 Motor vehicle – investigating CAN data bus signals
- T 7.2.2.1 Pulse code modulation (quantization)
- T 7.4.1 Physical principles of microwave technology (characteristics of the Gunn oscillator)
- T 7.4.2 Two-plate waveguide (TEM and TE modes)
- T 7.4.3 Microwave propagation in waveguides (measurement of the standing wave ratio)
- T 7.6 Antenna technology
- T 12.5.3 Drive engineering

## Motor vehicle – ignition systems



### Safety notes

Ignition systems reach power ranges where in the entire system, i.e. not only at individual units such as the ignition coil or the ignition distributor, but also at cables, plug-in connectors, connectors of test equipment etc. dangerous voltages may be present both on the secondary and on the primary side.

- Therefore the ignition has always to be switched off before manual operations on the ignition system!
- When the ignition is switched on, no voltage-carrying parts must be touched!
- Pay particular attention to ground connections between the individual training panels!

### Experiment description

In this experiment, the ignition oscillograms and the dwell angle adjustment of mechanical distributors are recorded.

The task of the ignition coil is to generate the ignition voltage of 15000 - 30000 volts required for the flashover. In the interior of the ignition coil, a soft-iron core is cast together with many turns of thin wire and a few turns of thick wire. The voltage transformation is determined by the ratio of the numbers of turns.

The primary coil (terminal 15) of the ignition coil is connected to the positive pole of the battery via the ignition lock. Apart form that, the common connection of the primary and the secondary coil (terminal 1) is connected to the ground when the switch is closed so that the primary circuit is closed. In the subsequent dwell period the magnetic field is built up. It breaks down when the switch is opened and induces a high voltage in the secondary coil. This high voltage reaches the spark plug from terminal 4 via the high-voltage cable and the high-voltage distributor.

The primary oscillogram shows the evolution of the voltage at the primary winding. It enables the contact open interval and the contact closed interval of the contact breaker to be determined. From typical changes in the normal oscillogram, certain faults in ignition systems can be identified.

The secondary oscillogram of an ignition system shows the evolution of the voltage at the ignition plug(s). For fault detection the ignition voltage with the ignition pin as well as the firing voltage are of particular importance. From typical changes in the normal oscillogram, certain faults in ignition systems can be identified.

In the dwell angle measurement, the angle at which the breaker contact is closed is measured electronically and displayed in %. The displayed values can be converted into angular degrees. The dwell angle change of a breaker-triggered ignition must not change by more than 2-3 % in an increase of the speed up to approx. 4500 1/min. In breakerless electronic ignition systems, the dwell angle cannot be adjusted and may depend strongly on the speed.

## Equipment list

| | | |
|---|---|---|
| 1 | Sensor-CASSY | 524 010 or 524 013 |
| 1 | CASSY Lab 2 | 524 220 |
| 1 | Car box i | 524 076 |
| 1 | Car box Z | 524 077 |
| 1 | Inductive-type pulse pick-up | 738 986 |
| 1 | Capacitive-type pick-up | 738 987 |
| 1 | PC with Windows XP/Vista/7 | |

and one of the following equipments:

T 3.2.4.2 Contact-controlled coil ignition system
T 3.2.4.3 Breakerless-controlled coil ignition system
T 3.2.4.4 Electronic spark advance (characteristic)
T 3.2.4.5 Distributorless ignition system (DIS)

## Experiment setup (see drawing)

You may use any of the above-mentioned ignition systems, including an original ignition system from a motor vehicle. Please refer to the corresponding experiment literature for further experiments!

In the case of a breaker-triggered ignition system, the capacitive clamp enables all four secondary pulses to be recorded via the feed line for the ignition distributor. In a DIS, only one secondary signal can be recorded.

The primary side is connected to the terminal 1 and to the ground. See to it that the ground is connected as close as possible to the terminal 1!

## Remark

If the signals are to be assigned to the corresponding signals in distributor-triggered ignition systems, you need the trigger clamp connected to the CASSY car box i (524 076). Connect this clamp to the ignition cable of the first cylinder. If you use this signal (E) as trigger signal, the recording always starts with cylinder 1.

## Carrying out the experiment

a) Recording the primary oscillogram

■ Load settings
- Start the measurement with ⏱.
- Change to the **Angular Representation** to be able to relate the oscillogram to the crankshaft angle.

b) Recording the secondary oscillogram

■ Load settings
- Start the measurement with ⏱.
- Change to the **Angular Representation** to be able to relate the oscillogram to the crankshaft angle.

Please keep in mind that the ignition voltages of ignition plugs that ignite in the unpressurized state are always lower than in an engine at approx. 10 bar! In air, the breakdown voltage of standard ignition plugs is only approx. 3.5 kV. For this reason, the height of the ignition pin can vary from cycle to cycle.

c) Recording the contact closed interval

■ Load settings
- Start the measurement with ⏱.
- Increase the speed form 800 to 5000 1/min

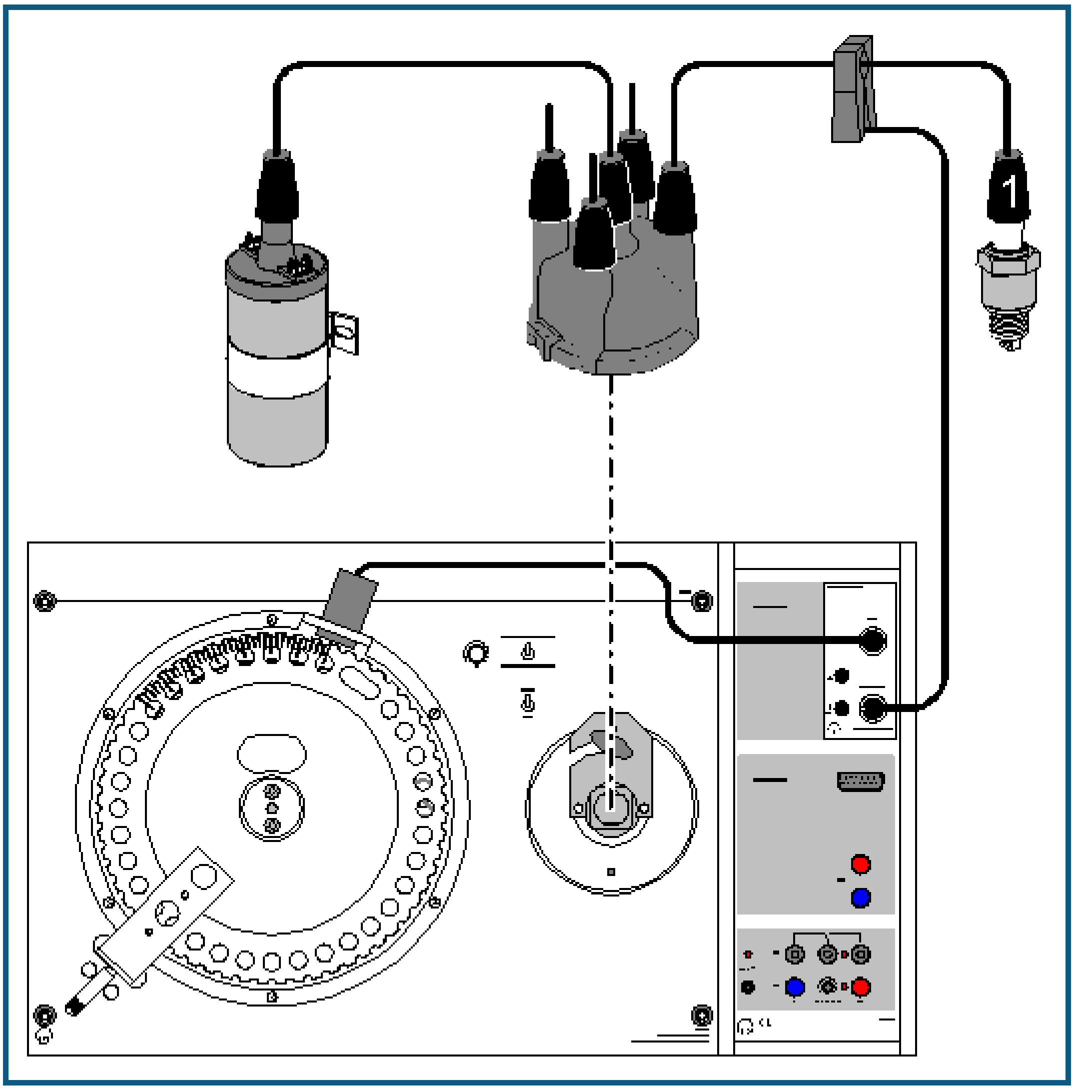
## Evaluation

In the example files, the measurements have been evaluated by way of example. Load the example files, and change to the **Evaluation** display. The contact closed interval was measured for a distributor with centrifugal advance. Up to approx. 4500 1/min, the contact closed interval does not change. Only at higher values of the speed does it decrease.

### Remark

Please refer to the corresponding experiment literature for further experiments!

## Motor vehicle – mixture formation systems



### Safety notes

Ignition systems reach power ranges where in the entire system, i.e. not only at individual units such as the ignition coil or the ignition distributor, but also at cables, plug-in connectors, connectors of test equipment etc. dangerous voltages may be present both on the secondary and on the primary side.

- Therefore the ignition has always to be switched off before manual operations on the ignition system!
- When the ignition is switched on, no voltage-carrying parts must be touched!
- Pay particular attention to ground connections between the individual training panels!

### Experiment description

In this example, the basic possibilities of signal acquisition of relevant quantities in mixture formation systems are demonstrated. These include the speed, the moment of ignition, the injection duration and the frequency and on/off ratio of rectangular signals.

### Equipment list

| | | |
|---|---|---|
| 2 | Sensor-CASSY | 524 010 or 524 013 |
| 1 | CASSY Lab 2 | 524 220 |
| 1 | Auto-Box i | 524 076 |
| 1 | Inductive-type pulse pick-up | 738 986 |
| 1 | Stand. workshop TDC generator | 738 989 |
| 1 | PC with Windows XP/Vista/7 | |
| | optionally for adjusting the vacuum: | |

| | | |
|---|---|---|
| 1 | Pressure sensor S, ±2000 hPa | 524 064 |
| 1 | Vacuum pump | 738 996 |

and one of the following equipments:

T 3.2.5.6 LU-Jetronic
T 3.2.5.7 Motronic
T 3.2.5.10 LH-Motronic M 1.5.4 or 1.5.2
T 3.2.5.11 MONO-Motronic

### Experiment setup (see drawing)

You can use one of the above-mentioned systems or a mixture formation system in a motor vehicle.

The ignition signal of cylinder 1 is detected by means of the trigger clamp. The TDC generator detects the upper dead centre of the cylinder. Apart from the speed, the moment of ignition is determined from these signals.

At the two 4 mm sockets, an arbitrary rectangular signal can be applied. The quantities that can be evaluated are the frequency, the on/off ratio and the operating time or shut-off time. If the signal of an injection valve is applied, the injection duration ti is displayed in ms.

For the measurement of the ignition angle, the crankshaft mark of the TDC and the ignition signal of cylinder 1 are recorded. The time between the ignition pulse and the TDC generator pulse is related to the time required by the flywheel for one revolution. The result is displayed as advance angle in degrees crankshaft angle. The mark for the TDC generator is not located in the upper dead centre of cylinder 1, but 20 degrees crankshaft angle later! This angle is taken into account automatically.

### Carrying out the experiment

a) Centrifugal advance

The centrifugal advance mechanism of a rotating distribution adjusts the moment of ignition depending on the speed of the engine. With increasing speed, the **cam** is moved in the direction of rotation of the ignition-distributor shaft, whereby the breaker contact is opened earlier. This leads to an earlier ignition. The centrifugal advance can only be determined, if the vacuum tubings are removed!

▨ Load settings
- Start the measurement with ⏱.
- Pass through the speed range from 600 to 6000 1/min

The centrifugal advance causes an adjustment of the ignition angle towards earlier ignition, which increases linearly up to approx. 3000 1/min. At higher speeds, there is no further advance as the centrifugal advance is limited mechanically. If vacuum advance is to be investigated subsequently, the corresponding centrifugal components can be determined from the diagram, which have to be subtracted from the vacuum advance.

b) Vacuum advance, advance unit

The vacuum advance mechanism adjusts the moment of ignition depending on the load of the engine. The vacuum unit is connected to the intake manifold above the throttle valve and adjusts the moment of ignition in the part-load range by turning the **breaker contact** in the direction opposite to the rotation of the ignition distributor shaft. This leads to an earlier ignition. This type of vacuum unit is called "advance unit".

The contribution of the vacuum advance to the total advance can be determined by first determining the pure centrifugal component and then subtracting it from the value measured in the vacuum experiment!

▨ Load settings
- Start the measurement with ⏱.
- Generate a vacuum of 0 to –600 hPa (-600 mbar) at 1000 1/min
- Repeat the measurement for 2000 and 4000 1/min

Regardless of the speed, the adjustment of the advance unit causes an advance of approx. 13 degrees crankshaft angle. For 1000 and 2000 1/min, the advance ranges are equal after subtraction of the centrifugal component!

c) Vacuum retard, retard unit

The vacuum unit for ignition retard is connected to the intake manifold below the throttle valve because in this position there is a high vacuum during idle and overrun. The retard unit adjusts the moment of ignition by turning the **breaker contact** in the direction of rotation of the ignition distributor shaft. This leads to a later ignition. This type of vacuum unit is called "retard unit".

The ignition retard is subordinate to ignition advance.

The contribution of the vacuum retard to the total advance can be determined by first determining the pure centrifugal component and then subtracting it from the value measured in the vacuum experiment!

☐ Load settings

- Start the measurement with ⏱.
- Generate a vacuum of 0 to –600 hPa (-600 mbar) at 1000 1/min
- Repeat the measurement for 2000 and 4000 1/min

Regardless of the speed, the adjustment of the retard unit causes an ignition retard of approx. –8 degrees crankshaft angle in the pressure range from –200 to –400 hPa. For 1000 and 2000 1/min, the advance ranges are equal after subtraction of the centrifugal component!

d) Injection valve

The function of the injection valves is to supply all cylinders (single-point injection) or individual cylinders (multipoint injection) with gasoline depending on the signal from the control unit. Usually they are triggered with 12 V via the ground cable. The injected fuel quantity depends solely on the injection duration as the opening cross-section and the pressure difference between the fuel-injection tubing and the intake manifold are kept constant. A typical effect of DC solenoid valves (injection valves) is the high induction voltage in the opposite direction when the voltage is switched off.

☐ Load settings

- Start the measurement with ⏱.
- Increase the speed of the engine at operating temperature and 50 % load from idle to approx. 5000 1/min
- Repeat the measurement for several load conditions (17 %, 33 %, 67 %, 83 %)

As the speed of the engine increases at constant air throughput, the absolute pressure behind the throttle valve decreases, and the cylinders can induce less mixture per lift. Therefore less fuel is required, which is achieved by a shorter injection duration. If the engine power increases at constant speed, the cylinder charge is greater. This leads to a greater fuel quantity and thus to longer injection times.

e) Lambda closed-loop control

If the exhaust-gas oxygen content is 3 % (lean mixture), the difference relative to the oxygen content of the ambient air leads to a voltage of 0.1 V. If the exhaust-gas oxygen content is less than 3% (rich mixture), the voltage of the lambda sensor increases relative to the increased difference to 0.9 V. Hence there is a control loop for each cylinder bank, which enables the mixture composition to be controlled. Depending on the sensor voltage, the injection duration is changed

☐ Load settings

- Activate the periodic change of the lambda voltage
- Start the measurement with ⏱ at 2000 1/min with the engine at operating temperature
- Repeat the measurement for a very cold engine and for full load, respectively

The lambda closed-loop control works such that the injection duration rises in the case of a lean mixture, which leads to a richer mixture. In the case of a rich mixture, the injection duration drops, which leads to a leaner mixture. The control does not work if the engine is cold because the fuel-air mixture has to be enriched to compensate for condensation losses at cold components. The mixture cannot be operated with ı = 1.

At full load, the control is also shut off as the engine has to be operated with a rich mixture to achieve maximum engine power.

f) Rotary idle actuator

During the fuel injection, the function of the rotary idle actuator is to open a bypass air channel around the throttle valve more or less thus controlling the idle operation. The percentage of the time within an interval of 100 ms, during which the electric motor receives a current pulse for opening, is called on/off ratio. It is, e.g., 50 % if the motor receives 12 V for 50 ms and then 0 V for another 50 ms. In this case, the inertia of the armature should lead to the bypass channel being opened for about 50 % of the time.

☐ Load settings

- Start the measurement with ⏱.

Reduce the speed of the engine at operating temperature from 850 to 400 1/min

Repeat the measurement for a cold engine and with the air conditioner being switched on

When the speed is decreased, the on/off ratio increases, as the engine tries to increase the speed. If the engine is cold, the on/off ratio is increased as well, as the higher engine friction has to be overcome. If the air conditioner is switched on, the engine also tries to increase the air throughput of the rotary idle actuator by increasing the on/off ratio in order to compensate for the drop in speed caused by the increased load.

g) Knocking sensor

"Knocking", an uncontrolled form of combustion, can lead to damage in the engine. However, as knock limits depend on many variable quantities such as fuel quality, engine condition and ambient conditions, a sufficient distance from the knock limit has to be kept in ignition systems with electronic adjustment, which leads to a deterioration of the fuel consumption. The distance of the program map from the knock limit, which has been indispensable up to now, may be cancelled if a knock during operation, e.g. caused by poor fuel quality, is detected and if the ignition angle is reduced accordingly. The knock control enables the engine to be operated in the limit range without damage.

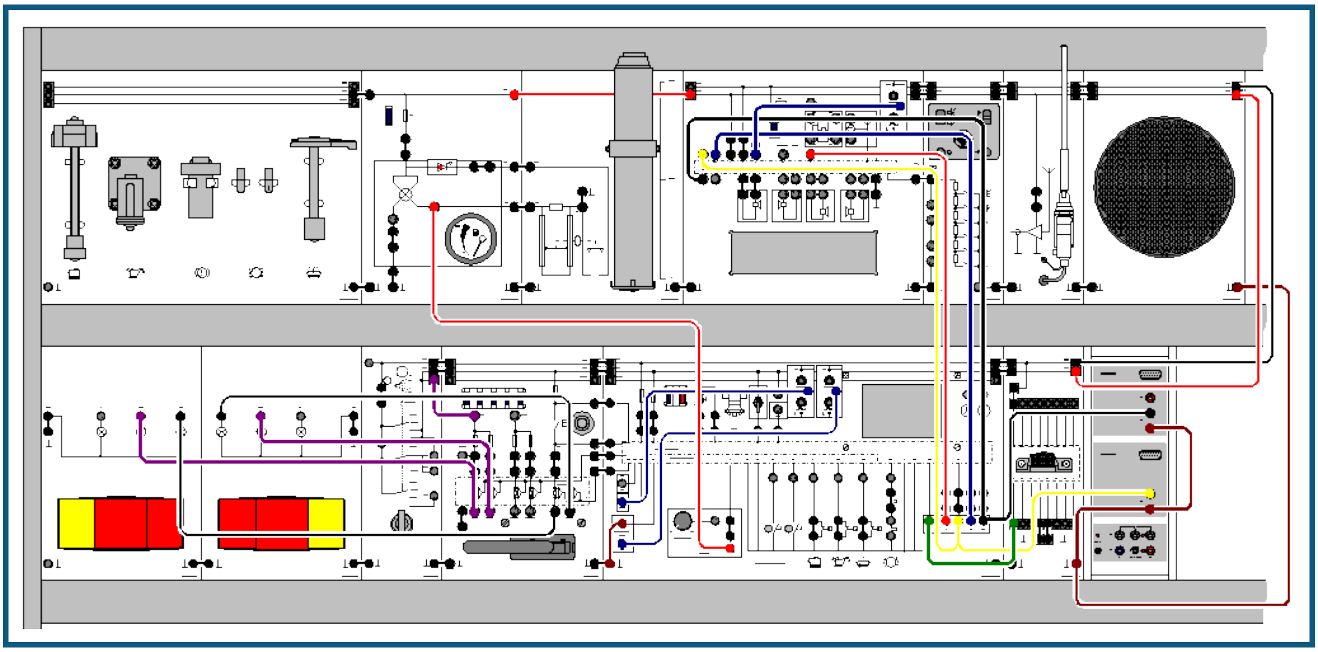
■ Load settings
- Start the measurement with ⏱.
- With the engine at operating temperature and running at a speed of 2500 1/min almost at full load, slightly hit the knock sensor against a metal block

In the case of combustion knock, the control circuit delays the moment of ignition of the knocking cylinder. Subsequently the moment of ignition is taken back to its original value slowly according to a particular scheme.

### Remark

Please refer to the corresponding experiment literature for further experiments!

## Motor vehicle – on-board computer with radio



### Experiment description

The present system is the multi-info display (MID) from the Opel Omega B, model year >1994. The info display is a central information system comprising the following individual systems:

- Clock
- On-board computer
- Check control
- **Radio display part**
- Date display part

The info display is integrated in the instrument assembly. It has a four-line display. Depending on the set operating mode, the above mentioned information is displayed. In this experiment, the communication between the radio and the display will be investigated. These two components communicate via the so-called "I$^2$C" bus, whose bus signal will be recorded.

For further information on this subject see: http://www.standardics.nxp.com/literature/i2c/.

### Equipment list

| | | |
|---|---|---|
| 1 | Sensor-CASSY | 524 010 or 524 013 |
| 1 | CASSY Lab 2 | 524 220 |
| 1 | Battery connection unit | 738 03 |
| 1 | Battery | 738 04 |
| | *or alternatively* | |
| | Power supply | 738 026 |
| 1 | Ignition switch | 738 10 |
| 1 | MID | 739 705 |
| 1 | Car radio | 739 711 |
| 1 | Short telescoping antenna | 739 742 |
| 1 | Broad band loudspeaker | 739 731 |
| 1 | PC with Windows XP/Vista/7 | |

### Accessories required

| | | |
|---|---|---|
| 1 | Set of 51 safety connection leads | 738 9821 |
| 5 | Sets of 10 safety bridging plugs black | 500 59 |
| 1 | Set of 10 safety bridging plugs with tap | 500 592 |

### Experiment setup (see drawing)

Set up the experiment as shown in the drawing. Some devices are optional and are not required for carrying out the experiment! Connect the Sensor-CASSY to a serial RS232 port or a USB port of the computer. Connect the measurement inputs to the experiment setup as shown in the drawing.

### Carrying out the experiment

▪ Load settings
- Switch the system on, first using the battery connection unit and then the ignition switch.
- Switch the radio on by pressing the volume key.
- Start the measurement with ⏱.
- Now switch over a station key of the radio to create a data flow.

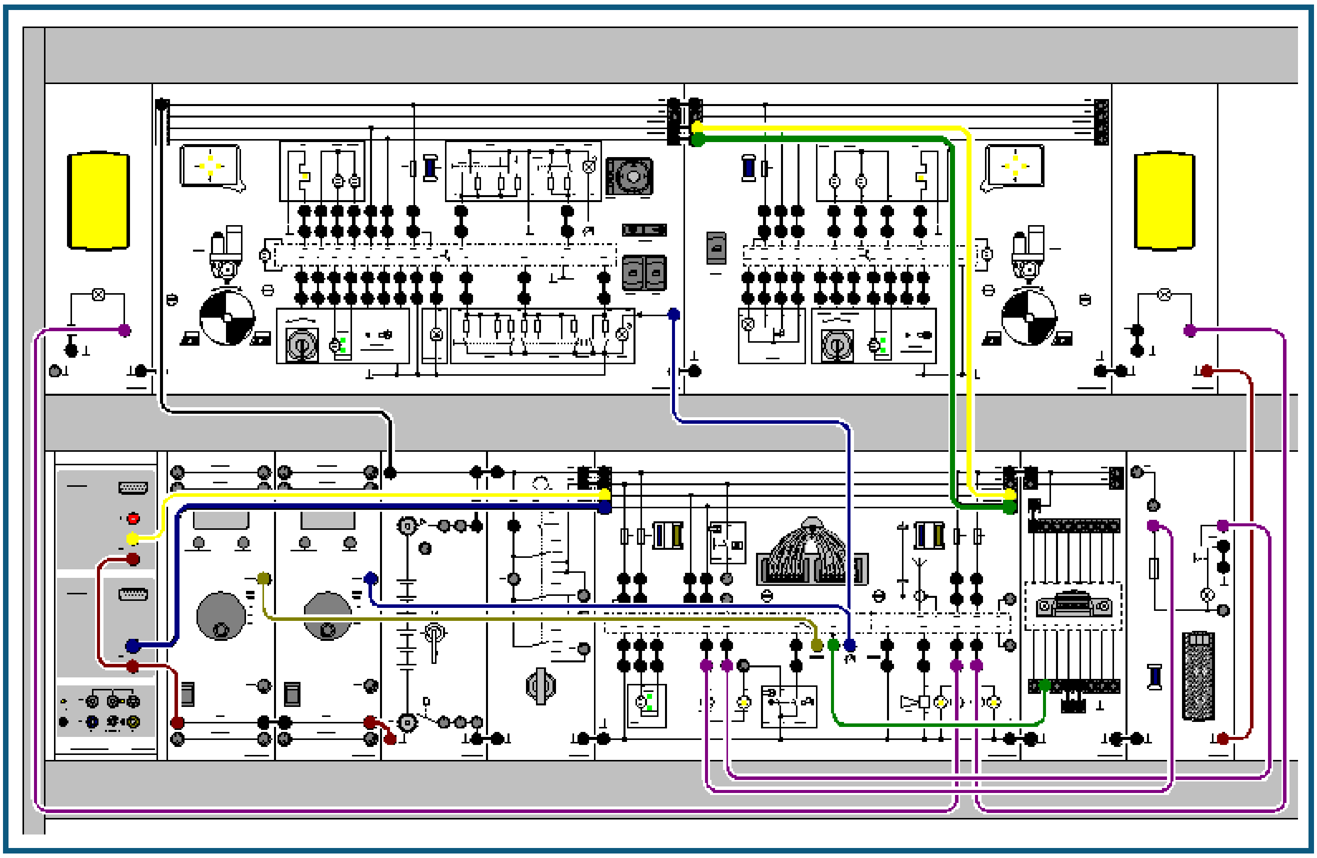
### Evaluation of the experiment

The following findings can be obtained from the diagrams:

- The address of the display is: 1 0 0 1 0 1 0
- A write access from the display to the radio takes place (RW bit)

Further variations of the experiment and their evaluation are found in the associated experiment literature.

## Motor vehicle – comfort system with CAN bus



### Experiment description

The new comfort system was first used in the VW Passat in the model year 1997 and has been available in the VW Golf since the model year 1998. The individual functionalities that belong to the comfort system such as the central locking system, the mirror adjusting system and the theft-deterrent system have not changed essentially. What is new, however, is the structure and the organisation of the comfort system. In contrast to conventional systems, it has a decentralized structure. That means tasks are shared by several control units.

The control units of the comfort system are connected to one another via two lines, the CAN data bus. A permanent data exchange between the control units takes place via these lines.

For this a control unit has to:

- provide data of its own,
- send these data to other control units,
- receive data from other control units,
- check these data and, if required, accept them.

The system consists of a central control unit and two door control units. The central control unit has no higher-level function. There is no hierarchy among the control units. Apart from its functionalities within the comfort system, the central control unit establishes the connection between the remaining vehicle electrical system and the diagnosis cables.

Functionalities of the central control unit:

- Mirror adjustment,
- Interior light control,
- Remote release of the luggage compartment lid,
- Radio remote control,
- Theft-deterrent system.

The door control units monitor and control the functionalities of the comfort system carried out in the doors.

### Equipment list

| | | |
|---|---|---|
| 1 | Sensor-CASSY | 524 010 or 524 013 |

| | | |
|---|---|---|
| 1 | CASSY Lab 2 | 524 220 |
| 1 | Battery connection unit | 738 03 |
| 1 | Battery | 738 04 |
| | *or alternatively* | |
| | Power supply | 738 026 |
| 1 | Ignition switch | 738 10 |
| 1 | Comfort system | 739 58 |
| 1 | PC with Windows XP/Vista/7 | |

### Accessories required

| | | |
|---|---|---|
| 1 | Set of 51 safety connection leads | 738 9821 |
| 5 | Sets of 10 safety bridging plugs black | 500 92 |
| 1 | Set of 10 safety bridging plugs with tap | 500 592 |

### Experiment setup (see drawing)

Set up the experiment as shown in the drawing. Connect the Sensor-CASSY to a serial RS232 port or a USB port of the computer. Connect the measurement inputs to the experiment setup as shown in the drawing.

### Carrying out the experiment

■ Load settings
- First switch the system on using the battery connection unit.
- Now open one of the two doors by turning the corresponding key switch in the "OPEN" direction.
- Switch the ignition on using the ignition switch.
- Start the measurement with ⏱.

### Evaluation of the experiment

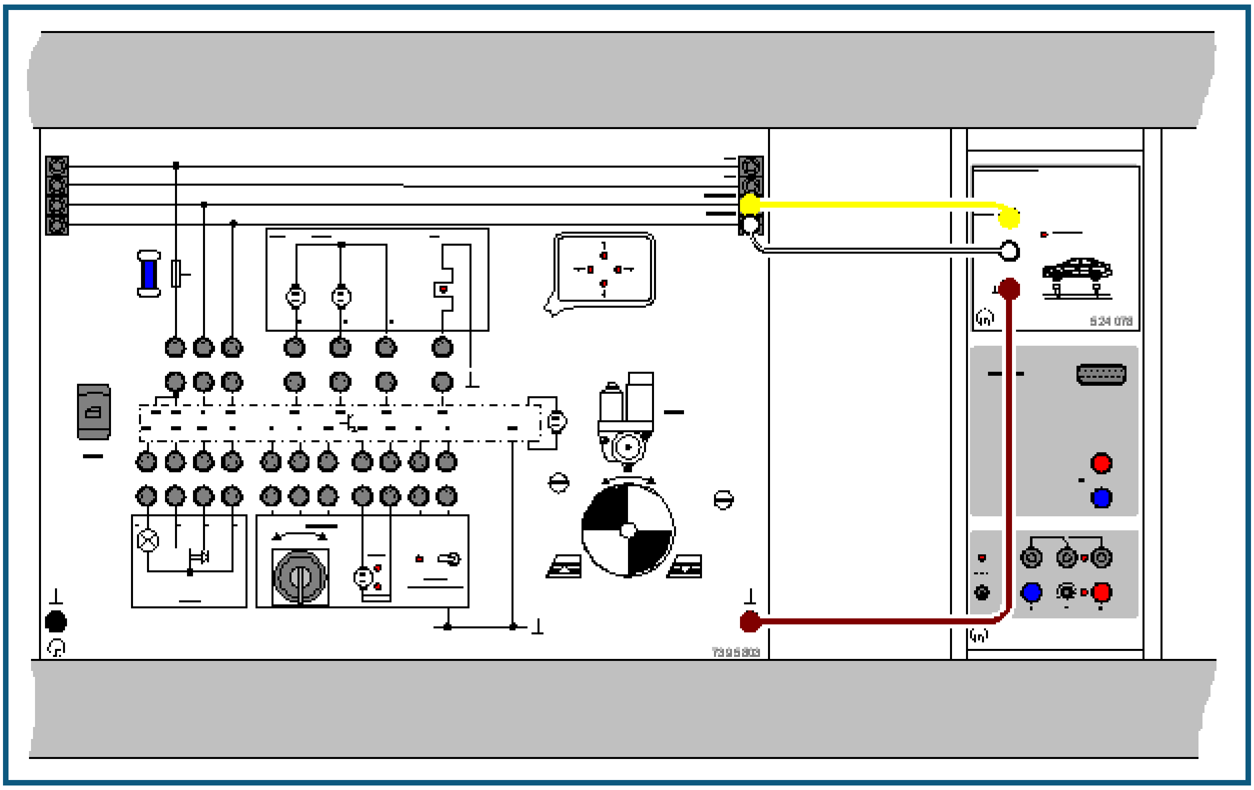
The following findings can be obtained from the diagrams:

- The signals on the lines CANH and CANL are mutually inverted.
- The messages are set in three frames with a repeat time of 20 ms.
- Two messages have equal lengths (approx. 1.34 ms) and one message in shorter (approx. 1 ms). The latter obviously concerns the door control unit of the co-driver side.

In addition to CANH and CANL, the **Difference** display also shows their difference ΓCAN=CANH-CANL, which is defined as a formula.

Further variations of the experiment and their evaluation are found in the associated experiment literature 566 1481.

## Motor vehicle – investigating CAN data bus signals



### Experiment description

In this example, a CAN message is recorded and evaluated graphically. This recording can be used to determine individual components of the protocol. These include:

- Start bit
- Identifier (incl. RTR)
- Length code (DLC)
- Data blocks
- Checksum (CRC)
- Acknowledgement field (ACK)
- End of file (EOF)

### Equipment list

| | | |
|---|---|---|
| 1 | Sensor-CASSY | 524 010 or 524 013 |
| 1 | CASSY Lab 2 | 524 220 |
| 1 | CAN bus box | 524 078 |
| 1 | PC with Windows XP/Vista/7 | |

In addition, one of the following equipments is required:

T 3.2.3.7: Automotive lighting with CAN bus
T 3.2.7.5: Comfort system with CAN bus
T 3.2.12.3: Networked vehicle systems 1 (lighting) and
T 3.2.12.5: Networked vehicle systems 3 (infotainment)

Alternatively it is, of course, possible to use the CAN bus signals of a low-speed bus in an original vehicle.

### Experiment setup (see drawing)

Connect the CAN bus box to a low-speed CAN bus in any position. Take care to establish a correct ground connection.

To gain workshop practice you may also connect the CAN bus of an available vehicle as long as it is a low-speed bus. Follow the manufacturer's circuit diagrams to get access to the two bus cables, and additionally connect the ground socket to the ground of the vehicle's body.

Hint: in modern vehicles, the CAN bus signals may be available at the 16-pole OBD socket!

## Carrying out the experiment

■ Load settings
- Start the measurement with ⏱.
- The measurement is stopped automatically after the first received message has been recorded.
- The measurement can be repeated for other data to be transmitted. To do this, first select the corresponding identifier in the ID filter in the Settings CANA1 (right mouse button on $\mathrm{CAN}_{A1}$) and restart with ⏱.

## Evaluation

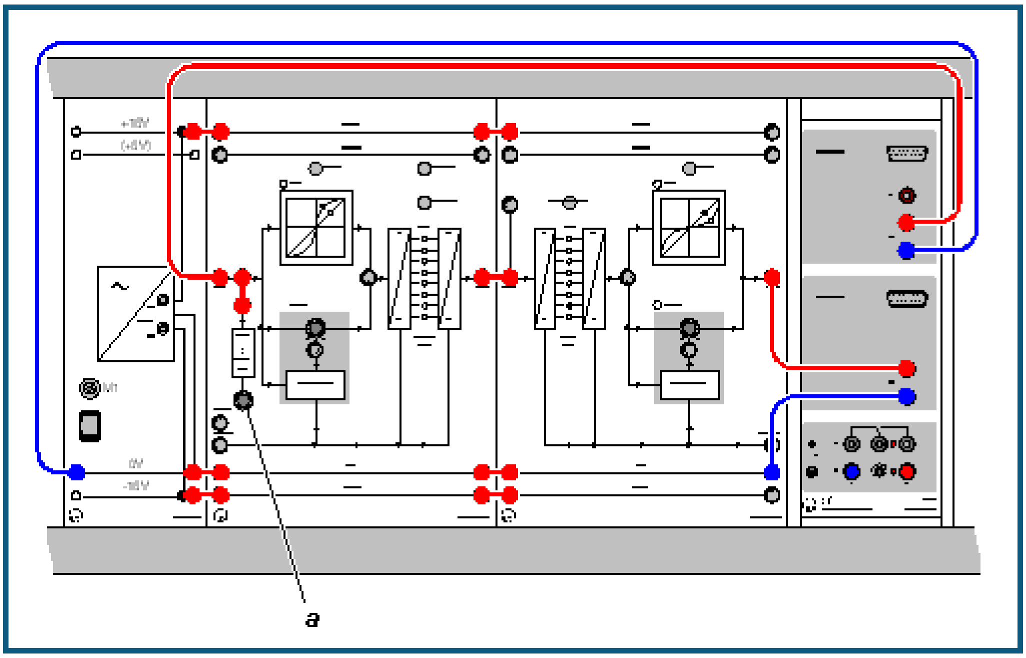
In the display all recorded messages are first shown as hexadecimal numbers. If there are more than two messages in the system which are repeated cyclically, the display shows these messages one after another. From the left to the right the following components are displayed:

- Identifier
- Data length code
- Data blocks
- Checksum
- Status of the acknowledgement

The displays are separated from one another by a blank character. In Settings CANA1 two different binary modes can also be selected:

- Raw data, i.e. all stuff bits are contained
- Binary data, i.e. all stuff bits are filtered out

## Pulse code modulation (quantization)



### Experiment description

The conversion of an analog signal into a digital signal requires 3 steps:

- Scanning
- Quantization
- Coding

Quantization will now be investigated experimentally. Switching on/off individual bits enables the resolution of the quantization to be reduced and the process to be represented graphically in an impressive manner. In addition, the expander and compressor characteristics are recorded during companding.

### Equipment list

| | | |
|---|---|---|
| 1 | Sensor-CASSY | 524 010 or 524 013 |
| 1 | CASSY Lab 2 | 524 220 |
| 1 | PCM modulator | 736 101 |
| 1 | PCM demodulator | 736 111 |
| 1 | DC power supply ±15 V, 3 A | 726 86 |
| 1 | Set of 10 bridging plugs | 501 511 |
| 2 | Pairs of cables, red and blue, 100 cm | 501 46 |
| 1 | PC with Windows XP/Vista/7 | |

### Experiment setup (see drawing)

Prepare the experiment setup and the cabling as indicated above and switch the power supply on. Please pay particular attention to the following points:

- Switch bits off coming from the LSB (key buttons SELECT and ON / OFF, see below).
- Turn the potentiometer *a* only slowly.
- In the range of small input voltages (< –10 V), overdriving the A/D converter can lead to a signal jump 0 V → –9.5 V. That is not critical, you may start the measurement at approx. –9.5 V.
- Theoretical and experimental aspects relating to this subject are discussed comprehensively in the manual (see T7.2.2.1 Pulse code modulation 564 001, page 52).

### Carrying out the experiment

☐ Load settings

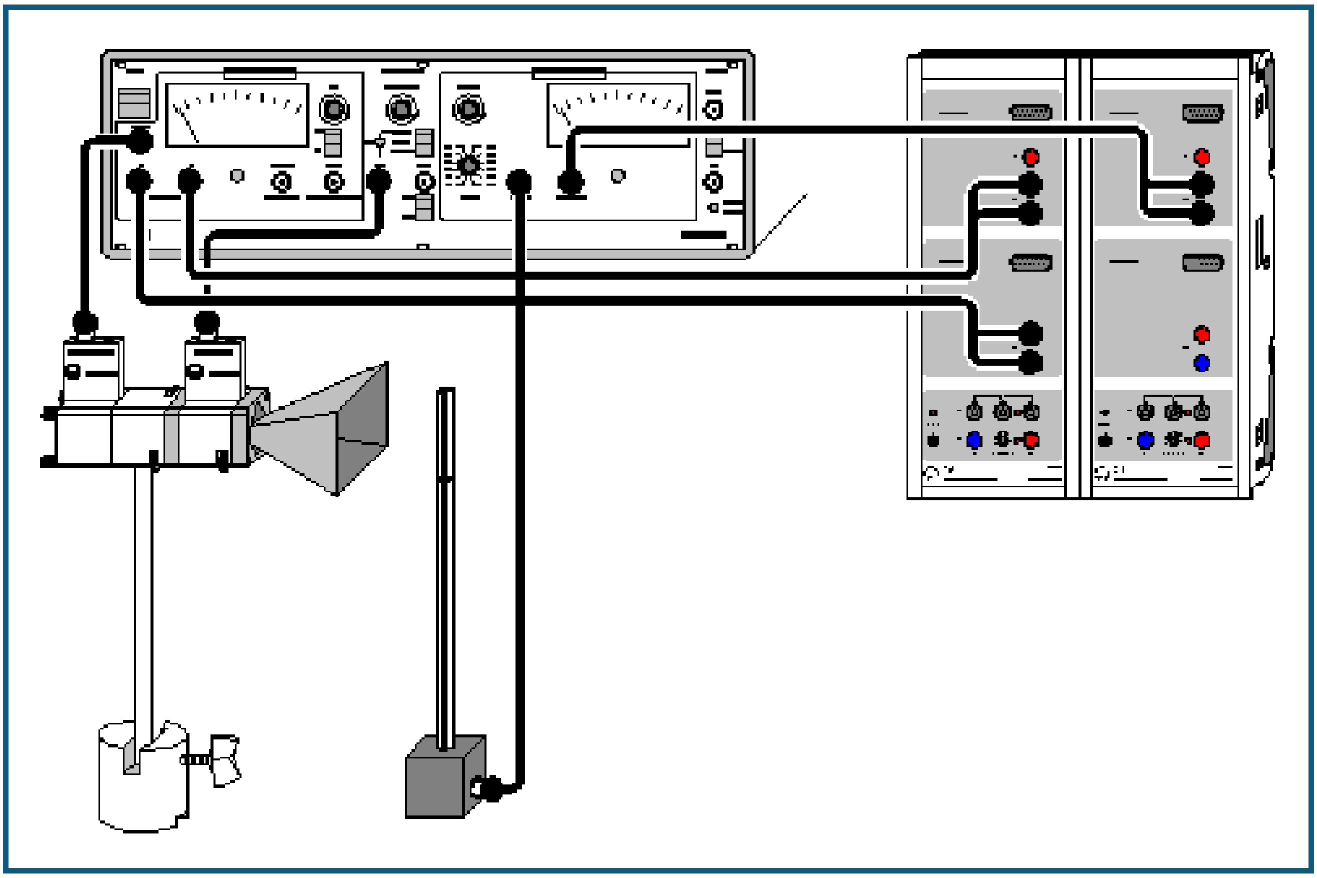
- Turn the potentiometer all the way round to the left.
- Start the measurement with ⏱.

- Turn the potentiometer *a* to the right. Now there is a voltage at the input of the PCM modulator (736 101), which increases slowly from –10 V up to +10 V. This input voltage is displayed as the voltage $U_{A1}$. The output voltage (after quantization) at the PCM demodulator (736 111) is displayed as the voltage $U_{B1}$.
- After recording the quantization characteristic, stop the measurement with ⏱.

## Variations

- Reduction of the resolution from 8 to 5 bits.
  Deactivate the 3 **l**east **s**ignificant **b**its (LSB) of the PCM modulator by pressing SELECT and ON/OFF. The position of the desired bit is reached by pressing SELECT repeatedly. ON/OFF changes between active/inactive. Turn the potentiometer *a* back to the left (minimum input voltage: approx. –10 V) and record the quantization characteristic again. The 32 steps of **equal height** resulting from the 5 bits are clearly seen.
- Non-linear quantization
  Press the MODE key buttons of the PCM modulator and of the PCM demodulator **once** each. Now both devices work in the non-linear quantization mode (in each case each indicated by an LED in the 13 segment characteristics). Then record the characteristic again.
- Compressor/expander characteristic
  For recording the compressor/expander characteristic, only one of the two devices is operated in the non-linear mode, whereas the other one works in the linear mode.

## Physical principles of microwave technology (characteristics of the Gunn oscillator)



### Experiment description

Gunn oscillators consist of a cavity resonator (= closed metallic cavity) and a Gunn element. The current-voltage characteristic $I_G=f(U_G)$ of the Gunn element exhibits a region with a negative slope. Only in this region of the characteristic does the Gunn element reduce damping and can balance the losses in the resonator so that a lasting oscillation and thus usable microwave power is generated. In this experiment, the Gunn current $I_G$ and the microwave power $P_M$ are displayed as functions of the DC voltage $U_G$ of the Gunn element.

### Equipment list

| | | |
|---|---|---|
| 1 | Sensor-CASSY | 524 010 or 524 013 |
| 1 | CASSY Lab 2 | 524 220 |
| 1 | Gunn oscillator | 737 01 |
| 1 | Gunn power supply with SWR meter | 737 021 |
| 1 | PIN modulator | 737 05 |
| 1 | Isolator | 737 06 |
| 1 | Support for waveguide components | 737 15 |
| 1 | Large horn antenna | 737 21 |
| 1 | E-field probe | 737 35 |
| 1 | Saddle base | 300 11 |
| 3 | HF cables, 1 m | 501 02 |
| 3 | Screened cables BNC/4 mm | 575 24 |
| 1 | Book: Physical Principles of Microwave Technology | 568 722 |
| 1 | PC with Windows XP/Vista/7 | |

### Experiment setup (see drawing)

Prepare the experiment setup and the cabling as indicated above and switch the Gunn power supply on. Please pay particular attention to the following points:

- Connections between the power supply and the Gunn oscillator and between the PIN modulator and the E-field probe with BNC cables male/male.
- Connections between the power supply (AMP OUT and RECORDER X,Y, respectively) and the Sensor-CASSY with screened cables BNC/4 mm.
- Power supply, MODULATION: select PIN INT.
- Select a suitable gain at the SWR meter (v/dB and ZERO).
- Theoretical and experimental aspects relating to this subject are discussed comprehensively in the manual (see pages 11ff).

### Remark

The illustration shows an experiment setup with a cascade arrangement of 2 Sensor-CASSYs. With this arrangement the characteristics $I_G$=f($U_G$) and $P_M$=f($U_G$) are recorded simultaneously. The second characteristic represents the microwave power of the Gunn oscillator as a function of the DC voltage $U_G$ of the Gunn element.

If only one Sensor-CASSY is available, the experiment is carried out in two steps.

### Carrying out the experiment with 2 Sensor-CASSYs

■ Load settings

- Turn the potentiometer $U_G$ all the way round to the left ($U_G$ = 0 V).
- Start the measurement with ⏱.
- Turn the potentiometer $U_G$ to the right. The Gunn voltage, the Gunn current and the microwave power are displayed on dedicated display instruments.
- After recording the two characteristics $I_G$=f($U_G$) and $P_M$=f($U_G$), stop the measurement with ⏱.

### Carrying out the experiment with 1 Sensor-CASSY

■ Load settings

- Turn the potentiometer $U_G$ all the way round to the left ($U_G$ = 0 V).
- Start the measurement with ⏱.
- Turn the potentiometer $U_G$ to the right. The Gunn voltage and the Gunn current are displayed on dedicated display instruments.
- After recording the characteristic $I_G$=f($U_G$), stop the measurement with ⏱.

The second characteristic $P_M$=f($U_G$) is recorded subsequently with the same Sensor-CASSY and the same settings. Therefore the relative microwave power is displayed in the Gunn current display instrument. For this:

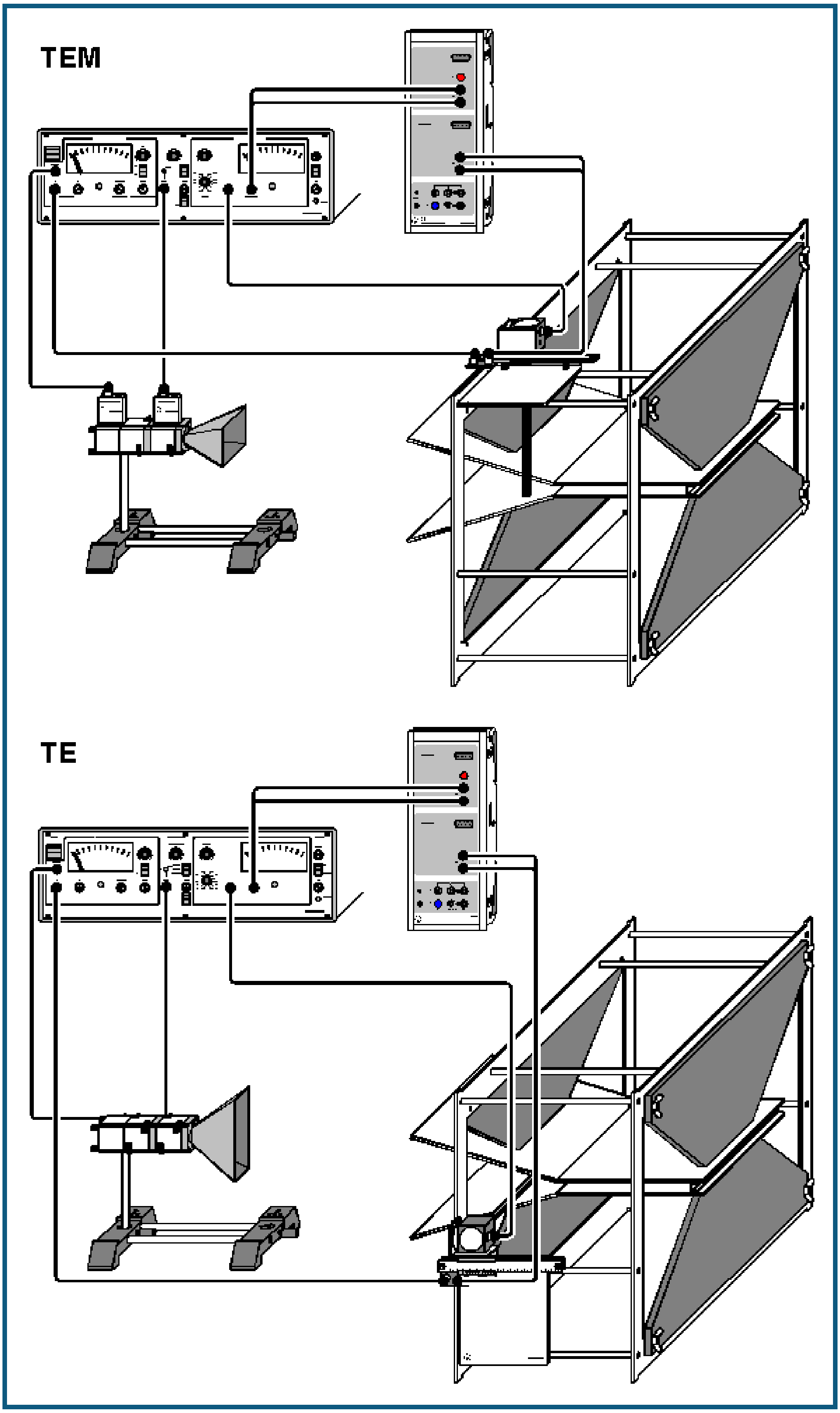
- Disconnect the Sensor-CASSY from the Gunn power supply (RECORDER Y) and change to AMP OUT.
- Select a suitable gain at the SWR meter (v/dB and ZERO).
- Record the characteristic again.

### Remarks

Characteristics of active elements in microwave experiments exhibit wide scattering. Therefore the characteristics shown in the examples should only be considered as examples. The important thing is the connection between the falling region of the current-voltage characteristic and the generation of microwave power. The absolute values or the shape of the curves can vary considerably, depending on the Gunn element used.

The measurement of the microwave power $P_M$ is made with an uncalibrated detector. Therefore its numerical value is arbitrary.

## Two-plate waveguide (TEM and TE modes)



## Experiment description

TEM or TE waves can be excited on the parallel plate line by rotating the direction of polarization of the exciting microwave field (pay attention to this in the experiment!). TE waves exhibit a cut-off phenomenon, i.e. for a given frequency of the exciting field, TE waves can only propagate if the plate distance exceeds a certain minimum value. In the case of an excitation with a variable frequency and a fixed plate distance, TE waves cannot propagate if the frequency is below the so-called cut-off frequency. As microwave experiments in free space are only permitted at certain, fixed frequencies, this experiment is carried out with a variable plate distance.

## Equipment list

| | | |
|---|---|---|
| 1 | Sensor-CASSY | 524 010 or 524 013 |
| 1 | CASSY Lab 2 | 524 220 |
| 1 | Gunn oscillator | 737 01 |
| 1 | Gunn power supply with SWR meter | 737 021 |
| 1 | PIN modulator | 737 05 |
| 1 | Isolator | 737 06 |
| 1 | Two-plate waveguide | 737 07 |
| 1 | Measuring carriage for parallel plate line | 737 071 |
| 1 | Support for waveguide components | 737 15 |
| 1 | Large horn antenna | 737 21 |
| 1 | E-field probe | 737 35 |
| 2 | HF cables, 1 m | 501 02 |
| 2 | HF cables, 2 m | 501 022 |
| 2 | Screened cables BNC/4 mm | 575 24 |
| 2 | Stand bases MF | 301 21 |
| 1 | Book: Parallel Plate Line | 568 661 |
| 1 | PC with Windows XP/Vista/7 | |

## Experiment setup TEM or TE (see drawing TEM or TE)

Prepare the experiment setup and the cabling as indicated above and switch the Gunn power supply on. Please pay particular attention to the following points:

- Connections form the power supply to the Gunn oscillator, to the PIN modulator and to the measuring carriage for parallel plate line (input IN 8-24 V) with BNC cables male/male.
- Connections from the power supply (AMP OUT) and from the measuring carriage for parallel plate line (output X) to the Sensor-CASSY with screened cables BNC/4 mm.
- Set the Gunn voltage to $U_G$ = 10 V at the power supply.
- Power supply, MODULATION: select PIN INT.
- Place the measuring carriage for parallel plate line on the props of the parallel plate line such that the E-field probe just reaches into the parallel part of the two-plate waveguide when it is at the left stop.
- The E-field probe should always be in mechanical contact with the edge of the plate when it is moved because this helps to avoid variations in position.
- One after another terminate the two-plate waveguides with the termination profiles 13 mm and 22 mm.
- For additional notes see the instruction sheets 737 07 and 737 071.
- Theoretical and experimental aspects relating to this subject are discussed comprehensively in the manual (see page 27).

## Carrying out the experiment

☐ Load settings
- Slide the calliper gauge of the measuring carriage (737 071) to the right (x = 75 mm).
- Use the mouse to take the numerical value of the displayed voltage $U_{B1}$ into the display instrument voltage $U_{75}$ (drag & drop, right calibration point for position measurement).
- Slide the calliper gauge of the measuring carriage (737 071) to the left (x = 25 mm).
- Use the mouse to take the numerical value of the displayed voltage $U_{B1}$ into the display instrument voltage $U_{25}$ (drag & drop, left calibration point for position measurement).
- Slide the calliper gauge to the left (x = 0 mm).
- Start the measurement with ⏱.
- Slowly move the calliper gauge to the right.
- You may readjust the gain v/dB and / or ZERO until the desired measuring signal arises. Keep the settings for the subsequent experiments!
- After recording the field as a function of the displacement, stop the measurement with ⏱.

### Evaluation wavelength

Using the Free Fit and the formula describing the dependence of the electric field E on x,

A*sqr(cos(360/B*x+D)^2+1/C^2*sin(360/B*x+D)^2)

or, in technical notation,

$$A \cdot \sqrt{\cos^2\left(\frac{2\pi}{\lambda_g} \cdot x + \varphi\right) + \frac{1}{SWR^2} \sin^2\left(\frac{2\pi}{\lambda_g} \cdot x + \varphi\right)}$$

with

A: amplitude of the electric field strength
ı$_g$: waveguide wavelength
SWR: standing wave ratio
θ: phase shift

the wavelength ı$_g$=B on the parallel plate line and the standing wave ratio SWR=C can be calculated directly from the measuring results (see also experiment Measurement of the standing wave ratio).

The initial values, in particular for the wavelength ı$_g$=B and the standing wave ratio SWR=C, have to be chosen sensibly because otherwise the free fit will not find any result or it will not find the best result. A fitted curve can be discarded by a double click on the curve. Then the fit can be repeated with other initial values.

The initial values entered should be ı$_g$=B=32 mm (free-space wavelength) for TEM modes, ı$_g$=B=45 mm (waveguide wavelength) for TE modes, and SWR=C=10 for the standing wave ratio.

### Evaluation cut-off

If the plate distance is too small in the TE arrangement with 13 mm, TE modes can not be excited any more (cut-off). The exponential shape of the field can be approximated with a free fit and the formula:

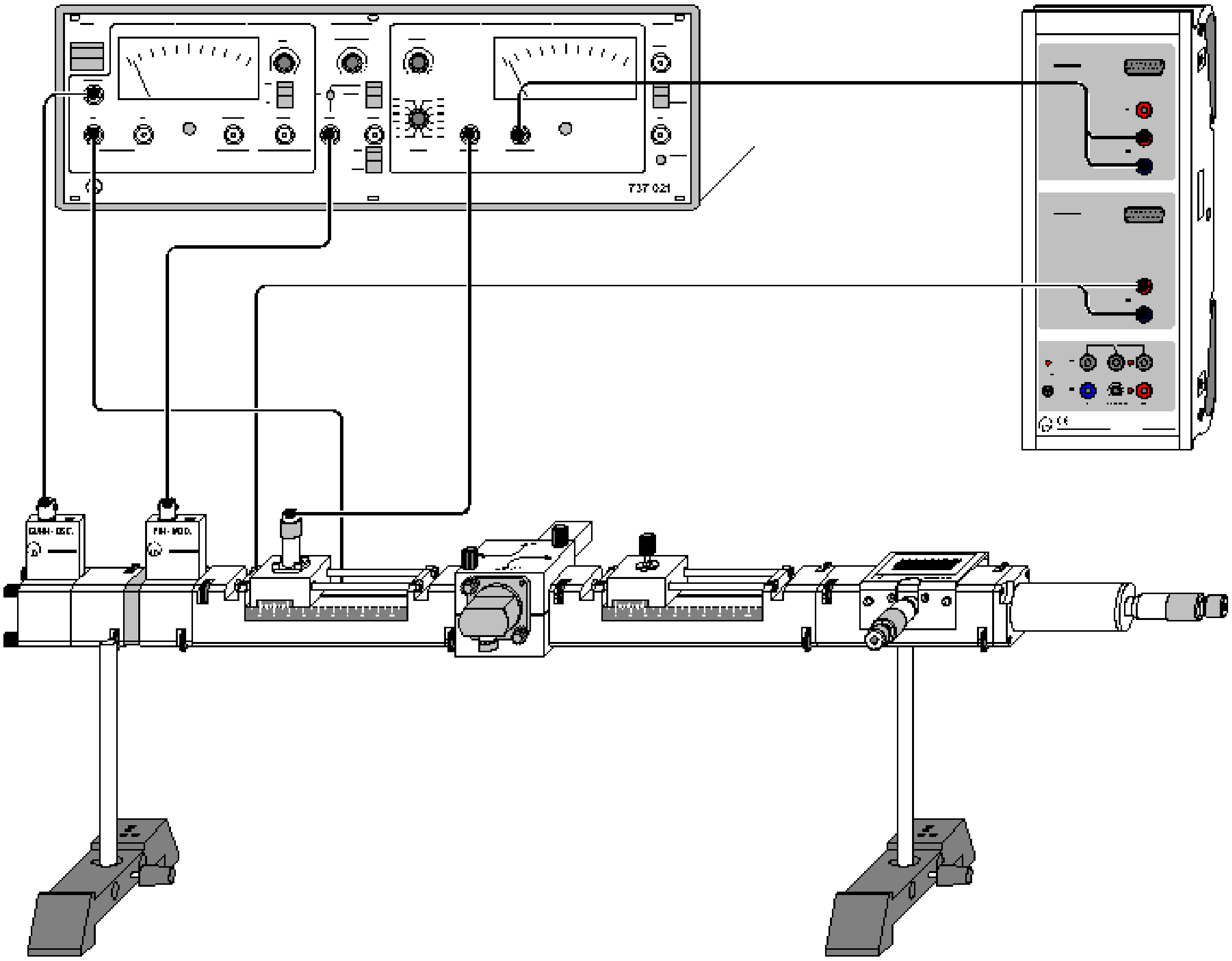
A*exp(-x/B)+C

Enter approximately 10 mm as initial value for B.

### Remark

The measured voltage $U_{A1}$ is proportional to the microwave power. Under the assumption that the characteristic of the coax detector is quadratic, this voltage can be converted into the electric field strength E ∝ sqr $U_{A1}$. As the detector characteristic is not calibrated, the numerical value of E is arbitrary.

## Microwave propagation in waveguides (measurement of the standing wave ratio)



### Experiment description

The standing wave ratio (SWR) is a scalar measure of the match. In experiments with microwaves, it determines the power transfer from the source to the load and the magnitude of the field strength in the components of the circuit. Therefore an SWR of approximately 1 is desired in most cases. In this experiment, the standing wave ratios of various waveguide terminations are compared. A variable attenuator (alters the magnitude of reflections) and an adjustable movable short (alters the phase of reflections) in series connection are used as a complex microwave load. For the case of an average standing wave ratio (SWR approximately 3), the match is improved by means of a slide screw transformer.

### Equipment list

| | | |
|---|---|---|
| 1 | Sensor-CASSY | 524 010 or 524 013 |
| 1 | CASSY Lab 2 | 524 220 |
| 1 | Gunn oscillator | 737 01 |
| 1 | Coax detector | 737 03 |
| 1 | Transition waveguide / coax | 737 035 |
| 1 | Gunn power supply with SWR meter | 737 021 |
| 1 | PIN modulator | 737 05 |
| 1 | Isolator | 737 06 |
| 1 | Variable attenuator | 737 09 |
| 1 | Movable short | 737 10 |
| 1 | Slotted measuring line | 737 111 |
| 1 | Slide screw transformer | 737 13 |
| 1 | Waveguide terminaton | 737 14 |
| 1 | Cross coupler | 737 18 |

| | | |
|---|---|---|
| 2 | Supports for waveguide components | 737 15 |
| 4 | HF cable, 1 m | 501 02 |
| 2 | Screened cables BNC/4 mm | 575 24 |
| 2 | Stand bases MF | 301 21 |
| 1 | Book: Microwave Propagation in Waveguides | 568 731 |
| 1 | PC with Windows XP/Vista/7 | |

### Experiment setup (see drawing)

Prepare the experiment setup and the cabling as indicated above and switch the Gunn power supply on. Please pay particular attention to the following points:

- Connections from the power supply to the Gunn oscillator, the PIN modulator and the slotted measuring line (INPUT) with BNC cables male/male.
- Connections from the power supply (AMP OUT) and the slotted measuring line (output X) to the Sensor-CASSY with screened cables BNC/4 mm.
- Set the Gunn voltage to $U_G$ = 10 V at the power supply.
- Power supply, MODULATION: select PIN INT.
- Connect INPUT at the slotted measuring line to RECORDER X at the power supply.
- Mount the cross coupler with two cross-shaped holes. Port 1 to slotted measuring line. Port 2 to slide screw transformer. Port 3 to transition waveguide / coax. Port 4 to waveguide termination.
- Turn the screw of the slide screw transformer far out of the waveguide. Position of the movable short arbitrary.
- Theoretical and experimental aspects relating to this subject are discussed comprehensively in the manual (see page 27ff).

### Carrying out the experiment

■ Load settings

- Slide the calliper gauge of the slotted measuring line (737 111) to the right (x = 75 mm).
- Use the mouse to take the numerical value of the displayed voltage $U_{B1}$ into the display instrument voltage $U_{75}$ (drag & drop, right calibration point for position measurement).
- Slide the calliper gauge of the slotted measuring line (737 111) to the left (x = 25 mm).
- Use the mouse to take the numerical value of the displayed voltage $U_{B1}$ into the display instrument voltage $U_{25}$ (drag & drop, left calibration point for position measurement).
- Slide the calliper gauge to the left (x = 0 mm).
- Set the attenuator to 0 dB.
- Start the measurement with ⏱.
- Slowly move the calliper gauge to the right.
- You may readjust the gain v/dB and / or ZERO until the desired measuring signal arises. Keep the settings for the subsequent experiments!
- After recording the field as a function of the displacement, stop the measurement with ⏱.

### Evaluation

Using the Free Fit and the formula describing the dependence of the electric field E on x,

A*sqr(cos(360/B*x+D)^2+1/C^2*sin(360/B*x+D)^2)

or, in technical notation,

$$A\cdot\sqrt{\cos^2\left(\frac{2\pi}{\lambda_g}\cdot x+\varphi\right)+\frac{1}{SWR^2}\sin^2\left(\frac{2\pi}{\lambda_g}\cdot x+\varphi\right)}$$

with

A: amplitude of the electric field strength
ı$_g$: waveguide wavelength
SWR: standing wave ratio
θ: phase shift

the wavelength ı$_g$=B in the waveguide and the standing wave ratio SWR=C can be calculated directly from the measuring results.

The initial values, in particular for the wavelength ı$_g$=B and the standing wave ratio SWR=C, have to be chosen sensibly (in this case B=45 mm and C=10) because otherwise the free fit will not find any result or it will not find the best result. A fitted curve can be discarded by a double click on the curve. Then the fit can be repeated with other initial values.

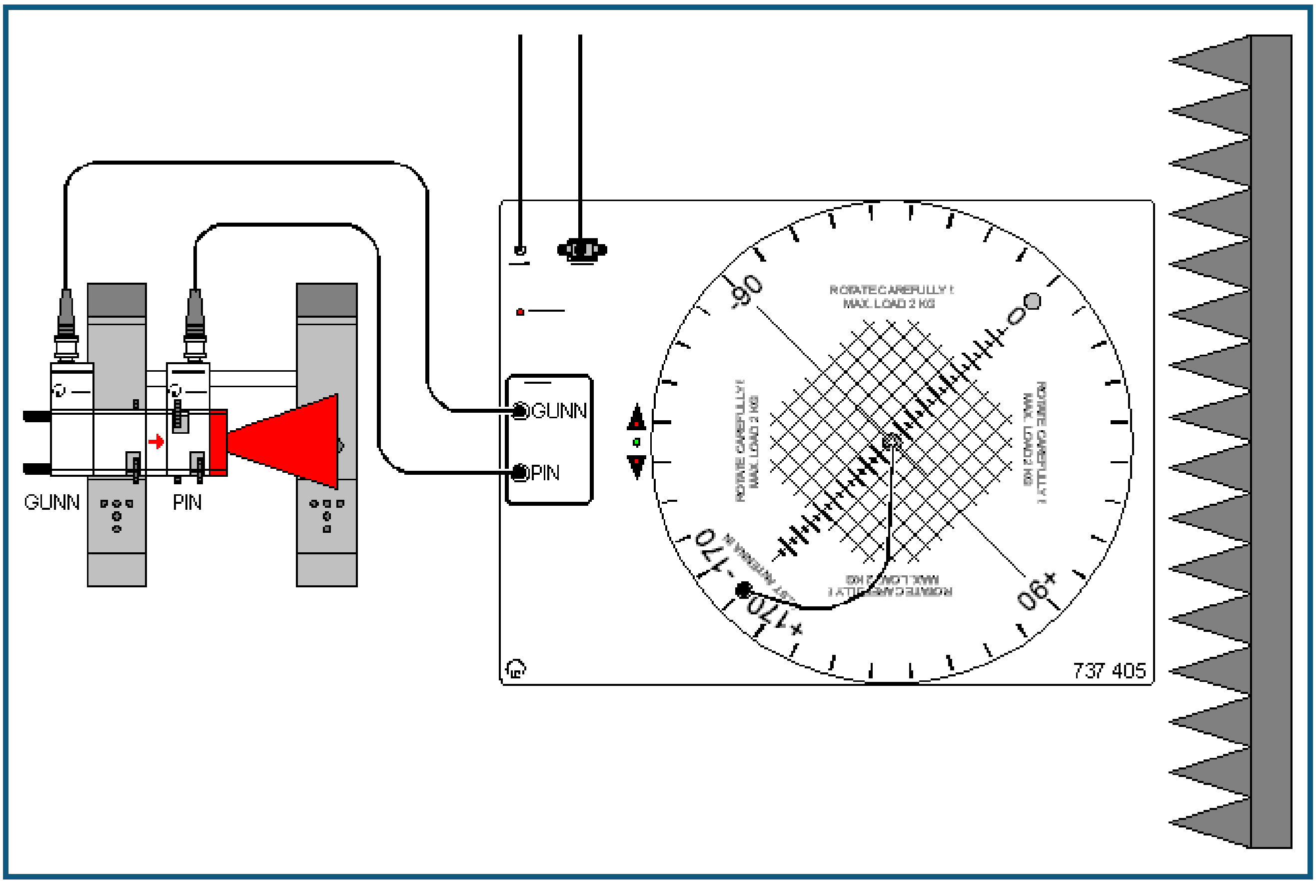
### Variations

- Recording the standing wave ratio for reduced reflection. The SWR is decreased by adjusting the attenuator (a > 0 dB).
- Improving the match with the aid of the slide screw transformer.
- Set a=3 dB at the attenuator. Now only 25 % of the incoming microwave power is reflected. The reflection coefficient is r=0.5 and the SWR is 3.
- Make a new measurement to verify what has changed.
- Screw the coax detector on the transition waveguide / coax. Now only the reflected signal is measured.
- Change the penetration depth and the position of the adjusting screw of the slide screw transformer, and reduce the reflected signal to its minimum.
- Screw the coax detector on the slotted measuring line again, and measure the SWR curve anew.

### Remark

The measured voltage $U_{A1}$ is proportional to the microwave power. Under the assumption that the characteristic of the coax detector is quadratic, this voltage can be converted into the electric field strength $E \propto \text{sqr}\ U_{A1}$. As the detector characteristic is not calibrated, the numerical value of E is arbitrary.

## Antenna technology



### Safety notes

Due to the low power of the Gunn oscillator (approx. 10 mW), there can be no danger to experimenters during antenna measurements. However, if stronger HF sources are used, the following rules should be kept to:

- Under no circumstances "look" directly "into" the transmitting antenna while it is radiating. This also applies to free ends of hollow conductors and horn antennas.
- When components of waveguides are exchanged during changes to the experimental setup, the supply voltage of the Gunn oscillator has to be switched off.

### Experiment description

Antennas serve to transmit or receive electromagnetic waves. For this they have to convert the conducted wave of the supply line into a free-space wave. Antennas therefore are transition structures, which connect the lines and free space to one another. The radiation characteristics of an antenna are of particular interest. They can vary considerably, depending on their use in broadcasting, microwave transmission or radar. A widespread type of antennas is given e.g. by antennas with a strong directivity.

Here the use of the antenna measuring station T 7.6.1 in conjunction with the rotating antenna platform (737 405) is explained. A ı /2 dipole antenna serves as an example of how to record a directional diagram. Readers who are interested in measurements with other test antennas (sets T 7.6.2 to T 7.6.5) are referred to the experiment manual T 7.6 Antenna Technology (568 701). Additional remarks are obtained from the instruction sheet 737 405.

### Equipment list

| | | |
|---|---|---|
| 1 | Rotating antenna platform | 737 405 |
| 1 | Gunn oscillator | 737 01 |
| 1 | Isolator (recommendable) | 737 06 |
| 1 | PIN modulator (recommendable) | 737 05 |
| 1 | Large horn antenna | 737 21 |
| 2 | Stand bases MF | 301 21 |
| 1 | Set of absorbers | 737 390 |
| 1 | Dipole antenna kit | 737 411 |

1 PC with Windows XP/Vista/7

### Experiment setup (see drawing)

Set up the experiment as shown in the drawing. Use the 345 mm stand rods supplied with the rotating antenna platform for setting up the transmitter (microwave components). For further remarks see instruction sheet 737 405. As a rule, the distance $r_0$ between the transmitting and the test antenna should fulfil the far-field condition. For dipole antennas this is fulfilled for $r_0$ > 100 cm in most cases. The Far-field computer to be found in the Settings A determines the minimum distance $r_0$ for the transition to the far field after $D_T$ has been entered.

Insert the test antenna (ı /2 dipole) in the central mounting for plug-in axles in the rotating antenna platform so that the axis is aligned with the reference lines on the rotary plate. Connect the BNC output socket of the test antenna to the BNC socket TEST ANTENNA IN in the rotary plate via a coaxial cable. Align the antenna so that its main-beam direction is in the 0° position. Switch the rotating antenna platform on by connecting the plug-in unit. The rotary plate moves to the starting position -180°.

### Carrying out the experiment

■ Load settings
- In the Settings Angle A enter the interface at which the rotating antenna platform is connected to the computer.
- If necessary, change the settings of the rotating antenna platform in Settings A. If the dipole antenna is used, the bias current has to be switched on. If no PIN modulator is available, you have to switch over to Gunn modulation.
- Start the measurement with ⏱. After a short break, the rotary plate starts to run in the forward direction, whereby the actual measurement of the directional diagram takes place. Immediately after reaching the set final angle, the rotary plate begins to return to its starting position.
- Normalize A(ϑ) with **Normalize Level** in Settings A so that it is 1 in the maximum.

### Evaluation

The measurement example shows the horizontal directional diagram of a ı /2 dipole. In Settings A the maximum of the measured curve was rotated to 0°. The black curve represents the measured curve whereas the theoretical directional diagram is given by the red curve. The theoretical curve was obtained by means of a Free fit (see below).

### Notes

- The axis of symmetry of the test antenna and the centre of the rotary plate have to be in line. If the antenna has been inserted in the central mounting of the rotary plate, this is in general fulfilled. However, there are test antennas which are mounted by means of stand material. In this case, the antenna has to be aligned carefully over the centre of the rotary plate in order that during rotation no eccentric motion occurs (which would lead to asymmetries in the directional diagrams).
- If the main lobe of the test antenna is to be located at 0° in the directional diagram, the test antenna has to be aligned so that its main-beam direction points into the 0° direction. Furthermore it has to be aligned with the transmitting antenna. That means its "back" "looks over" to the exiting source antenna. The reason for this lies in the nature of the process: the main-beam direction is thus measured in one run instead of being divided into two halves. Environmental influences on the system thus have less effect on the important region of the main lobe.
- Depending on the test antenna, the measurement can be made at various degrees of angular resolution. In principle complicated antennas with many or narrow lobes have to be measured at high resolution.
- The measurement process can be observed simultaneously on the measuring instruments (e. g for the angle, voltage and level), which can be inserted/hidden, and in the graphical display. In the graphical display, the directional diagram is constructed step by step (Cartesian co-ordinates or polar diagram with freely selectable axes). Scaling can be shifted with the left mouse button and it can be changed with the right mouse button.
- The actual antenna signal A from the detector cannot be measured directly. Only the voltage drop U generated by detector current at the measuring amplifier is measurable. In general, U is not proportional to A but

  $$U \propto A^m$$

  The exponent m describes the detector characteristic. If the antenna signal A(ϑ) is normalized with **Normalize Level** in Settings A so that it is 1 in the maximum, we have:

  $$A = \left(\frac{U}{U_{\max}}\right)^{\frac{1}{m}}$$

  $$a = 20 \cdot \log A$$

  where $U_{\max}$ is the maximum voltage U measured.

  The exponent m depends on the power of the incoming microwaves. In the low-power range it is m=2, i.e.

  $$U \propto A^2$$

  Experience has shown that the assumed quadratic behavior only applies at very low microwave powers or received voltages U < 5 mV. However, the antenna measurement system makes it possible to enter other detector characteristics. Strictly speaking, the selected characteristic has to be checked. For this a variable attenuator (737 09) is required which enables the antenna signal in front of the detector to be attenuated in a well-defined way.

### Formulas in directional diagrams

Measuring results can be compared with theoretical directional diagrams if a suitable formula is available or can be derived. Formulas can be used in various ways:

- The formula can be defined as a new quantity. Then all parameters of the Formula have to be entered explicitly.
- The formula can be entered for carrying out a Free fit. In this case, up to 4 parameters of the formula are varied automatically so that the best agreement between the measuring results and the formula is obtained. The method is very elegant in the case of antenna measurements and shall be explained briefly in the following paragraphs.

### Free fit for directional diagrams

After the measurement with the rotating antenna platform has been carried out, the following steps are required for performing a Free fit:

- Select Free fit (click Fit Function → Free Fit in the diagram with the right mouse button)
- Enter the formula in the input field, select it from the list, or copy it via the clipboard (via copy and paste, e.g. the examples below) having marked just the formula.
- Having estimated sensible starting values for A, B, C and D (see examples below), enter them.
- Select **Mark range**, and mark the entire measuring curve with the left mouse button. Then the fit is performed, and the best approximation of the formula found during the fitting procedure is displayed.
- Note: It is easier to mark ranges in the cartesian diagram. The coordinate system can be changed in Settings Display.

### Examples

Remark: the formulas given in the following examples can simply be marked with the cursor and copied into the input field.

### 1 Technical dipoles

$$A\cdot\left|\frac{\cos\left(\frac{\pi\cdot l_{\mathrm{el}}}{\lambda_0}\right)\cdot\sin(\vartheta+\vartheta_0)-\cos\left(\frac{\pi\cdot l_{\mathrm{el}}}{\lambda_0}\right)}{\cos(\vartheta+\vartheta_0)}\right|$$

The formula describes the dependence of the directional diagram on the polar angle in the case of a dipole antenna for which a sinusoidal distribution of the currents on the antenna conductors has been assumed. Distortions due to current displacement, which is down to a low reduction factor (finite thickness of the antenna conductors), are not taken into account.

$\vartheta$: polar angle

$\vartheta_0$: angular misalignment

$l_{el}$: electric length of the dipole (shortening not taken into account)

ı $_0$: wavelength in free space

### Formula to copy

**A*abs((cos(180*B/32*sin(x+D))-cos(180*B/32))/cos(x+D))**

x: polar angle $\vartheta$
32: wavelength in free space in mm (ı $_0$ = 32 mm for 9.40 GHz).

From the measured values, the program obtains optimum values for:

A: amplitude fit
B: electric length $l_{el}$
D: angular misalignment $\vartheta_0$ (deviation of the antenna from the direction of reference)

### Starting values for the parameters A, B and D

| Antenna | A | B/mm | D/deg |
|---|---|---|---|
| ı /2 dipole | 1 | 16 | 0 |
| ı dipole | 1 | 32 | 0 |

| | | | |
|---|---|---|---|
| 3ı /2 dipole | 1 | 48 | 0 |
| 2ı dipole | 1 | 64 | 0 |
| 4ı dipole | 1 | 128 | 0 |

## 2 Yagi antennas

### 2.1 Yagis with one parasitic element

- Yagi-R: dipole and 1 reflector
- Yagi-D: dipole and 1 director

Both cases are approximately described by the directional diagram of a conducting sheet (reflector):

$$A \cdot \left|\cos(\vartheta + \vartheta_0)\right| \cdot \left|\cos\left(\frac{\pi}{2} + \frac{\pi \cdot a}{\lambda_0} \cdot \cos(\vartheta + \vartheta_0)\right)\right|$$

A: amplitude fit
a: distance between the dipole and the reflector
$\vartheta$: polar angle
ı $_0$: wavelength in free space

### Formula to copy

**A*abs(cos(x+B))*abs(cos(C+D*cos(x+B)))**

x: polar angle $\vartheta$

The factor **A*cos(x+B)** corresponds to the directional diagram of a Hertz dipole. This ideal transmitting antenna is so short as compared with the wavelength that the current distribution on it can be assumed to be constant. The factor **abs(cos(C+D*cos(x+B)))** describes the effect of the parasitic element (reflector or director).

### Starting values

A=1 amplitude fit
B=0 angular misalignment $\vartheta_0$, deviation of the antenna from the direction of reference
C=90 phase
D=60 factor depending on the construction, takes into account the ratio a/ı $_0$

### 2.2 Yagis with several parasitic elements

These cases are approximately described by the directional diagram of a single dipole and so-called array factors (here: horizontal array factor):

$$A \cdot \left|\cos(\vartheta)\right| \cdot \left|\frac{\cos\left(n \cdot \left(\frac{\beta_0}{2} + \frac{\pi \cdot a}{\lambda_0} \cdot \cos\vartheta\right)\right)}{\cos\left(\frac{\beta_0}{2} + \frac{\pi \cdot a}{\lambda_0} \cdot \cos\vartheta\right)}\right|$$

A: amplitude fit
n: number of Yagi elements, including the dipole
a: average distance between the parasitic elements (directors, reflector)
$\beta_0$: phase angle
$\vartheta$: polar angle
ı $_0$: wavelength in free space

### Formula to copy

**A*abs(cos(x))*abs(cos(B*(C+D*cos(x)))/cos(C+D*cos(x)))**

x: polar angle

### Starting values

A=0.4 amplitude fit
B=3 (6) number n of transmitting elements, including dipole (select **constant**)
C=-60 (-20) phase angle $\beta_0$
D=50 (36) factor depending on the construction, takes into account the ratio a/ı $_0$

### 3 Slot antenna

The horizontal directional diagram of a slot antenna contains the factors D*H*R:

D: directional diagram of the individual transmitting element
H: horizontal array factor
R: reflector factor

$$A\cdot\left|\sin(\vartheta+\vartheta_0)\right|\cdot\left|\frac{\sin\left(\frac{n\cdot\pi\cdot b}{\lambda_0}\cdot\cos(\vartheta+\vartheta_0)\right)}{\sin\left(\frac{\pi\cdot b}{\lambda_0}\cdot\cos(\vartheta+\vartheta_0)\right)}\right|\cdot\left|2\cdot\cos\left(\frac{\pi}{4}\cdot\left(-1+\sin(\vartheta+\vartheta_0)\right)\right)\right|$$

A: amplitude fit
n: number of transmitting slots
b: distance between slots (half waveguide wavelength ı $_G$/2)
$\vartheta$: polar angle
$\vartheta_0$: angular misalignment
ı $_0$: wavelength in free space

### Formula to copy

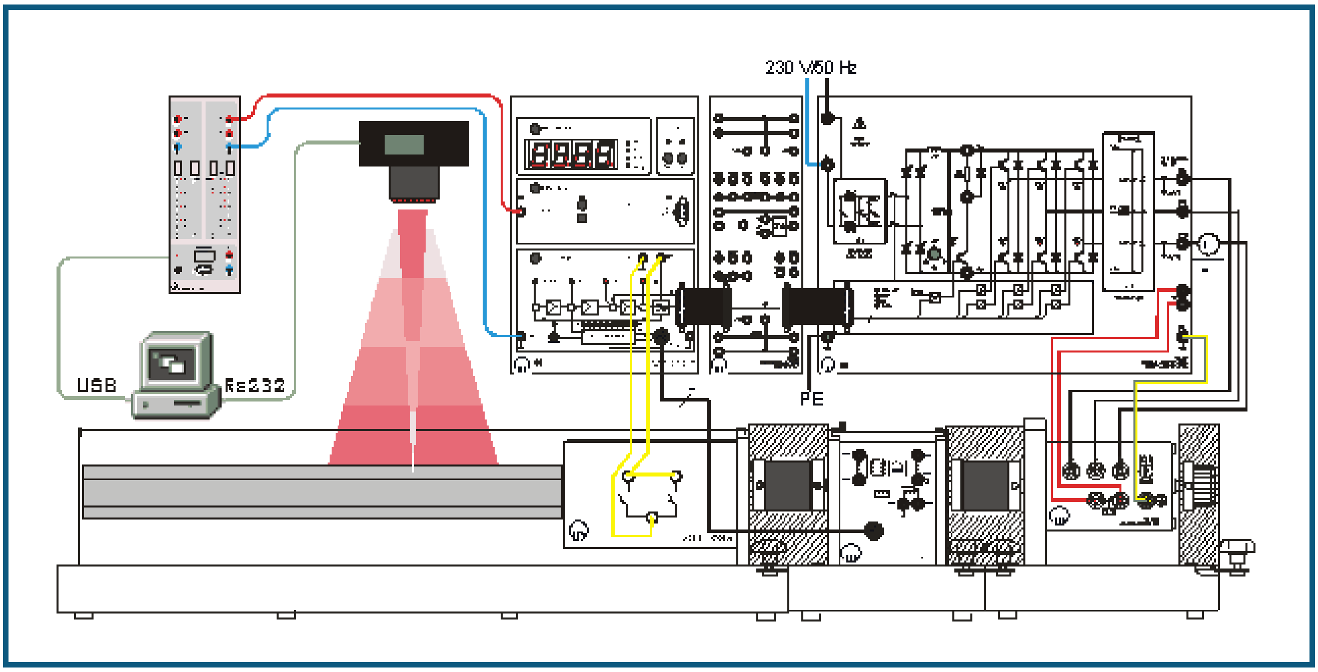
**A*abs(sin(x+B))*abs((sin(D*180*C/32*cos(x+B))/sin(180*C/32*cos(x+B)))*cos(45*(-1+sin(x+B))))**

x: polar angle $\vartheta$

### Starting values

A=1 amplitude fit
B=0 angle fit $\vartheta_0$
C=23 distance b between slots
D=7 number n of slots (select **constant**)

## Drive engineering



### Safety notes

Be sure to get familiar with the devices and the respective instruction sheets before putting the devices into operation!

Mind the connection between the position switches of the linear unit and the control unit sine commutation!

### Experiment description

Servo drives are frequently used for positioning purposes. In this experiment a AC servo with sine commutation drives a linear unit which moves the workpiece to be positioned. In the process of position control with "direct positioning", the VideoCom camera, which uses a single-line CCD (Charge-Coupled Device), registers the controlled variable "position". The software logs the controlled variable and calculates the manipulated variable "voltage" for the AC servo based on the reference input variable specified in the PC.

For recording the movement, a strip of retroreflecting film is attached to the simulated workpiece. VideoCom detects the light pulses of the flash LEDs reflected by the film and pinpoints the actual positions of the body. By repeating this position detection in regular intervals, a high-resolution, contact-free record of the movement is obtained.

### Equipment list

| | | |
|---|---|---|
| 1 | Profi-CASSY | 524 016 |
| 1 | CASSY Lab 2 | 524 220 |
| 1 | VideoCom | 337 47 |
| 1 | Universal converter 3x230 V | 735 297 |
| 1 | Control unit sine commutation | 735 293 |
| 1 | AC servo 0.3 | 731 994 |
| 1 | Resolver | 731 094 |
| 1 | Linear unit 0.1/0.3 | 731 085 |
| 2 | Coupling guards | 731 081 |
| 1 | Shaft end guard | 731 071 |
| 2 | Couplings 0.1/0.3 | 731 06 |
| 1 | Camera tripod, e.g. | 300 59 |
| | various safety connecting leads | |
| 1 | PC with Windows XP/Vista/7 | |

For connecting the universal converter to the mains, a single-phase supply unit (e.g. 726 71) is recommendable.

## Experiment setup

Set up the experiment according to the drawing. Connect the Profi-CASSY to a USB port and the VideoCom to a serial RS232 port of the PC. Do **NOT** yet couple the linear unit to the drive line! Couple the AC servo and the resolver as described in the instruction sheet, and put the system into operation. Turn the slide of the linear unit approximately into the centre. Attach the camera to a stand at a height of approximately 1 m over the centre of the linear unit. Switch the control unit sine commutation into the mode "Closed-loop Speed Control".

## Carrying out the experiment

■ Load settings
- In the settings Position s enter the interface at which the VideoCom is connected to the computer.
- If no value is displayed in the window for the controlled variable path s, adjust the camera so that the position is displayed.
- Set the reference input variable w to a value of 0.5 m.
- Start the measurement with ⏱. The motor starts up. Turn the positioning unit manually until the motor stops.
- Now couple the positioning unit and the drive line together. By changing the reference input variable w you can specify positions, which then are approached.
- Now you can change the control parameters $K_p$ and $T_n$ and observe the effect of these changes on the control. in the same way you can set the limits for the speed and the current at the control unit sine commutation (see instruction sheet).

# Appendix

## Scintillation counter

With a scintillation counter (559 901) the energy of γ radiation can be determined. By interaction with the scintillation crystal the radiation gives rise to light flashes, which are converted into a voltage pulse by a photomultiplier. The number of emitted photons, and therefore the pulse height is proportional to the γ energy. The pulse-height analysis in made with a multichannel analyzer (MCA), e.g. with the MCA box in conjunction with the Sensor-CASSY.

The energy of α radiation can be determined with a semiconductor detector.

### NaI(Tl) scintillators

A common material for the construction of scintillation counters is NaI(Tl). Doping with thallium (Tl) generates luminescent centres. The iodine content (Z=53) leads to a very high detection probability for γ radiation. Detection of γ quanta emitted from a source takes place via energy transfer to electrons of NaI, which are slowed down in the scintillation crystal. Thereby pairs of populated states in the conduction band and unpopulated states in the valence band are released. The number of these electron-hole pairs is proportional to the absorbed energy as the energy required to produce an electron-hole pair is always the same. The thallium atoms bonded in the crystal are ionized by interaction with the holes which arise while the primary electron is slowed down. After subsequent recombination with an electron, they emit photons with an energy between 2.9 and 3.1 eV. The number of photons is thus proportional to the absorbed energy.

The NaI crystal is transparent for the emitted photons. The absorption of these photons by other thallium atoms is very unlikely because of the low thallium concentration. As the scintillation crystal is a crystal, there is no scattering from grain boundaries in the crystal. Moreover, the crystal has a light-tight encapsulation and is coated with a highly reflecting material. So a great part of the emitted photons reaches the attached photocathode of the photomultiplier. In the photocathode the emitted photons knock out electrons. Next the electron current is avalanche-like amplified through generation of secondary electrons in a series of dynodes that follow one another. The gain for one dynode stage depends, among other things, on the potential difference between the dynodes and on the dynode material. The dynode potentials are tapped at a voltage divider where a thermally and long-term stable high voltage is applied. A charge that is proportional to the number of photons reaches the anode and causes a current, which leads to a voltage signal at a load resistor. This signal is proportional to the charge if the decay time of the output pulse is considerably larger than the time constant for the emission of light by the excited thallium atoms (t = 0.23 κs). Altogether the pulse amplitude is thus proportional to the energy of the absorbed radiation.

This voltage pulse is then evaluated, e.g. with a system consisting of the MCA box, the Sensor-CASSY and the CASSY Lab software on a PC.

The energy of the radiation entering the detector is not always completely converted in the scintillation crystal, but part of it can escape, e.g. via the Compton effect.

### Caution

- The NaI(Tl) crystal at the end of the scintillation counter is sensitive to mechanical damage.
- The NaI(Tl) crystal is also sensitive to quick changes in temperature, which can occur, e.g., on unpacking after transport.

In both cases cracks in the crystal arise and lead to a reduced sensitivity and, above all, to a worse energy resolution because of scattering.

## Semiconductor counter

For the detection of α radiation, semiconductor barrier layer detectors are preferred. Ionizing α radiation generates a charge in the barrier layer of a semiconductor diode (559 921). This charge, which is proportional to the α energy, is measured electronically and can be made available at the output of a suitable preamplifier (559 931). The pulse can be further processed with a multichannel analyzer, e.g. with the MCA box in conjunction with the Sensor-CASSY.

The preparations used in this experiment emit α particles with an energy around 6 MeV. In silicon these particles have a penetration depth of approx. 50 κm. The width of the barrier layer of the semiconductor diode depends on the applied reverse voltage and is of the order of 70 κm at a reverse voltage of 10 V.

## Multichannel pulse-height analysis

The detector signals are further processed in a multichannel analyzer whose central components are a peak detector and an analog-to-digital converter. The peak detector stores the maximum value of the input pulse U, and the analog-to-digital converter converts the measured value into a proportional digital value k. More precisely, k corresponds to an interval of pulse heights, whose width depends on the resolution of the analog-to-digital converter. The computer assigns a storage location to each digital value and counts the events in each storage location. The result is a histogram which represents the frequency distribution of the pulse heights. For a quantitative evaluation an energy calibration is required as the proportionality factors between the energy and the pulse height are unknown at first.

For the energy calibration a spectrum of a known source is recorded. Then the channel numbers can be assigned to the corresponding energies. This calibration is then valid for other spectra recorded under the same conditions.

The MCA box (524 058) is such a multichannel analyzer.

## Interaction of γ radiation with matter

In the γ energy range between 50 and 2000 keV, two interaction processes of γ radiation with the scintillation crystal play the major role.

In the photoelectric effect, the γ quantum transfers its total energy $E_\gamma$ to an atom in the crystal and releases a bound electron. Apart from the amount of the binding energy, the γ energy is converted into kinetic energy of the electron. This kinetic energy is transferred to the crystal through inelastic scattering.The ionized atom emits X-ray quanta or Auger electrons, whose energy is completely absorbed in the detector in most cases. Then the total amount of absorbed energy corresponds to the energy of the γ quantum. The γ radiation is registered in the peak of total absorption of the pulse-height distribution in this case.

In the Compton effect, part of the γ energy is converted into kinetic energy of a quasi-free electron in an elastic collision. The rest of the original γ energy is left with the scattered γ quantum, which escapes from the scintillation crystal with a certain probability certain probability. The energy of the electron absorbed in the detector then lies between 0 keV (forward scattering of the γ quantum) and a maximum value $E_C$ (backward scattering of the γ quantum). This leads to a Compton distribution with a Compton edge at the energy $E_C$.

## Internal conversion

After a radioactive decay (α or β decay), the daughter nucleus may be in an excited state.In the transition to the energetically more favourable ground state energy is released, which can be given off in different ways.

Apart from giving off the energy by direct emission of a γ quantum, the nucleus may as well transfer the energy to an electron of its atomic shell. The probability of finding shell electrons in the nucleus is not zero. The energy is preferably transferred to electrons of the inner shells. These carry the energy of the excited state away as kinetic energy and leave behind a singly ionized atom. The hole left in the inner atomic shell is replenished by electrons from higher shells. The energy that is released in this process can be transferred to outer electrons of the same nucleus (Auger process) or emitted in the form of characteristic X radiation.

As the de-excitation of the nucleus via internal conversion competes with γ emission, γ emitting isotopes are favourable candidates for the observation of $K_\alpha$ emissions.

## Characteristic X radiation

In several processes such as internal conversion and the photoelectric effect under irradiation, an atom can be ionized. In nuclear physics, an electron of the innermost shell is removed in most cases because of the high energies. The hole left in the inner atomic shell is replenished by electrons from higher shells. The energy that is released in this process can be transferred to outer electrons of the same nucleus (Auger process) or emitted in the form of characteristic X radiation.

If a hole in the K shell is replenished from the L shell, $K_\alpha$ radiation is emitted. If it is replenished from the M shell, $K_\beta$ radiation is emitted which has a higher energy.

According to Moseley, the energy of the $K_\alpha$ line can be estimated for different atoms of atomic charge Z by:

$$E_{K_\alpha} = \frac{3}{4}R(Z-1)^2$$

with the Rydberg constant R= 13.605 691 72(53) eV.

More precise analyses show an energy splitting of all shells higher than the K shell. The L shell consists of three subshells. From two of these subshells transitions to the K shell are allowed. The lines are called $K_{\alpha 1}$ and $K_{\alpha 2}$. They cannot be resolved with a scintillation counter. The corresponding topics will for this reason be investigated by means of an x-ray apparatus.

The exact values of the binding energies of the individual shells are found in the literature, e.g. C. M. Lederer and V. S. Shirley, Table Of Isotopes, 7th Edition, (Wiley-Interscience, 1978), or in the Internet: http://nucleardata.nuclear.lu.se/NuclearData/toi/.

By means of Diagram → Set Marker → X-Ray Energies the x-ray energies of a selected element can be entered in an energy-calibrated spectrum.

## Compton effect (principles)

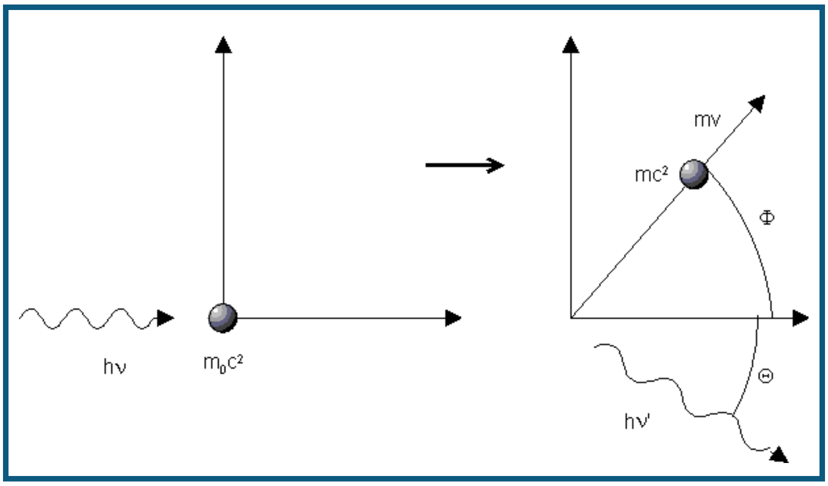
### History

Electromagnetic radiation is scattered when it passes through matter. In 1921 A.H. Compton made the following observation: X rays scattered from matter do not only contain the unshifted spectral components but also a component that is shifted against the spectrum dependent on the scattering angle. Compton interpreted this effect in terms of the particle aspect of radiation as a collision between the X-ray quantum and an electron of the scattering matter taking account of energy and momentum conservation.

The observed change in wavelength depends only on the scattering angle and not on the material of the scatterer. Materials with small atomic charges, e.g. aluminum, are particularly suited for studying the Compton effect because of the reduced absorption in the scatterer.

### Derivation of the Compton shift

The Compton effect can be treated as an elastic collision between a photon and an electron. The calculation has to be semi-relativistic because the energies are higher than the rest mass of the electron.



From energy conservation

$$h\nu + m_0c^2 = h\nu' + mc^2$$

with

$$m = m_0 / \sqrt{1 - v^2 / c^2}$$

and the conservation of momentum in the direction of the co-ordinates

$$\frac{h\nu}{c} = \frac{h\nu'}{c}\cos\theta + mv\cos\phi$$

$$0 \quad = \frac{h\nu'}{c}\sin\theta - mv\sin\phi$$

we obtain

$$\lambda - \lambda' = \frac{h}{m_0c}(1 - \cos\theta)$$

and with

$$E'_\gamma = h\nu' = \frac{hc}{\lambda'}$$

it follows that

$$E'_\gamma = E_\gamma \Big/ \left(1 + \frac{E_\gamma}{m_0c^2}(1 - \cos\theta)\right)$$

## Compton effect (spectrum)

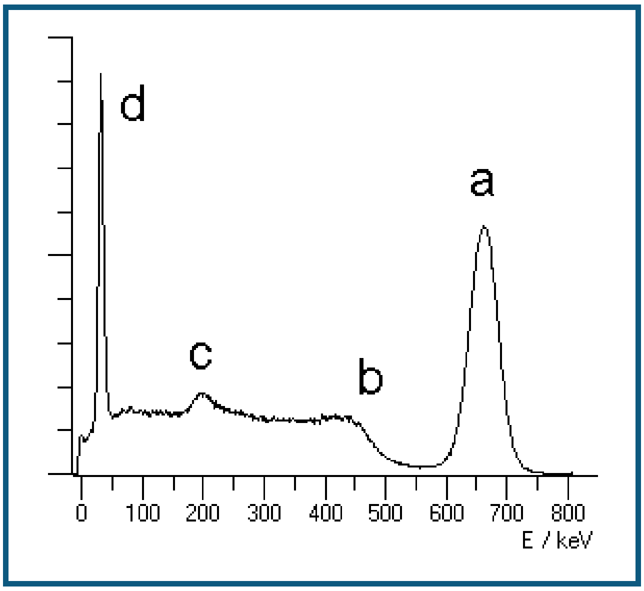
The Compton effect generally occurs when electromagnetic radiation passes through matter. It can also prevent radiation emitted by the preparation from being completely converted in the scintillation crystal. In the experiment the Compton effect is observed in both the preparation and the detector. However, the effects on the spectrum are different in both cases.

As an example, let us assume a preparation that emits only one monoenergetic γ line with the energy $E_\gamma$. The numbers are calculated here for the 662 keV line of the Cs-137 source (a in the spectrum). Line d is another emission line from the Cs-137 decay which in of no interest here.

A Compton collision outside the detector leads to an energy loss of the γ quantum before it reaches the detector. A continuum of scattered photons arises with energies from $E_\gamma$ (662 keV) down to the energy after 180° backscattering (184 keV, point c in the spectrum). Because of the angular dependence of the scattering coefficient (Klein-Nishina formula), the probability of 180° backscattering is enhanced. This leads to the backscatter peak c in the spectrum.

In the detector the γ quantum with the energy $E_\gamma$ can be completely absorbed (photopeak), but a Compton effect can occur as well so that the γ quantum escapes from the detector and only the energy of the electron is detected. The energy of this electron lies between zero and the maximum value, which corresponds to 180° backscattering, leading to a continuum from zero up to the Compton edge (478 keV, point b).

Another possibility of incomplete energy absorption in the detector is given by the $K_\alpha$ escape process. The incoming γ quantum transfers its energy or part of it to an electron of an inner shell. A hole is left in the atomic shell from which the electron has been knocked out. The hole is replenished whereby characteristic X radiation is emitted, which can escape from the scintillation crystal. For instance the energy of a $K_\alpha$ quantum may be missing. Therefore a line shifted by 28.6 keV (iodine $K_\alpha$) can be seen in the NaI scintillator under certain circumstances.



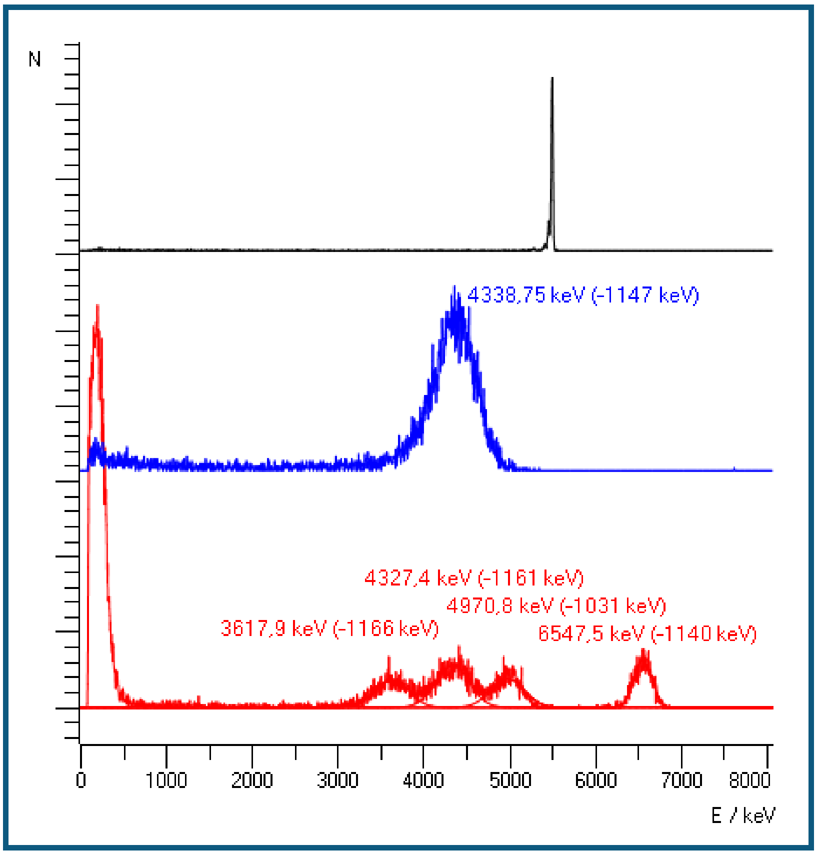
## Covered preparations

The radioactive substances in the preparations for α-radiation are normally rolled metal foils. This means that the radioactive substance is fixed, safe to handle and therefore suitable for type approval.

However, the α-radiation has to pass through the upper metal foil when it leaves the preparation. As is shown in the experiment on the determination of the energy loss of α-radiation in aluminum and gold, α-particles lose considerable energy during this process.

In order to avoid this energy loss, weak preparations below the exemption limit may be designed as open preparations where the radioactive substance is deposited onto the surface of a metal plate, and therefore is no longer covered. The α-radiation can radiate without any loss of energy. On account of the depositing process, the radioactive substance adheres firmly to the substrate and can therefore not simply be wiped off.

If one compares the emissions from covered and non-covered preparations, one will find the following spectra:



All spectra were recorded using the same settings. The upper spectrum comes from the non-covered americium (559 825) and was used for the energy calibration. The spectrum below comes from the covered americium (559 821) and the spectrum below that from the covered radium (559 430). For the covered preparations the measured value is approx. 1100 keV below that given by the literature, thus indicating the energy loss in the covering. The comparison of the two americium spectra shows clearly that not only is energy lost but also the line is considerably widened, as the energy loss is not the same for every emitted particle.

### Energy calibration

In the case of covered preparations, the energy loss can be compensated for during the energy calibration by allocating to the lines the energy values found in the literature. However, some experiments look at the energy loss of the α-particles outside of the preparation in air, aluminum or gold. In these experiments the actual energies of the radiation are to be used, the estimated energy loss in the covering of the preparation should therefore be subtracted from the value given in the literature.

## Radioactive sources

arranged in the order of increasing energies:

### γ radiators:

| Energy | Preparation | Source | |
|---|---|---|---|
| 32.19 keV | Cs-137 | Ba-137 | $K_\alpha$ line after internal conversion |
| 53.23 keV | Ra-226 | Bi-214 | γ emission from excited state |
| 59.54 keV | Am-241 | Np-237 | γ emission from excited state |
| 74.96 keV | | Lead | screening, $K_\alpha$ line after ionization in the lead |
| 74.96 keV | Th-232 | Pb-208 | $K_\alpha$ line after internal conversion |
| 77.10 keV | Th-232 | Bi-212 | $K_\alpha$ line after internal conversion |
| 77.10 keV | Ra-226 | Bi-214 | $K_\alpha$ line after internal conversion |
| 79.30 keV | Ra-226 | Po-214 | $K_\alpha$ line after internal conversion |
| 93.33 keV | Th-232 | Th-228 | $K_\alpha$ line after internal conversion |
| 186.10 keV | Ra-226 | Rn-222 | γ emission from excited state |
| 238.63 keV | Th-232 | Bi-212 | γ emission from excited state |
| 241.98 keV | Ra-226 | Bi-214 | γ emission from excited state |
| 295.21 keV | Ra-226 | Bi-214 | γ emission from excited state |
| 338.32 keV | Th-232 | Th-228 | γ emission from excited state |
| 351.92 keV | Ra-226 | Bi-214 | γ emission from excited state |
| 511.00 keV | Na-22 | $\beta^+$ | positron annihilation in matter |
| 583.19 keV | Th-232 | Pb-208 | γ emission from excited state |
| 609.31 keV | Ra-226 | Po-214 | γ emission from excited state |
| 661.66 keV | Cs-137 | Ba-137 | γ emission from excited state |
| 911.20 keV | Th-232 | Th-228 | γ emission from excited state |
| 968.97 keV | Th-232 | Th-228 | γ emission from excited state |
| 1173.23 keV | Co-60 | Ni-60 | γ emission from excited state |
| 1274.5.3 keV | Na-22 | Ne-22 | γ emission from excited state |
| 1332.50 keV | Co-60 | Ni-60 | γ emission from excited state |
| 1460.81 keV | K-40 | Ar-40 | γ emission from excited state |

### α radiators:

As the sample has to be covered, the energy of the α particles escaping from the preparation is reduced by an energy-dependent amount. For the Am-241 lines this loss is approx. 1 - 2 MeV.

| Energy | Preparation | Source | |
|---|---|---|---|
| 4784.34 keV | Ra-226 | Ra-226 | |
| 5304.38 keV | Ra-226 | Po-210 | |
| 5489.52 keV | Ra-226 | Rn-222 | |
| 6002.35 keV | Ra-226 | Po-218 | |
| 7686.82 keV | Ra-226 | Po-214 | |
| 5388.23 keV | Am-241 | Am-241 | fine structure of Np-237, intensity 1.6% |
| 5442.80 keV | Am-241 | Am-241 | fine structure of Np-237, intensity 13% |
| 5485.56 keV | Am-241 | Am-241 | fine structure of Np-237, intensity 84% |
| 5511.47 keV | Am-241 | Am-241 | fine structure of Np-237, intensity 0.22% |
| 5544.50 keV | Am-241 | Am-241 | fine structure of Np-237, intensity 0.34% |

### β radiators, end-point energy:

| Energy | Preparation | Source | |
|---|---|---|---|
| 317.88 keV | Co-60 | Co-60 | is absorbed in the wall |
| 513.97 keV | Cs-137 | Cs-137 | $\beta^-$ decay |
| 546.00 keV | Sr-90 | Sr-90 | is absorbed in the wall |
| 546.00 keV | Na-22 | Na-22 | $\beta^+$ decay |
| 625.67 keV | Cs-137 | Ba-137 | monoenergetic conversion electrons |
| 1175.60 keV | Cs-137 | Cs-137 | $\beta^-$ decay |
| 1820.20 keV | Na-22 | Na-22 | $\beta^+$ decay |
| 2280.10 keV | Sr-90 | Y-90 | $\beta^-$ decay |

The data are taken from:
The Lund/LBNL Nuclear Data Search
Version 2.0, February 1999
S.Y.F. Chu 1, L.P. Ekstroem 1,2 and R.B. Firestone 1
1 LBNL, Berkeley, USA
2 Department of Physics, Lund University, Sweden
and are also available under http://nucleardata.nuclear.lu.se/nucleardata/toi/index.asp.

**The following preparations are currently available from LD DIDACTIC:**

| Cat. No. | Designation | Status according to StrlSchV (Germany) |
|---|---|---|
| 672 7300 | K-40 in potassium sulphate | below exemption limit |
| 559 435 | Ra-226 preparation, 5 kBq | below exemption limit |
| 559 821 | Am-241 preparation, 74 kBq | type approved: BfS 01/10 |
| 559 825 | Am-241 preparation, 3.7 kBq non-encapsulated | below exemption limit, non-encapsulated preparation |
| 559 809 | Cs-137 preparation, 3.7 MBq | handling authorization required according to StrlSchV in germany |
| 559 885 | Cs-137 preparation, 5 kBq, for Marinelli beaker | below exemption limit |
| 559 835 | set of radioactive preparations<br>Am-241 preparation 74 kBq<br>Sr-90 preparation 45 kBq<br>Cs-137 preparation 74 kBq | type approved: BfS 01/10 |
| 559 845 | mixed preparation α, β, γ, containing<br>Cs-137, 74 kBq<br>Am-241, 4.4 kBq<br>Sr-90, 4.4 kBq | type approved: BfS 01/10 |
| 559 855 | Co-60 preparation, 74 kBq | below exemption limit |
| 559 865 | Na-22 preparation, 74 kBq | below exemption limit |

To Table of experiments

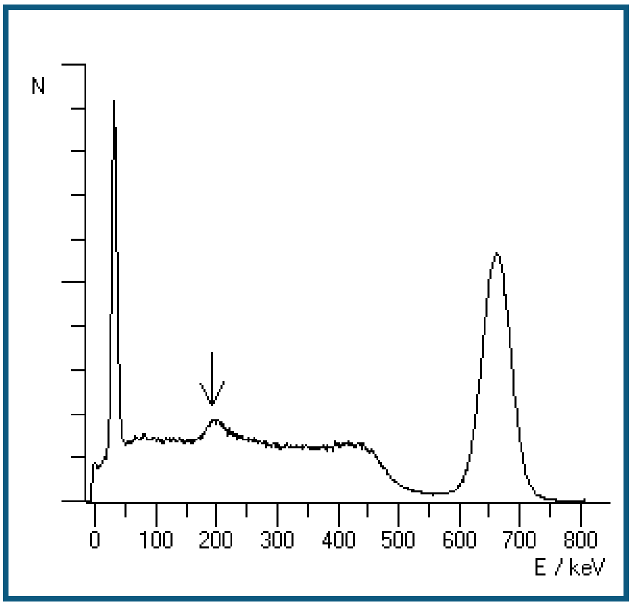
## Caesium-137

Caesium-137 is a man-made radioactive isotope with a half-life of 32 years. It decays via β decay into barium-137. Of these decays 94.6 % lead to a metastable excited state of barium, Ba-137 m, which passes into the ground state with a half-life of 156 s, whereby a γ quantum of 661.6 keV is emitted. The remaining 5.4 % lead directly to the ground state of barium. The maximum energies of the emitted electrons are 513.97 keV and 1175.6 keV.

Emission of a 661.6 keV γ quantum is not the only way metastable barium gives off its energy. In other cases it can transfer its energy to an electron of the 1s shell of its atomic shell ("internal conversion"). The electrons than have an energy of 625.67 keV, that is the difference between the excitation energy of barium and the electron's binding energy. In contrast to beta decay, there is no continuum of the electron energy because no third particle is involved. The hole in the 1s shell is replenished from higher shells. This process gives rise to emission of the characteristic X radiation of barium, particularly of the $K_\alpha$ line at 32.19 keV.

Because of the monoenergetic γ line at 661.6 keV, this isotope is well suited for studying the Compton effect and for energy calibration.

Depending on the cover of the preparation, the $K_\alpha$ conversion line at 32.19 keV is also visible and can be used for energy calibration, too. The Cs/Ba-137 isotope generator (559 815) contains Cs-137 as a salt from which Ba-137 can be washed out. Because of the low mass of the covering plastic housing, this source exhibits a distinct line at 32.19 keV and a very weak backscatter peak even without washing the barium out. By contrast, the mixed preparation (559 84) exhibits a distinct backscatter peak because of the aluminum holder but no $K_\alpha$ conversion line. In addition Am-241 is contained, whose 59.54 keV line can also be used for calibration.



γ spectrum of Cs-137, preparation with little backscattering and with $K_\alpha$ line

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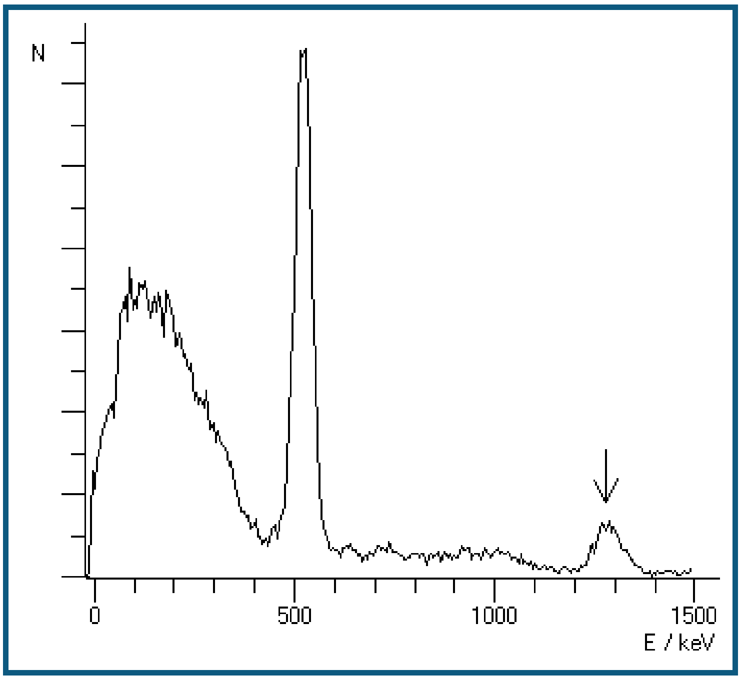
## Sodium-22

Sodium-22 is a man-made isotope with a half-life of 2.6 years. It decays emitting a positron ($\beta^+$ decay) into stable neon-22. A very small part (0.06 %) of the decays leads directly to the ground state of neon. The rest leads to an excited state of neon, partly via electron capture (9.5 %) from the inner atomic shell, but mainly via positron emission. The excited neon state passes into the ground state whereby a 1275 keV γ quantum is emitted. The lifetime of this excited neon is only 3.7 ps.

The emitted positrons react with the electrons of the surrounding matter and lead to a characteristic annihilation radiation at 511 keV. Because of momentum conservation two γ quanta are produced in the pair annihilation of a positron and an electron. These photons are emitted in opposite directions.

As the time delay between the 1275 keV line and the annihilation radiation is unresolvably small, there appears also a line at 1275 + 511 = 1786 keV as a result of simultaneous absorption of both γ quanta.



γ-spectrum of Na-22

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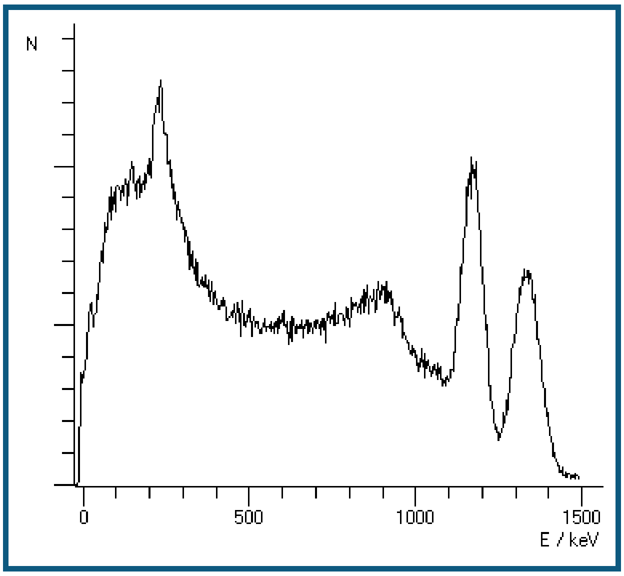
## Cobalt-60

Cobalt-60 is a man-made isotope with a half-life of 5.27 years. It decays emitting an electron with a maximum energy of 318 keV (β decay) into an excited state of the stable nickel-60. From this state a transition into another excited state takes place with emission of a 1173 keV γ quantum, then the ground state is reached whereby a γ quantum of 1333 keV is emitted.

The jacket of the preparation used in the experiments absorbs the β particles. Therefore only γ quanta can be observed.

When doing γ spectroscopy with a scintillation counter, keep in mind that the Compton edge of the line with the higher energy 1333 keV is at 1119 keV, i.e. it is located in the low-energy edge of the second line at 1173 keV and distorts its shape.



γ spectrum of Co-60

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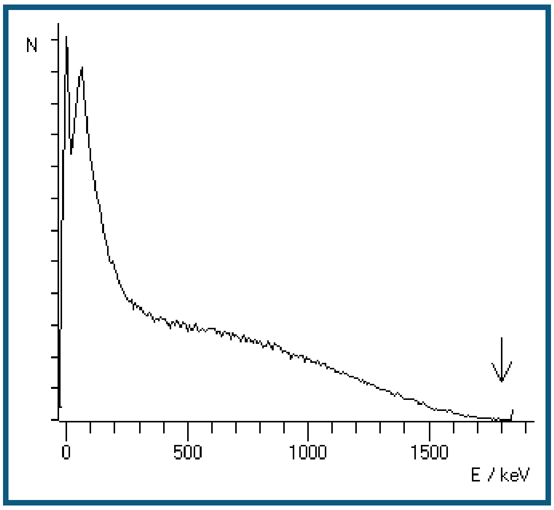
## Strontium-90

Strontium-90 is a man-made isotope with a half-life of 28.5 years. It decays emitting an electron with a maximum energy of 546 keV (β decay) into yttrium-90. The latter decays through β decay with a maximum energy of 2274 keV into zirconium-90 with a half-life of 64.1 hours.



β spectrum of Sr-90 recorded with the scintillation counter.

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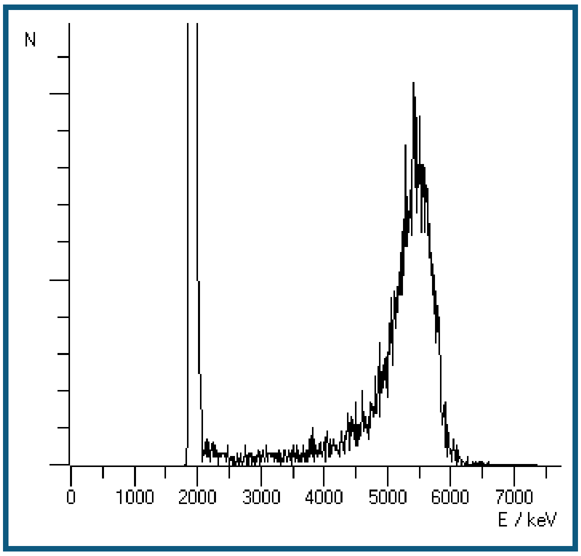
## Americium-241

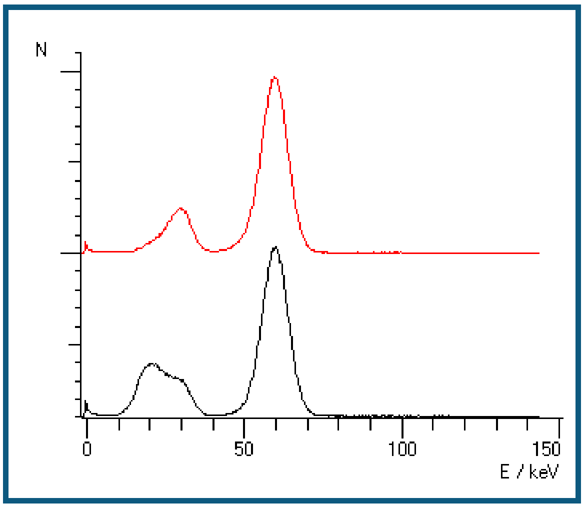
Americium-241 is a man-made isotope with a half-life of 433 years. It decays emitting an α particle with an energy of approximately 5500 keV into excited states of neptunium-237. The individual lines at 5388, 5443, 5486, 5511 and 5545 keV that correspond to decays into different excited states cannot be observed separately in the framework of this experiment. Two of these lines dominate the measured spectrum, the line at 5486 keV, which is emitted in 84 % of all decays and thus has the strongest intensity, and the line at 5443 keV, which is emitted in 13 % of all decays. The remaining 3 % are distributed over the other three lines.

Due to the necessary cover of the preparation, the α particles already loose energy before reaching the detector. A hypothetical α particle of approx. 1.5 MeV would just reach the detector and trigger a minimal electric pulse. Therefore an energy offset is observed in the spectrum when the measured lines are calibrated with values taken from the literature. The measured spectrum starts only at approx. 1.5 MeV.

One of the excited states of neptunium-237 decays emitting a γ quantum of 59.54 keV into the ground state.



α spectrum of Am-241



γ spectrum of Am-241, upper curve: emission from the side of the preparation with the wall of the preparation as a filter, lower curve: emission from the preparation through the borehole

In the gamma spectrum other lines are seen near the Np-237 emission line at 59.54 keV. These might be the L line of neptunium (17 keV) and the iodine Kα escape line (26.3 keV).

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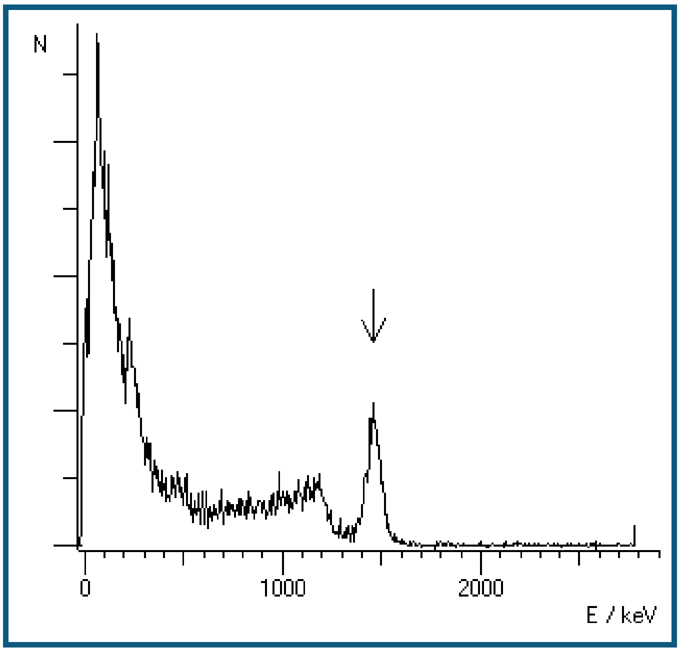
## Potassium-40

Natural potassium contains 0.012 % of the radioactive isotope K-40, which has a half-life of 1.27 billion years. 90 % of K-40 undergo a β transition into the ground state of Ca-40, whereas the remaining 10 % decay into an excited state of Ar-40, either by $\beta^+$ emission or by electron capture. In the transition to its ground state, Ar-40 emits a gamma quantum of 1460.81 keV.



γ spectrum of K-40

The activity of natural potassium is 32 Becquerel per gram of metallic potassium, 17 Becquerel for a gram of KCl or 9 Becquerel per gram of potassium sulphate $KSO_4$.

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## Radium-226

Radium is found in nature. Its half-life is 1600 years, and it is indirectly produced in the radioactive series of uranium-238, the so-called the 4n+2 series.

Radium is chemically related to barium and calcium and therefore accumulates, e.g., in Brazil nuts so that it is contained in Brazil nut ash. The content, which fluctuates depending on the area of cultivation, is of the order of magnitude of 10 picograms per gram of ash.

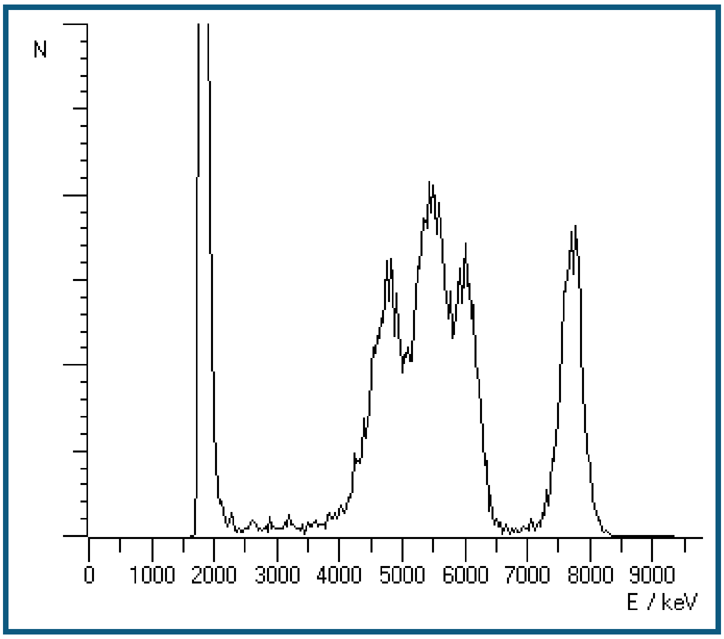
Pure radium-226 is an α radiator, and the subsequent decay products are mainly α radiators, too, but there are also β and γ radiators among them. For details of the decay see below.

For producing the preparation pure radium in used. In the course of time, the isotopes of the radioactive series accumulate until an equilibrium is reached. The first elements of the radioactive series have very short half-lives so that this equilibrium is reached after a short time. However, the isotope lead-210 has a half-life of 22.3 years. Correspondingly, it takes a long time until the equilibrium is reached so that the activity of the subsequent decays (e.g. polonium-210) can be used for dating of the source.

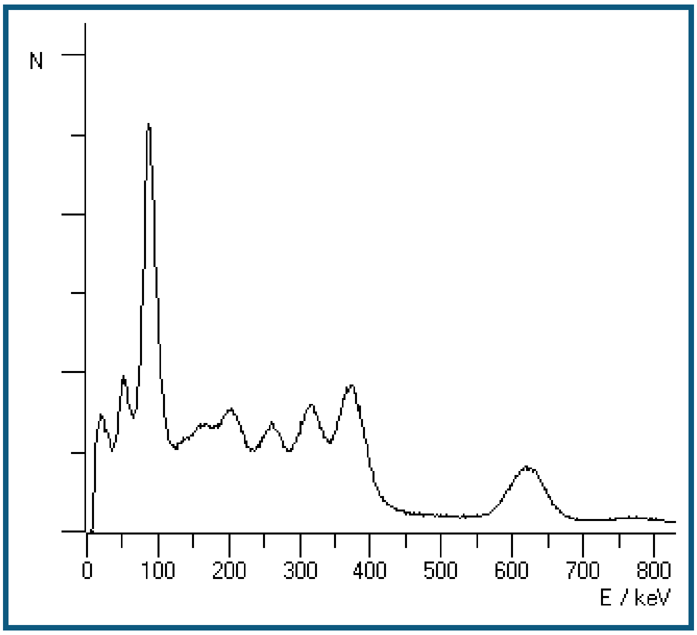
In this experiment the **α spectrum** exhibits five lines in the energy region around 6 MeV. Unfortunately the lines of Po-210 and Rn-222 cannot be separated clearly because of the unsharpness of the energy which is due to the cover of the preparation.

| **Energy** | **Source** |
|---|---|
| 4784 keV | Ra-226 |
| 5304 keV | Po-210 |
| 5489 keV | Rn-222 |
| 6002 keV | Po-218 |
| 7687 keV | Po-214 |

Due to the necessary cover of the preparation, the α particles already loose energy before reaching the detector. A hypothetical α particle of approx. 2 MeV would just reach the detector and trigger a minimal electric pulse. Therefore an energy offset is observed in the spectrum when the measured lines are calibrated with values taken from the literature. The measured spectrum starts only at approx. 2 MeV.



The **γ spectrum** of a radium source exhibits many lines, which come from the different isotopes of the radioactive series. The line at 186 keV is the only one which comes immediately from the radium-226 decay, namely from an excited state of radon-222. The excited states of Bi-214 render four lines at 352 keV, 295 keV, 242 keV and 53 keV. The excited state of Po-214 leads to the line at 609 keV. The strong line at approx. 80 keV is a superposition of $K_\alpha$ conversion lines and presumably of Bi-214 (77.1 keV) and Po-214 (79.3 keV). If a thorough evaluation is made, a weak line shows up at approx. 90 keV. It can be explained as the associated $K_\beta$ line, but it may also be the $K_\alpha$ line of radium after ionization by α radiation.



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## The radioactive series of radium-226

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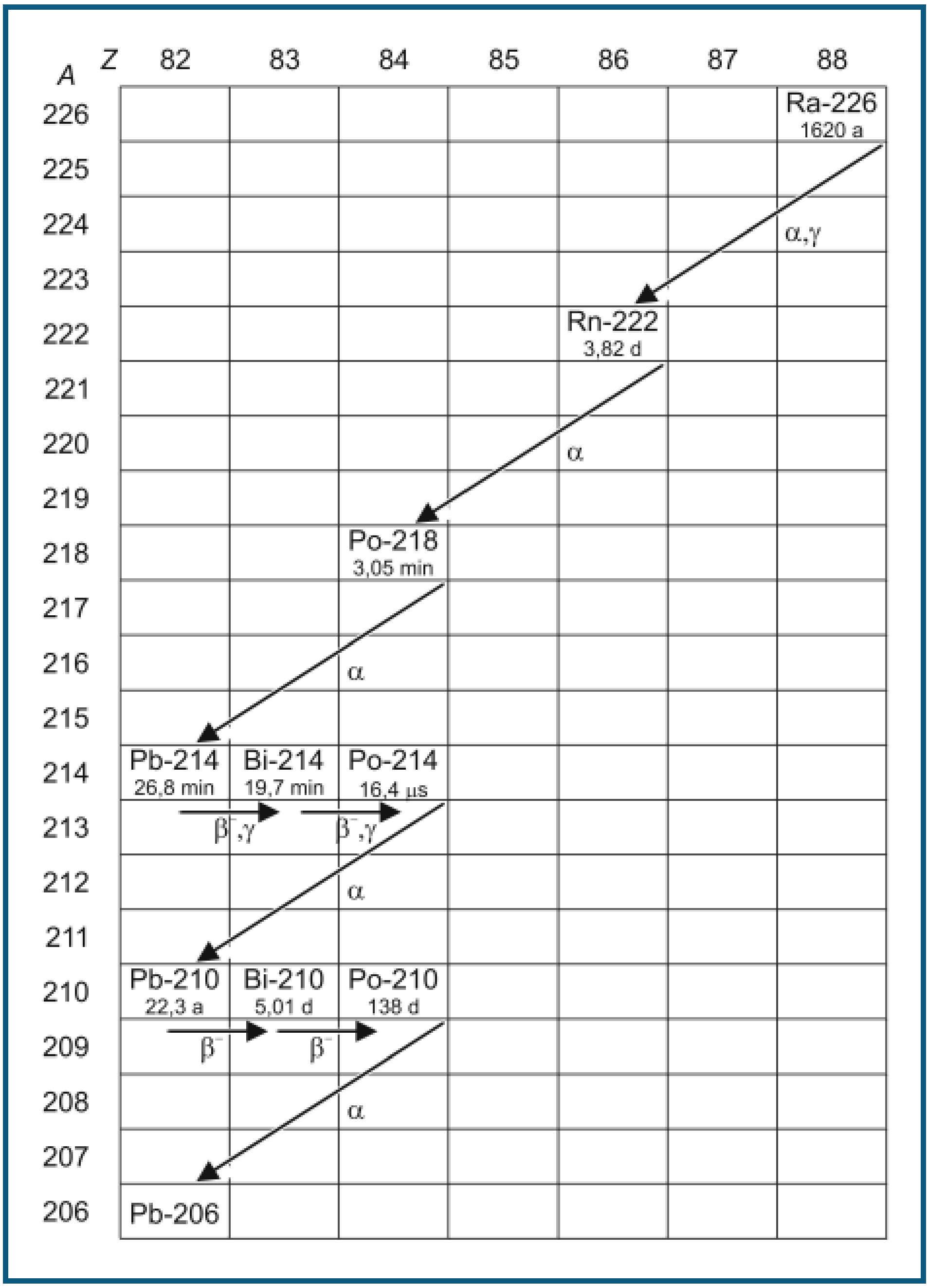

### 88-Ra-226

Radium-226
Half-life: 1600 years
Mode of decay: alpha into Rn-222
Decay energy: 4.871 MeV
Subsequently γ radiation of Rn-222 at 186 keV possible

### 86-Rn-222

Radon-222, noble gas
Half-life: 3.8235 days
Mode of decay: alpha into Po-218
Decay energy: 5.590 MeV

### 84-Po-218

Polonium-218
(Historically Po-218 is also called radium A)
Half-life: 3.10 minutes
Mode of decay: alpha into Pb-214
Probability: 99.98 %
Decay energy: 6.115 MeV

Mode of decay: beta into At-218
Probability: 0.02 %
Decay energy: 0.265 MeV

### 85-At-218

Astatine-218
Half-life: 1.5 seconds
Mode of decay: alpha into Bi-214
Probability: 99.90 %
Decay energy: 6.874 MeV

Mode of decay: beta into Rn-218
Probability: 0.1 %
Decay energy: 2.883 MeV

### 86-Rn-218

Radon-218
Half-life: 35 milliseconds
Mode of decay: alpha into Po-214
Decay energy: 7.263 MeV

### 82-Pb-214

Lead-214
(Historically Pb-214 is also called radium B)
Half-life: 26.8 minutes
Mode of decay: beta into Bi-214
Decay energy: 1.024 MeV
Subsequently γ radiation of Bi-214 at 352 keV, 295 keV, 242 keV, 53 keV possible

### 83-Bi-214

Bismuth-214
(Historically Bi-214 is also called radium C)
Half-life: 19.9 minutes
Mode of decay: beta into Po-214
Probability: 99.98 %
Decay energy: 3.272 MeV
Subsequently γ radiation of Po-214 at 609 keV possible

Mode of decay: alpha into Tl-210
Probability: 0.02 %
Decay energy: 5.617 MeV

### 84-Po-214

Polonium-214
(Historically Po-214 is also called radium C')
Half-life: 164.3 κs
Mode of decay: alpha into Pb-210
Decay energy: 7.833 MeV

### 81-Tl-210

Thallium-210
(Historically Tl-210 is also called radium C")
Half-life: 1.3 Minutes
Mode of decay: beta into Pb-210
Decay energy: 5.484 MeV

### 82-Pb-210

Lead-210
(Historically Pb-210 is also called radium D)
Half-life: 22.3 years
Mode of decay: beta into Bi-210
Decay energy: 0.064 MeV

Mode of decay: alpha into Hg-206
Probability: $1.9^{-6}$ %
Decay energy: 3.792 MeV

### 83-Bi-210

Bismuth-210
(Historically Bi-210 is also called radium E)
Half-life: 5.013 days
Mode of decay: beta into Po-210
Decay energy: 1.163 MeV

Mode of decay: alpha into Tl-206
Probability: 0.00013 %
Decay energy: 5.037 MeV

### 84-Po-210

Polonium-210
(Historically Po-210 is also called radium F)
Half-life: 138.376 days
Mode of decay: alpha into Pb-206
Decay energy: 5.407 MeV

### 82-Pb-206

Lead-206
(Historically Pb-206 is also called Radium G)
Pb-206 is the final product of the U-238 radioactive series. It is stable.

The entries are taken from the NUDAT database, see:

R.R.Kinsey, et al., *The NUDAT/PCNUDAT Program for Nuclear Data*, paper submitted to the 9 th International Symposium of Capture-Gamma_ray Spectroscopy and Related Topics, Budapest, Hungary, Octover 1996. Data extracted from NUDAT database (Dec.18, 1997).

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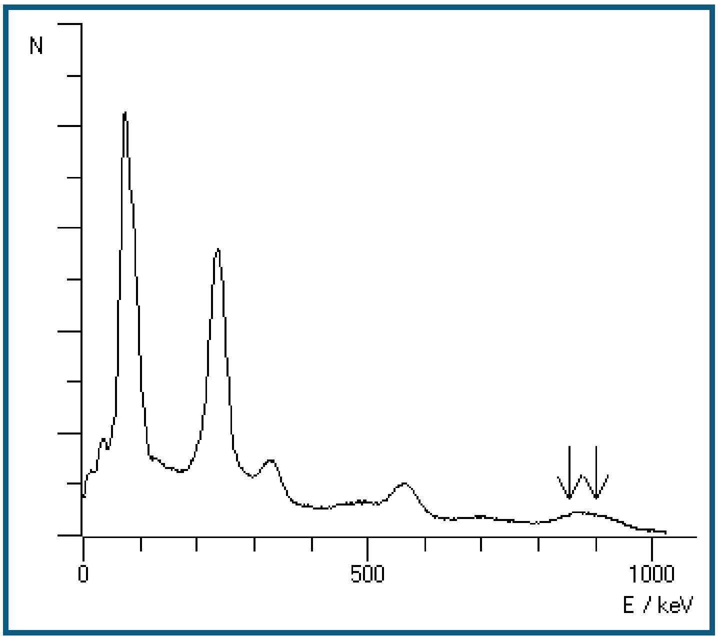
## Thorium-22

Thorium is found in nature. It occurs mainly in the ore monazite, a complex phosphate of thorium, uranium, cerium and lanthanoids. Its half-life is 14 billion years, and it is the parent isotope of the 4n+0 radioactive series. For details of the decay see below.

Thorium is still present in some incandescent gas hoods used in camping gas lamps. Incandescent gas hoods that are not burnt in are well suited for recording the complex γ spectrum of thorium and its decay products. Incandescent gas hoods that have already been used in a lamp are brittle and quickly decay into radioactive powder so that handling is made very difficult. Depending on the way of production, the thorium isotopes Th-232 and Th-228 are present in newly manufactured incandescent gas hoods, the other elements of the radioactive series being produced only in the course of time. Because of the presence of two isotopes, the daughter nuclei are not produced according to a simple exponential law. A complicated course of the intensities is observed, which corresponds to the half-lives of thorium-228 (approx. 2 years) and radium-228 (almost 6 years).

Thorium oxide provides a particularly high light yield because it is no black body, but emits little thermal infrared radiation and more visible light (selective radiator). The radioactivity of thorium is not relevant for the light yield. Because of the problems of radioactivity incandescent gas hoods are made from yttrium oxide in recent time, which is not radioactive, but shines less brightly.



γ spectrum of a 15 year old thorium source

In the γ spectrum of thorium the lines of several isotopes of the radioactive series are found. The following lines, which all come from excited states of a nucleus after β decay, are clearly visible.

Th-228*: 338.32 keV, 911.204 keV
Bi-212*: 238.632 keV
Pb-208*: 583.191 keV, 860.564 keV

Moreover, there is the superposition of $K_\alpha$ lines in the range 80-90 keV. In contrast to radium, here a superposition of at least two lines can be discerned because a component occurs at 90 keV near the line at 80 keV. As internal conversion competes with γ emission in the de-excitation of nuclei, γ emitting isotopes are also good candidates for $K_\alpha$ emission. The energies are at 74.96 keV (Pb-208), 77.1 keV (Bi-212) and 93.3 keV (Th-228).

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## The radioactive series of thorium-232

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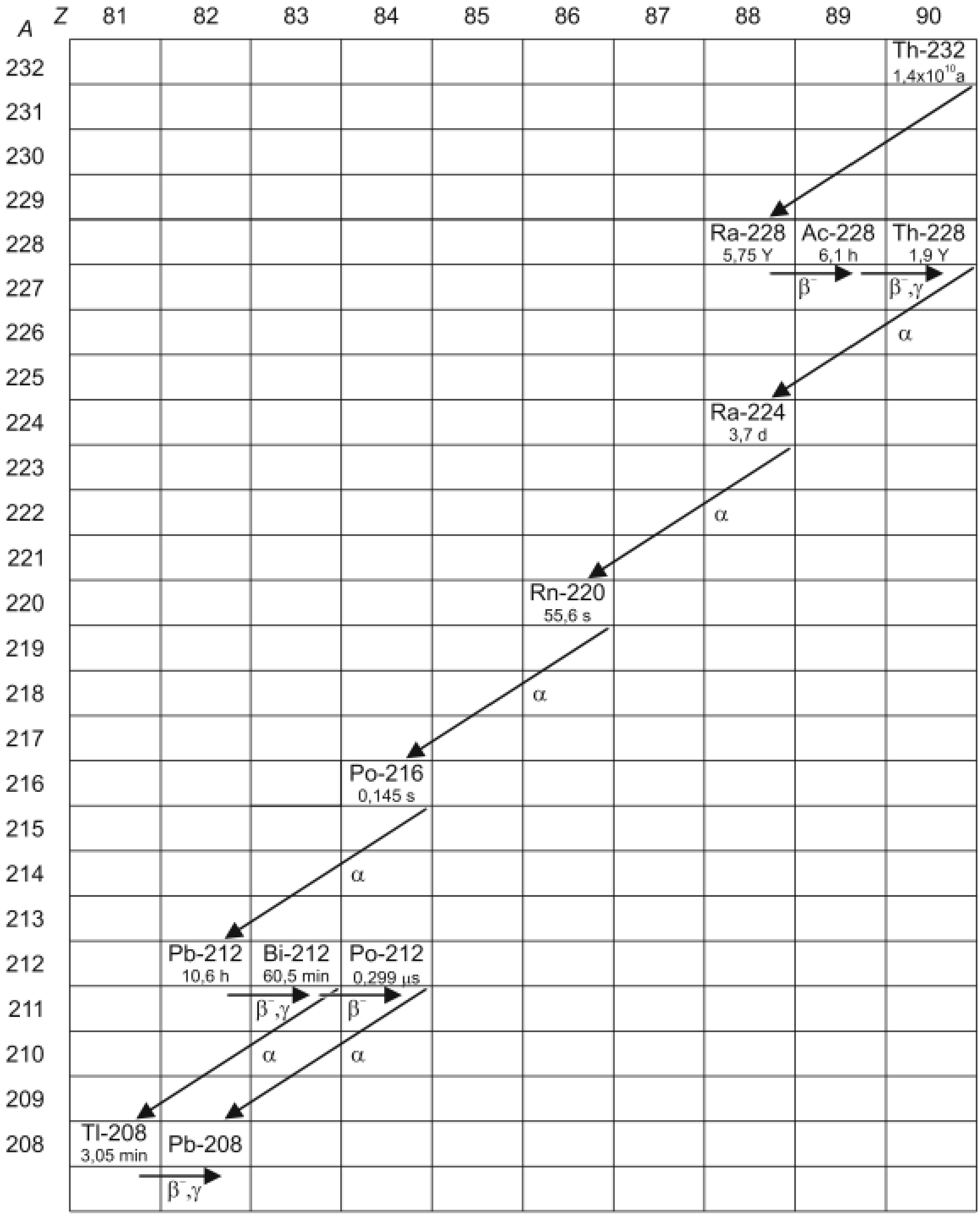

The energies of electrons emitted after β decays are not listed here.

### 90-Th-232

Thorium-22
Half-life: 14 billion years
Mode of decay: alpha into Ra-228

| $E_\alpha$ (keV) | $I_\alpha$ (%) |
|---|---|
| 3947.2 | 21.7 |
| 4012.3 | 78.2 |

### 88-Ra-228

Radium-228
Half-life: 5.75 years
Historically also called Mesothorium 1
Mode of decay: beta into Ac-228

### 89-Ac-228

Actinium-228
Half-life: 6.15 hours
Historically also called Mesothorium 2
Mode of decay: beta into Th-228

| $E_\gamma$ (keV) | $I_\gamma$ (%) |
|---|---|
| 338.320 | 11.27 |
| 911.204 | 25.8 |

### 90-Th-228

Thorium-228
Half-life: 1.9 years
Historically also called Radiothorium
Mode of decay: alpha into Ra-224

| $E_\alpha$ (keV) | $I_\alpha$ (%) |
|---|---|
| 5340.36 | 27.2 |
| 5423.15 | 72.2 |

### 88-Ra-224

Radium-224
Half-life: 3.7 days
Historically also called Thorium X
Mode of decay: alpha into Rn-220

| $E_\alpha$ (keV) | $I_\alpha$ (%) |
|---|---|
| 5448.6 | 5.06 |
| 5685.37 | 94.92 |

### 86-Rn-220

Radon-220, noble gas
Half-life: 55.6 seconds
Historically also called Thoron
Mode of decay: alpha into Po-216

| $E_\alpha$ (keV) | $I_\alpha$ (%) |
|---|---|
| 6288.08 | 99.886 |

### 84-Po-216

Polonium-216
Half-life: 0.145 s
Historically also called Thorium A
Mode of decay: alpha into Pb-212

| $E_\alpha$ (keV) | $I_\alpha$ (%) |
|---|---|
| 6778.3 | 99.9981 |

### 82-Pb-212

Lead-212
Half-life: 10.64 hours
Historically also called Thorium B
Mode of decay: beta into Bi-212

| $E_\gamma$ (keV) | $I_\gamma$ (%) |
|---|---|
| 238.632 | 43.3 |

### 83-Bi-212

Bismuth-212
Half-life: 60.55 minutes
Historically also called Thorium C
Mode of decay:64 % beta into Po-212
36 % alpha into Tl-208

| $E_\alpha$ (keV) | $I_\alpha$ (%) |
|---|---|
| 6050.78 | 70 |
| 6089.88 | 27 |

### 84-Po-212

Polonium-212
Half-life: 0.299 κs
Historically also called Thorium C'
Mode of decay: alpha into Pb-208

| $E_\alpha$ (keV) | $I_\alpha$ (%) |
|---|---|
| 8784.37 | 100 |

### 81-Tl-208

Thallium-208
Half-life: 3.05 minutes
Historically also called Thorium C''
Mode of decay: beta into Pb-208

| $E_\gamma$ (keV) | $I_\gamma$ (%) |
|---|---|
| 510.77 | 22.6 |
| 583.191 | 84.5 |
| 2614.533 | 99 |

### 82-Pb-208

Lead-208
Stable

## Radioactive series

The decay of natural radioactive elements mainly occurs through α and β decay. Excited nuclear states that arise occasionally also emit γ radiation. In α decay, the masses of nuclei change by four nucleon masses, whereas the mass change in β and γ decay is negligible. Thus a nucleus can change its mass only by multiples of 4 nucleon masses in these modes of decay. Therefore all natural radioactive nuclei can be assigned to one of four radioactive series according to their mass number. These series contain the nuclei with the mass numbers 4n, 4n+1, 4n+2 or 4n+3 respectively. Each of the series has a long-lived starting isotope. When the parent nucleus undergoes its first decay, the subsequent decays follow at a relative quick rate until the stable final nucleus is reached.

| **Mass** | **Examples** |
|---|---|
| 4n+0 | Th-232, Ra-228, Ra-224, Pb-208 |
| 4n+1 | Np-237, U-233, Bi-209 |
| 4n+2 | U-238, Ra-226, Pb-206 |
| 4n+3 | U-235, Ra-223, Pb-207 |

The 4n+1 series is very rare in nature because the isotope Np-237 has a half-life of only 2 million years. Since the earth came into being, it has almost entirely decayed. The parent isotopes of the other three series have half-lives of the order of magnitude of billion years.

There are other ways for atomic nuclei than α and β decay to decay, e.g. by evaporating neutrons or spontaneous fission so that a transition between the 4n+x groups is possible. However, in natural nuclei these decay channels are rather seldom. For instance, in uranium-235 one nucleus out of 14 billion decays in a spontaneous fission, all others through α decay.

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