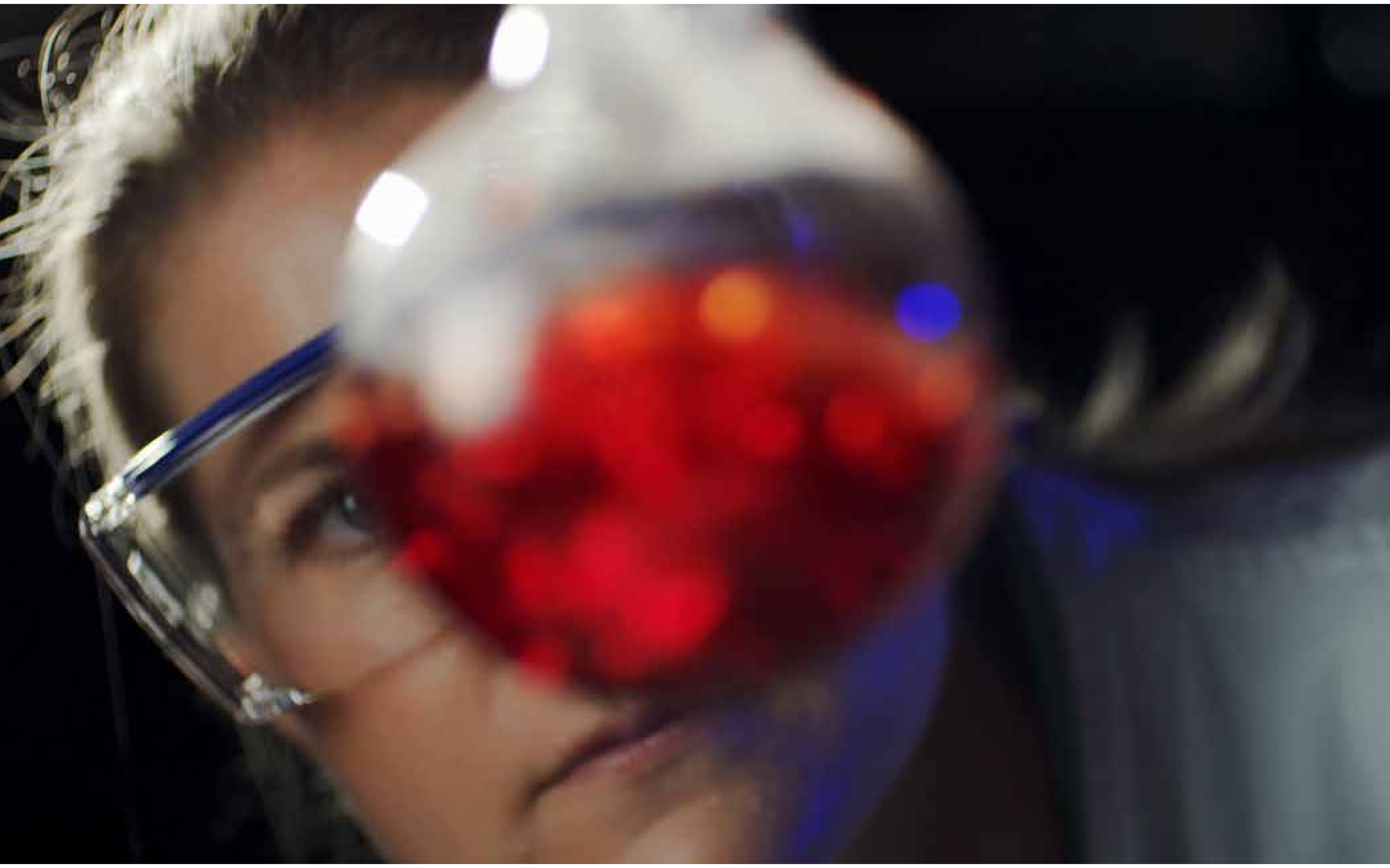
LEYBOLD®

CHEMISTRY EXPERIMENTS

FOR HIGHER EDUCATION UP TO UNIVERSITY LEVEL

LD DIDACTIC

CHEMISTRY
WITH LEYBOLD



CHEMISTRY EXPERIMENTS IN TRUSTED LEYBOLD QUALITY

Experiments are an indispensable part of education to combine theoretical knowledge with experimental learning sessions to ensure sustainable and successful learning.

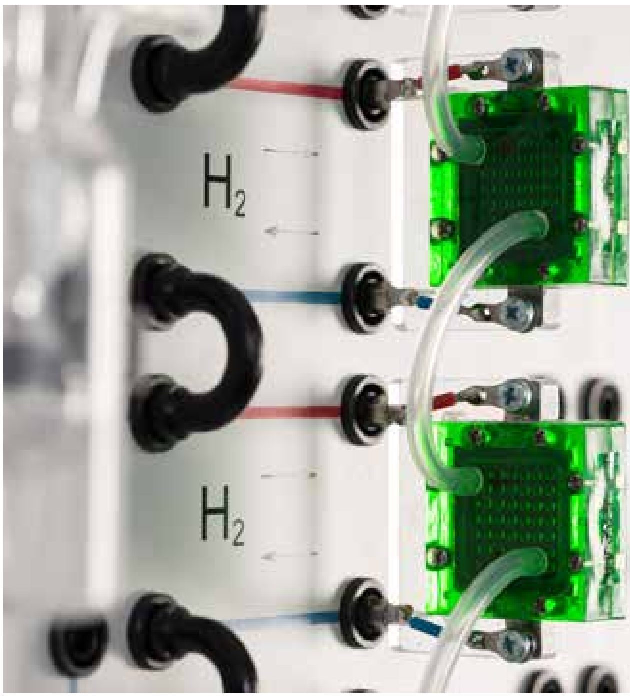
More than 100 experiments from all areas of chemistry are highlighted in this catalogue. Our proven LEYBOLD quality guarantees durability and safety during the complete experiment setup and conduction. At LEYBOLD you will find a comprehensive experiment collection for students starting with fundamentals up to lab work in advanced chemistry at colleges and universities. The experiments can be adapted to the time requirements and student's level of knowledge.

We will advise you personally and demonstrate our experiments for you.

Have fun experimenting!

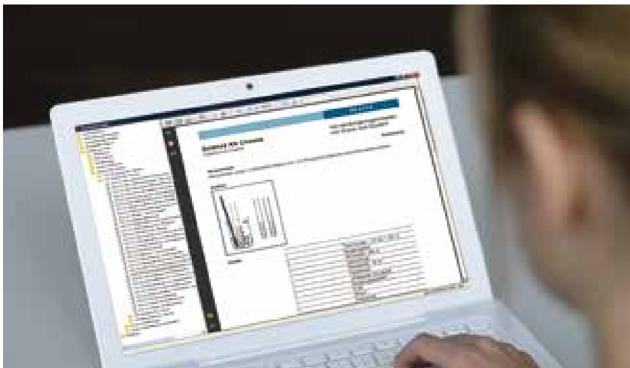
CONTENTS

INTRODUCTION



DEMONSTRATION EXPERIMENTS

APPENDIX



EXPERIMENTATION IS OUR PASSION

LD DIDACTIC GROUP: EXPERIMENTS FOR STUDENTS & DEMONSTRATION FOR MORE THAN 170 YEARS

Experimentation has always been a core competence of scientists and ensures to really understand scientifc phenomena.

The planning, carrying out and recording of experiments is an important element of a well-founded education in science. In order to reinforce newly acquired knowledge, experiments must be well matched to the theory. Investing in the practical training of your students, you equip them with important science skills that the labour market requires.

The LD DIDACTIC Group is a leading global manufacturer of high quality teaching and training systems. From the very beginning in 1850 we at LEYBOLD concentrate on how to make academic content understandable and tangible for students at different levels of education. Therefore we are proud that for generations our training and educational systems have made a significant contribution to knowledge transfer in natural sciences.

MORE THAN 100 EXPERIMENTS FOR COLLEGE & UNIVERSITY LAB WORK

- Benefit from 170 years of experience.
- Explore more than 100 ready-to-use experiment set-ups.
  The collection matches international curricula and can be used for bachelor and master courses.
- Get an individual, matching end-to-end solution including equipment, measuring devices, software and experiment instructions.
- Realise successful and sustainable learning outcomes.
- Rely on a future-ready solution for digital education.
- Profit from premium quality developed and designed in Germany from a highly specialised development team with didactic background.
- Ensure group-based student centred lab work with robust materials and easy-to-use, secure set-ups.
- Bank on tried and tested experiments in top schools, colleges and universities worldwide.

CHEMISTRY EXPERIMENTS

HIGHLIGHTS

TOP FIVE

SPECIAL & UNIQUE

C1.7.2.2

ANALYSIS OF TRIPROTIC PHOSPHORIC ACID BY TITRATION

- Example of an automatic titration with a drop counter
- Determination of the first two equivalence points of phosphoric acid with precise measuring system CASSY
- Detection of the buffer effect of solutions (phosphate buffer)

C2.3.2.1

FRACTIONATED PETROLEUM DISTILLATION WITH A BUBBLE TRAY COLUMN

- Investigation and work with crude oil
- Operation and studying of a bubble tray column
- Combination of chemistry presentation system (CPS) and measurement system CASSY in one experiment

C3.2.1.2

GAS CHROMATOGRAPHY

- Studying the basic principles of gas chromatography
- Investigation of temperature effects in gas chromatography
- Evaluation with CASSY measuring system

C4.4.7.2

RECORDING THE CHARACTERISTIC CURVES OF A PEM FUEL CELL STACK

- Analysing alternative energy sources with the fuel cell
- Usage of a metal hydride stick as hydrogen source
- Recording of the characteristics of a fuel cell

C5.1.1.2

SYNTHESIS OF AMMONIA BY THE HABER-BOSCH PROCESS

- Classic experiment from historical chemistry; can also be performed in demonstration
- Understanding how difficult the invention of the Haber-Bosch process must have been
- Usage of CPS and the metal hydride stick

STAND SYSTEMS

FOR EVERY EXPERIMENTAL SITUATION

BENEFITS AT A GLANCE

- Optimal work safety through stable, torsion-resistant construction
- Easy to set up thanks to pre-set assembly axes
- Can be adapted to fit the special requirements of each experimental situation

THREE VARIANTS

SET-UP WITH BASE RAILS

FOR PERFECTLY ALIGNED SET-UPS ON A SINGLE RAIL.

The base rail makes it easy to create large set-ups. The stability of the system comes from a solid T-profile made of anodised aluminium, which enables safe set-ups even with heavy components.

- Three different base rails are available for different sized set-ups (110 mm, 550 mm and 950 mm).
- Even large set-ups can be assembled on a single base rail.
- Completely assembled set-ups can be moved or stored in a cabinet.
- The base rails can also be used as an optical test bench.

SET-UP ON EXPERIMENT TRAY WITH INTEGRATED RAILS

FOR EXPERIMENTS WITH LIQUIDS

The experiment tray is suitable for experiments using liquids.

- The experiment tray acts as a containment basin in case of chemical spills or glass breaks.
- The integrated rails save time when setting up experiments on the experiment tray.
- Fitting universal clamps onto the angular mounting rail makes it possible to install vertical stands.
- The stable, torsion-free construction also makes it possible to move completely assembled systems.

SET-UP ON STAND BASES MADE OF PLASTIC

FOR A MAXIMUM OF FLEXIBILITY

This stand system allows a maximum of flexibility when setting up experiments.

- The stand bases used are very lightweight.
- Thanks to double strut construction, the assembled stand system is almost completely torsion-free, which makes it possible to move apparatus before they have been completely set up.
- The stand can be disassembled to save space during storage.
- The stand is made of solid materials (ABS plastic and stainless steel).
- The stand materials are used in chemistry, biology and physics experiments.

CHEMISTRY PRESENTATION SYSTEM

MODULAR AND CLEARLY ARRANGED EXPERIMENTS

- Clear experimental set-ups against a single-colour background
- Rapid set-up in just seconds
- Predefined distances eliminate the need for painstaking glassware adjustments
- Extremely rapid assembly or modification of the experiment set-ups
- GL screw connectors ensure secure, leak-tight connections between the individual modules – no more fused ground glass joints
- Glassware is mounted securely to the experimentation boards – this reduces the risk of breakage
- Safe and convenient storage in the cabinet with groove profiles

FAST AND EASY SET-UP

1.

FAST AND SAFE SET-UP BASED ON MODULES

Install the experiment panels in the profile rails of the CPS frame.

Installing the experimentation panels in the CPS frame.

The magnetic holders make it possible to assemble experiment set-ups on an individual basis.

ASSEMBLY AND MODIFICATION OF THE EQUIPMENT IN JUST SECONDS WITH THE MAGNETIC HOLDERS

FAST INSTALLATION AND REMOVAL OF GLASSWARE USING FLEXIBLE CLIPS AND MAGNETIC HOLDERS

2. Push a GL connector cap (silicone seals are included) onto a glass component (e.g. three-way stopcock) and screw it onto the glass connector.

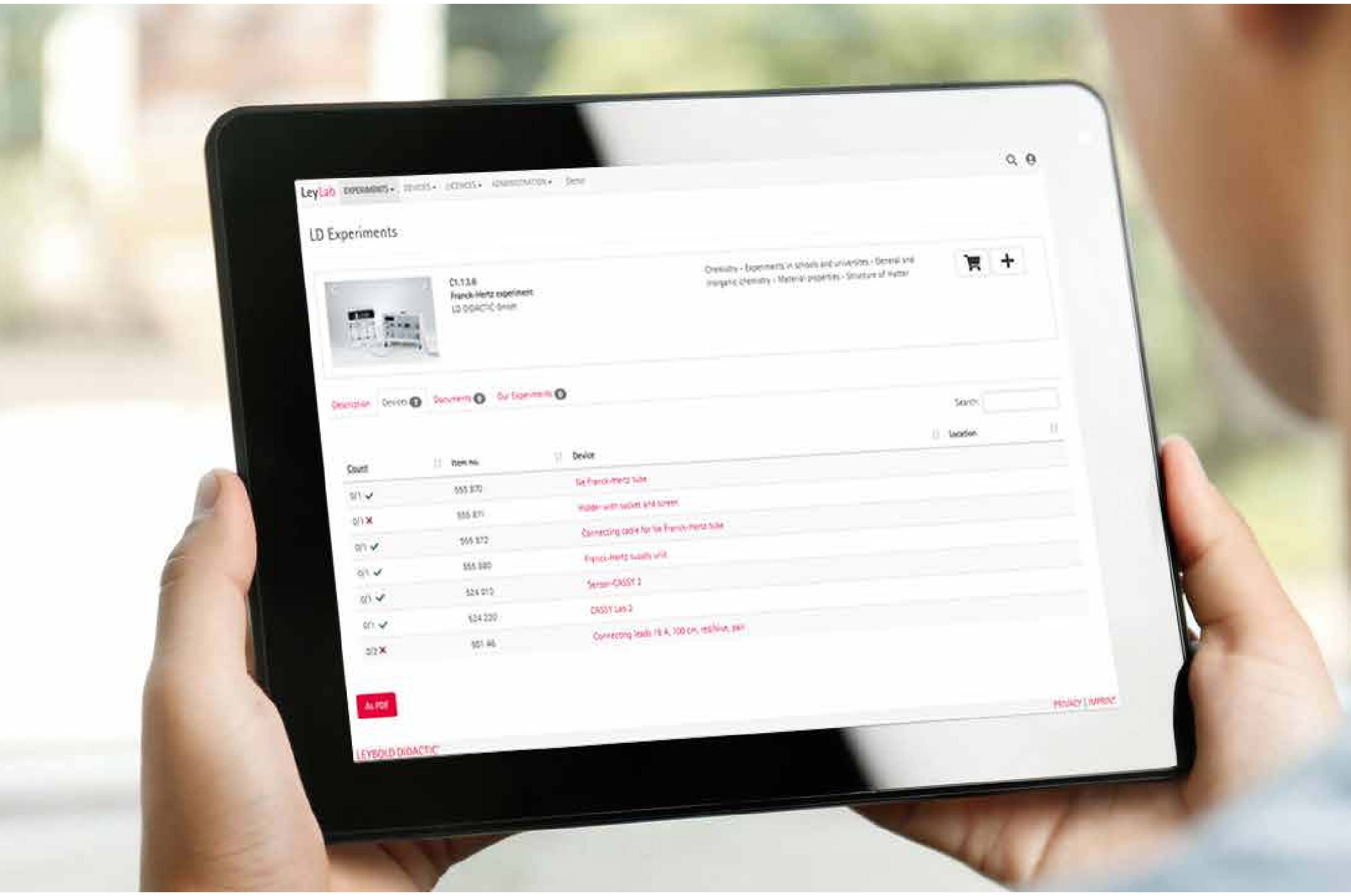
3. Slide the second experiment panel up to the first panel and screw the glass component with the attached GL connector cap (e.g. a gas syringe) onto the glass connector. The glassware fits together perfectly because the dimensions are standardised. This ensures secure, leak-tight connections between the glassware of the two experimentation panels.

CPS FRAMES

- Accommodate any number of experimentation panels
- Fit inside every fume cupboard:
  50 cm wide for narrow experiments
  97 cm wide for wide experiments

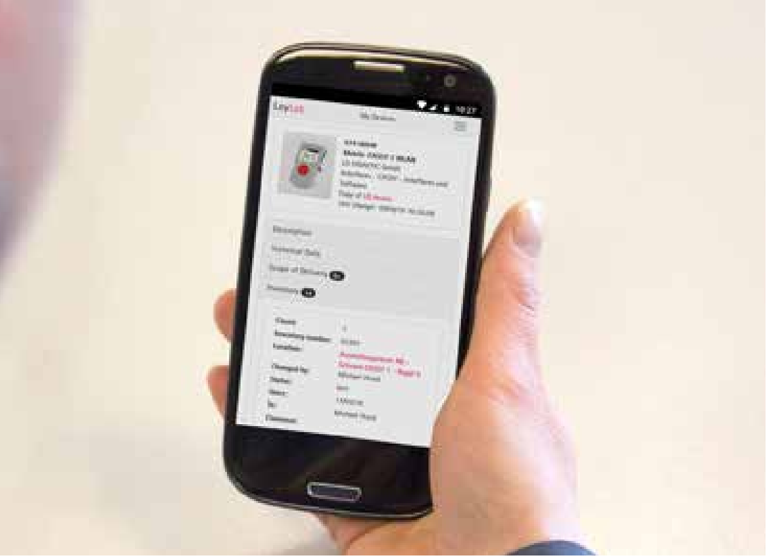
LEYLAB

ONLINE-PORTAL FOR ORGANISATION & MANAGEMENT OF EXPERIMENTS, DEVICES AND LITERATURE



LEYLAB

- Complete online portal
- Central organisation & management of experiments and devices
- No installation needed
- For all platforms, tablets, smartphones, laptops or PCs
- Video tutorials included
- Access at anytime from anywhere



DEVICE COLLECTION

- Direct overview of all available devices including quantity and storage location
- Save time searching for equipment
- Detailed information on every item
- Easy inventory of the complete collection
  - *LD devices and other manufacturers' devices*
  - *With bar code functionality*
- Clear inventory management with borrowing and return function

LITERATURE

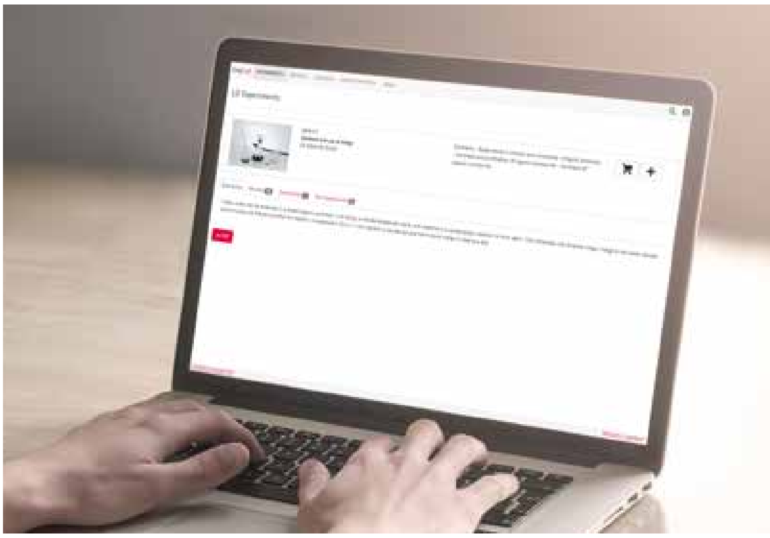
- Purchased LD literature will be visible at related experiment
- Can be easily shared with all students
- Own experiment instructions can be included

LICENSE MANAGEMENT

- Manage all LD software and literature
- License codes are safely stored in the cloud, so they are not lost and can be used to install software on new hardware

EXPERIMENT COLLECTION

- Access to the whole LD experiments catalog with all the relevant information for every experiment
- Find desired experiment quickly and reliably
- Set-up own experiment collection
- Easily expand the LD experiments
- Easily create own, new experiments
- Intelligently link devices
- Additional documents are where you need them for the experiment
- Collection of all kinds of documents like PDFs, videos or links to websites or apps; can be shared with students



GUEST ACCESS & COLLABORATION

- Third party access to LeyLab is possible
- Collaborate with colleagues
- User administration with different access levels
- Share information with other lecturers from other institutes
- Enables a centralised organisation (e.g. by ministry) of many institutes and therefore a more efficient use of equipment, documents, etc.

LEYLAB - ONLINE PORTAL

- School/college/university license
- For any number of users
- Unlimited inventory of devices & experiments
- Numerous experiment instructions available

200 310	LeyLab (License code)

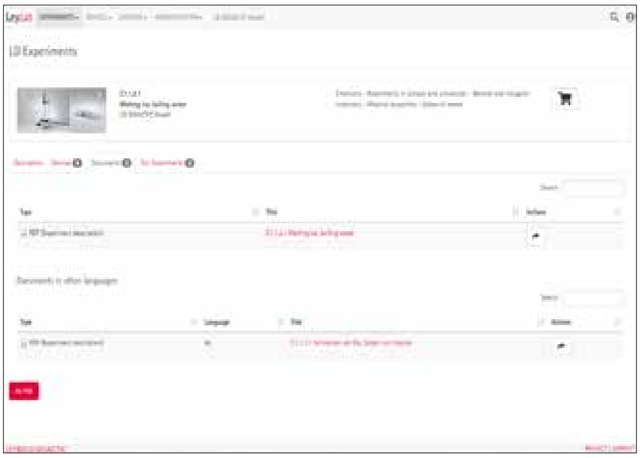
http://www.leybold-shop.com/200310

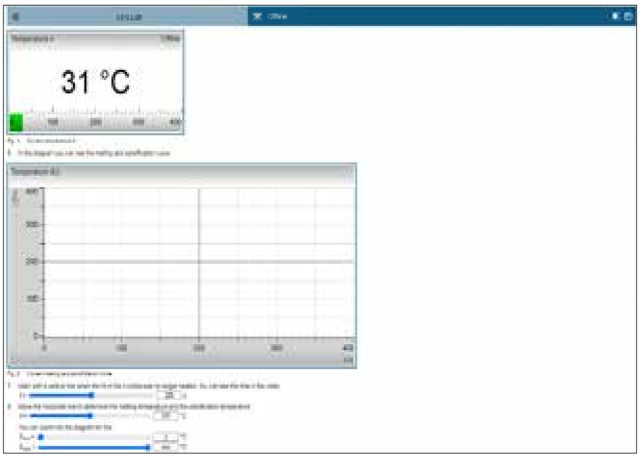
EXPERIMENT INSTRUCTIONS

ENHANCED DIGITALLY FOR YOUR LAB WORK

1. PREPARATION

- LeyLab contains all purchased LD experiment instructions, can be accessed from anywhere
- Time-saving preparation - all information is available directly on the experiment - literature, needed devices and location, extra information
- List of conductable experiments with existing devices can be downloaded
- Experiment instructions contain detailed accompanying information with experiment objectives, evaluation and further information
- Easy sharing of experiment instruction
- Free-of-charge online updates of experiment instructions in LeyLab





3. EXPERIMENTING

- Clearly structured worksheets with hints and illustrations
- Step-by-step guide to perform experiment and warning notices for safe experimentation
- Real example measurement results and diagrams for students own monitoring

2. DISTRIBUTION

- Share experiment instruction in LeyLab with all students
- Via QR code on-site or online classes
- Via link per e-mail, learning platforms or online classes
- Via PDF file per e-mail, learning platforms or online classes

EXPERIMENT INSTRUCTIONS

Experiment descriptions from all areas of chemistry for advanced secondary level or for practical exercises in colleges and universities.

- Product key for online use in LeyLab
- Complete package of all experiment instructions within this catalogue

597 320	LIT: Chemistry leaflets, digital (product key)

http://www.leybold-shop.com/597320

Lab Docs Editor is an easy-to-use tool that revolutionises the editing of experiment instructions. Without any knowledge of HTML, the Lab Docs Editor allows the creation of digital and interactive experiment instructions.

- Create instruction & assignments; integrate & adapt interactive diagrams and tables; add text and response fields
- Insert images, vector graphics, hyperlink, etc.
- Prepare and create material lists
- Create formulas in LaTeX syntax

200 320	Lab Docs Editor

http:www.leybold-shop.com/200320

CASSY – THE SYSTEM

DATA LOGGING & MEASUREMENT

1. BASIC UNITS

WITH OR WITHOUT PC
& WIFI OPTION

MOBILE-CASSY 2
WIFI

SENSOR-CASSY 2
(ALSO WITH WIFI)

POCKET-CASSY 2

- For all teaching & training situations and requirements
- Easy use
- Fast & precise recording of data acquisition
- Wide choice
- Libraries for MATLAB and LabVIEW available free of charge

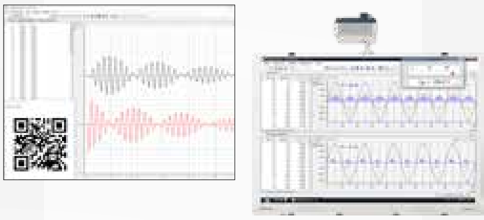
2. SENSORS

FOR ALL
MEASURING TASKS

- More than 50 CASSY sensors
- Compatible across the CASSY system
- Measurement data acquisition of more than 50 measured quantities
- Automatic detection
- Existing sensors can be integrated

3. SOFTWARE

DATA ACQUISITION,
ANALYSING & EVALUATION



- Intuitively usable, all-round user-friendly software
- Interpretation & evaluation of the measured values
- Integrated experiment examples or own configurations
- Saving and sharing of measured values

CASSY – ALWAYS THE RIGHT SOLUTION

Whether you want to record the measured data from the experiments with or without a computer, or even want to include tablets in your digital class, CASSY has been developed for every need and can be flexibly expanded. You will always find the right combination of measuring device, sensor and measuring software for your specific requirements.

Detailed information on CASSY sensors

https://www.ld-didactic.de/en/products-solutions/data-logging-and-measuring-technology/cassy-sensors.html

ENTIRE EXPERIMENT SET-UPS WITH MATCHING MEASURING DEVICES, SENSORS & SOFTWARE

For each experiment, the recommended CASSY device and sensor is included in the experiment set-up for ideal data logging of the specific experiment.

With our selection of the measuring equipment for each single experiment we make sure that the devices perfectly meet the requirements of the measurement ranges and the measurement accuracy with no overpowering. While designing and testing every experiment set-up, we furthermore include factors such as technical conditions and ease of use for students into consideration.

If you want to acquire several experiments for your laboratory, we will be happy to advise you on how to optimise the measuring system.

YOU GET EXPERIMENT SET-UPS THAT PERFECTLY WORK!

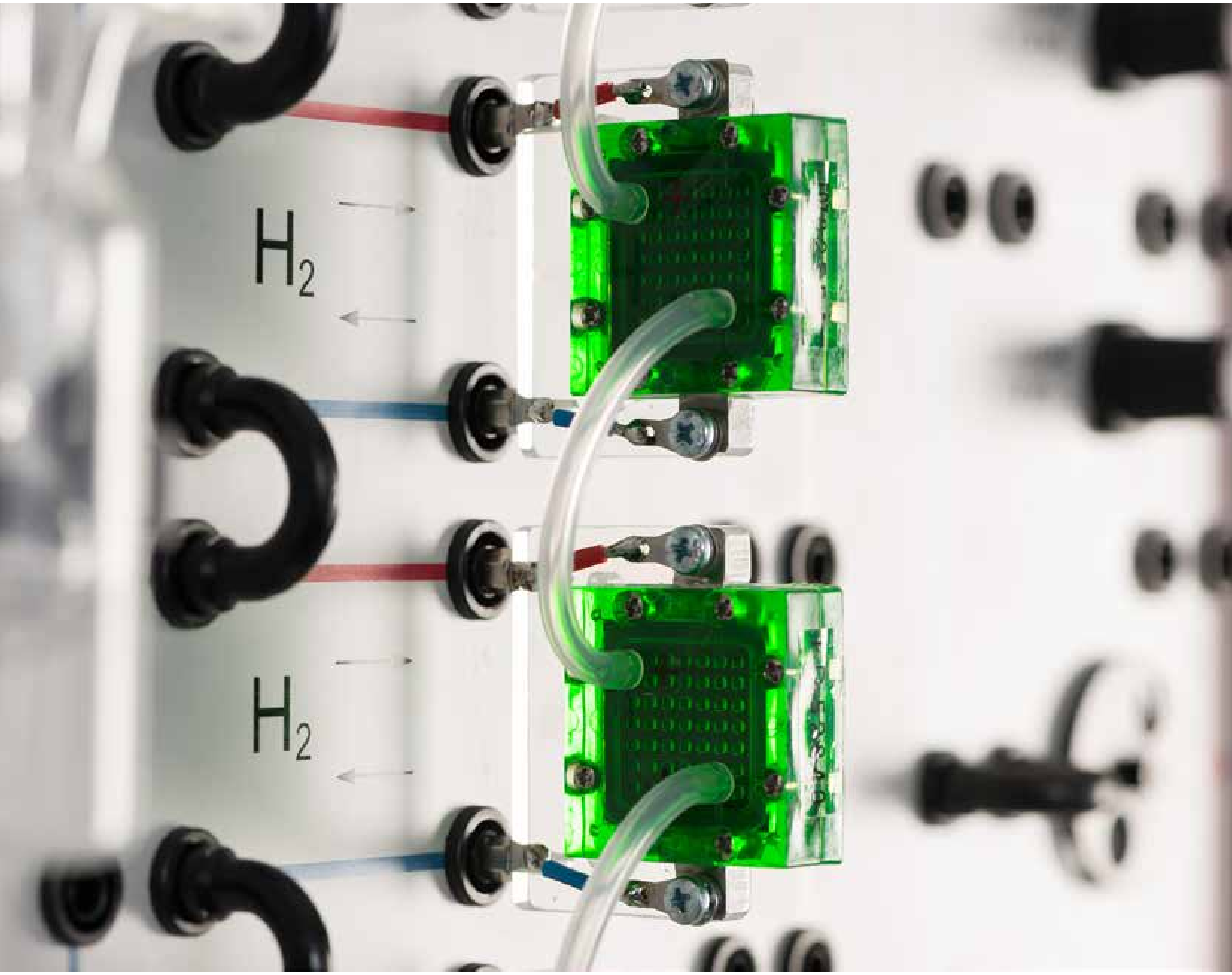
CASSY LAB 2

PROVEN SOFTWARE FOR RECORDING & EVALUATING MEASUREMENT DATA FROM ALL CASSY DEVICES

- Supports all CASSY devices and sensors
- Including measurement server for the distribution of live measurements, table and diagram as well as measurement files on tablets or smartphones, etc.
- One licence for use on any number of PCs in a school, college or university
- Automatic detection and display of all CASSYs sensors and sensor boxes
- Automatic loading of typical experiment parameters
- Operable experiment examples included
- Manual or automatic recording of measured values
- Measurement data can be displayed in the form of analog/digital instruments, tables and/or graphs (also simultaneously, with user-definable axis assignment)
- Powerful evaluation functions including various fits (straight line, parabola, hyperbola, exponential function, free fitting), integrals, diagram labelling, calculation of user-definable formulas, differentiation, integration, Fourier transforms
- Using a QR code, students can follow measurement directly on their smartphone/tablet and then evaluate the measured data

Basic device		No. of sensor sockets	No. of channels for simultaneous measurement	Integrated ability to measure	Inte-grated display	Data storage in the unit	Computer interface	Supported sensor types	Software support
	Sensor-CASSY 2 (524 013)	2	4	U, I, P, E	NO	NO	USB, WiFi adapter	CASSY sensors S	CASSY App CASSY Lab 2 MATLAB LabVIEW
	Mobile-CASSY 2 WiFi (524 005W)	2	3	U, I, P, E & temperature	YES	YES	Integrated WiFi, USB, standalone	CASSY sensors S, CASSY sensors M	CASSY App CASSY Lab 2 MATLAB LabVIEW
	Pocket-CASSY 2 Bluetooth (524 018)	1	1	NONE	NO	NO	Bluetooth, USB	CASSY sensors S	CASSY App CASSY Lab 2 MATLAB LabVIEW
	Universal measurement instrument chemistry (531 836)	1	1	temperature	YES	NO	USB, standalone	CASSY sensors S (partial)	CASSY Lab 2 MATLAB LabVIEW

UNDERSTANDING
FUEL CELL TECHNOLOGY



PEM fuel cell stack (666 4812).

CHARGING HYDROGEN QUICKLY AND EASILY

WITH THE LEYBOLD CPS FUEL CELL SYSTEM

- PEM fuel cell stack consisting of four individual cells which can be quickly connected in series or in parallel
- Clear layout makes the experiments simple to perform and easy to understand
- In combination with the electrical load module: simple recording of characteristic curves and measurement of efficiency factors
- Hydrogen from the HydroStik PRO: no gas bottle needed

Recording of characteristic curves using Sensor-CASSY 2 and CASSY Display (no computer necessary).

HydroStik PRO, CPS	666 4795
Bubble counter, CPS	666 4794
PEM fuel cell stack, CPS	666 4812
Electrical load, CPS	666 4831
HydroFill PRO	666 4798

THE EASY WAY TO PRODUCE ALL THE H_2 YOU NEED RIGHT FROM THE WALL SOCKET – AND SAVE SPACE AT THE SAME TIME!

The HydroFill PRO (666 4798) supplies hydrogen through the electrolysis of distilled water. Only a wall socket is required. The hydrogen is stored directly in the HydroStik PRO (666 4796) in the form of a metal hydride. In this way, experiments can be performed with hydrogen without the use of gas bottles, e.g. for experiments with fuels cells.

HydroFill PRO Video at the LD DIDACTIC YouTube Channel.

Charging the HydroStik PRO – as easy as a mobile phone:

1. Place it in the HydroFill PRO charging station
2. Charge it with hydrogen for 4 to 6 hours.
3. Use the hydrogen in experiments.

UNDERSTANDING
ELECTROCHEMISTRY

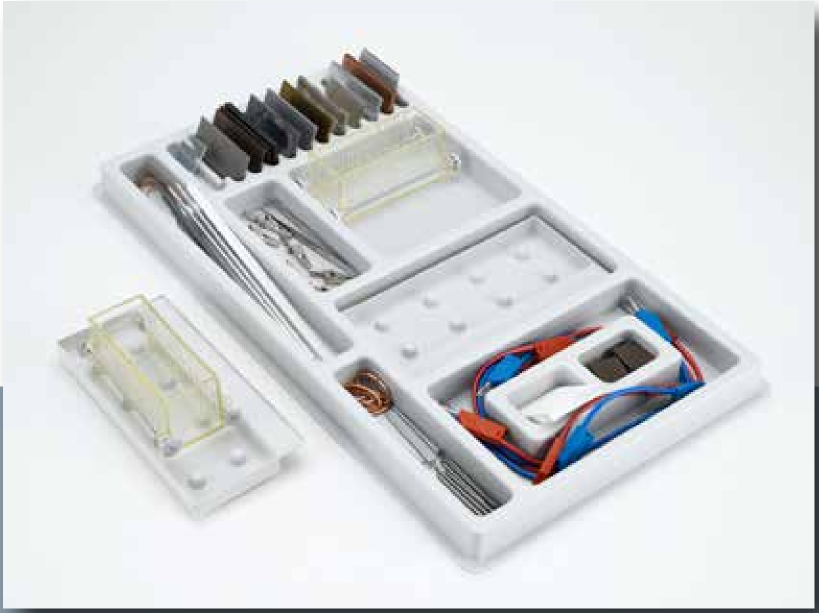
The electrochemistry demonstration system:
ideal for performing electrochemical experiments.

WITH THE ELECTROCHEMISTRY DEMONSTRATION SYSTEM

- The demonstration system fulfils 3 functions:
    - It includes two separate instruments to measure voltage and current.
    - It operates as a power supply for direct and alternating current.
    - A small integrated motor with segmented disc serves as a power indicator.
- Its large, clear displays are easy to read and allow the students to focus on conducting the experiment.
- With the accessory set and experiment instructions, up to 40 experiments can be carried out.
- Topics
    - Conductivity of solids and liquids
    - Electrochemical series of metals and non-metals
    - Corrosion and corrosion protection
    - Faraday's laws
    - Galvanic cells

The electrochemical demonstration system can be mounted in a CPS frame. All experiments can then be carried out on the experiment table, which is also mounted in the frame.

Electrochemistry demonstration, CPS, Equipment set	664 4071P
Electrochemistry demonstration unit, CPS	664 4071
Electrochemistry accessory set	664 401
Panel frame C50, two-level, for CPS	666 425
Table for electrochemistry, CPS	666 472



Electrochemistry accessories set (664 401)

COMPACT SPECTROMETER

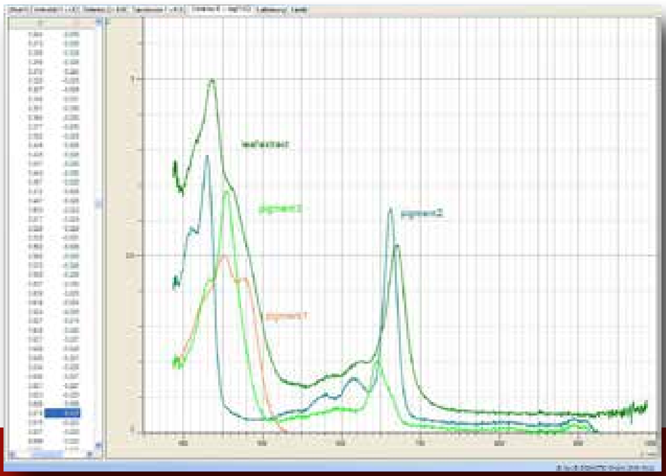
SAVES SPACE AND CAN BE USED FOR A WIDE RANGE OF EXPERIMENTS

In combination with the fibre optic cable, the spectrometer is particularly well-suited for analysing flame colourations.

FAST AND EASY-TO-INTERPRET SPECTRAL MEASUREMENTS

- Small device with USB connection
- SpectraLab software: displays spectra while taking measurements
- Simultaneous measurement of all wavelengths
- Cuvette holder with integrated lamp (optional)
- Example experiments
- Flame colouration
- UV/VIS spectra of dyes
- Fluorescence spectra
- Determination of pK_a values of indicators
- Variants for VIS or UV/VIS measurements

The cuvette holder also makes it possible to carry out photometric measurements on small quantities.



Analysis of leaf pigments with the SpectraLab software.

SpectraLab	467 250
Compact spectrometer, physics (spectral photometer)	467 251
Compact spectrometer, complete	467 252
Cell holder with light source	467 253
Optical fibre waveguide VIS/NIR	467 254
Compact UV spectrometer, physics	467 261
Compact UV spectrometer, complete	467 262
Cell holder with UV light source	467 263

THE LD SOLUTION

MUCH MORE THAN HARDWARE

SOLUTION OFFER

DETAILED INDIVIDUAL OFFER

CONSULTING

FINANCE

LECTURER ACADEMY TRAINING

PRODUCTION AND QUALITY CONTROL

AFTER SALES SUPPORT

INSTALLATION AND TRAINING ON SITE

LEYBOLD DIDACTIC ACADEMY

THE PATH TO TEACHING EXCELLENCE

TRAINING PROGRAMS TO ENSURE SUSTAINABLE FACILITIES AND RESOURCES

- Specialised training programs for teachers, lecturers and trainers
- Methodological, didactic and technical training
- Content and training focus is chosen on requirements
- Practical work is central point, incl. whole process to perform experiments
- Organisation & maintenance of equipment
- Seminar has external parts at well-known schools, universities and institutions
- Insights into German didactic standards and trends
- Comprehensive guides and seminar documentation
- Possibility to achieve qualification to train other teachers, lecturers or trainers

REFERENCE PROJECT MEXICO

The university "Universidad Autónoma del Estado de Hidalgo" achieved a higher educational level for teachers in implementing experiments in classes through practical lab work and theory. They also obtained sustainable know-how in lab management and the all related work flow processes.

The seminar took place in the labs at LEYBOLD, the University of Cologne and an extracurricular place of learning.

EXPERIMENTS AT A GLANCE

C1.5 Metals and their properties

Extraction of metals,

Corrosion

Pages 54–58

C1.6 Non-metals and their properties

The oxygen group

Page 59

C1.7 Acids, bases and salts

Acid strengths and pH values,

Salts and ionic compounds

Pages 60–63

C3.5 Quantitative analysis

Potentiometric and acid-base titrations,

Conductometric titrations,

Redox titrations

Pages 98–103

C3.6 Applied analytics

Water analytics,

Air analytics,

Food analytics,

Material analytics

Pages 104–108

C4.6 Transport processes

Osmosis

Page 148

HOW TO USE THIS CATALOGUE

PAGE STRUCTURE

ANALYTICAL CHEMISTRY
CHROMATOGRAPHY

Gas chromatographical analysis of cigarette lighter gas (butane gas) (C3.2.1.1)

C3.2.1
GAS CHROMATOGRAPHY

C3.2.1.1
Gas chromatographical analysis of cigarette lighter gas (butane gas)

Cat.-Nr.	Name	C3.2.1.1
665 580	Gas chromatograph LD 1	1
665 582	Hydrocarbon sensor	1
665 5831	Separation column silicone OV101	1
524 018	Pocket-CASSY 2 Bluetooth	1
524 019	Rechargeable battery for Pocket-CASSY 2 Bluetooth	1*
524 0031	Bluetooth dongle	1*
524 220	CASSY Lab 2	1
524 0621	UIP sensor S	1
662 2861	Aquarium pump, 100 l/h	1
664 814	Bubble counter, with flash back valve	1
665 957	Disposable syringe, 1 ml, with Luer fitting	1
665 960	Cannula, 0.45 diam., 10 pcs., with Luer fitting	1
501 45	Connecting leads, 19 A, 50 cm, red/blue, pair	1
666 503	Base plate for bunsen stand, 130 x 210 mm	1
666 523	Stand rod, 450 x 12 mm diam., M10 thread	1
666 555	Universal clamp, 0...80 mm	1
301 09	Bosshead S	1
665 585	Septa, silicone, 13 mm diam., 10 pcs.	1
667 197	Silicone tubing, 4 mm diam., 1 m	1
660 980	Fine regulating valve for minican gas canisters	1
660 988	Minican pressurised gas canister, ethane	1
660 985	Minican pressurised gas canister, n-Butane	1
	additionally required: cigarette lighter(s)	1

* additionally recommended

In use all around the world today, gas chromatography is a method for analyzing chemical substances and mixtures. Especially useful for identifying the components of gaseous hydrocarbons, e.g. natural gas, it can also be used to study volatile substances such as fragrances or alcohols. Substances are separated in a two-phase system comprising a stationary phase – the separation column with column material – and a mobile phase – the carrier gas. Samples are introduced into the carrier gas stream and travel along the column at different speeds depending on polarity, which makes it possible to separate them.

Cigarette lighter gas is a mixture of different gaseous hydrocarbons. They can be easily separated by gas chromatography techniques. The stationary phase is silicone oil OV-101 on silica gel. Air is used as the mobile phase. The proportions of the individual hydrocarbons in the gas mixture is different in every cigarette lighter – depending on the source of the natural gas. This is studied in experiment C3.2.1.1.

Chromatogram of the analysis of lighter gases

www.ld-didactic.com

Section
Subsection

Experiment set-up

Measurement option
With computer-assisted experiments, the recommended basic unit is shown

Topic

Experiment

Each experiment is identified by a C and a four-digit number.

Short description of the experiment

Experiment results

Equipment list

C1 GENERAL AND INORGANIC CHEMISTRY

Determination of the relative atomic mass of metals (C1.1.1.1)

C1.1.1

DETERMINATION OF MOLAR MASS

C1.1.1.1
Determination of the relative atomic mass of metals

Cat. No.	Description	C1.1.1.1
664 097	Stoichiometric reaction vessel	1
665 914	Gas syringe, 100 ml with 3-way stopcock	1
665 936	Immersion tube manometer, after Schiele	1
664 352	Topping-up reservoir, 250 ml	1
667 194	Silicone tubing 7 mm Ø, 1 m	1
382 21	Stirring thermometer -10...+110 °C	1
667 312	Glass connector, 2 x GL 18	1
667 017	Scissors 125 mm, round-ended	1
667 027	Tweezers, blunt, 130 mm	1
664 131	Beaker Boro 3.3, 400 ml, squat	1
665 753	Measuring cylinder 50 ml, with plastic base	1
666 4659	Adhesive magnetic board 500 mm	2
666 4662	Holder, magnetic, size 2, 11...14 mm	1
666 4665	Holder, magnetic, size 5, 30...32 mm	3
666 425	Panel frame C50, two-level, for CPS	1
ADA NBL124E	Analytical balance 120 g; 0,0001g, with USB interface	1
674 6810	Hydrochloric acid, 10 %, 1 l	1
673 1000	Magnesium, ribbon, 25 g	1
661 081	Aluminium, foil, 1 roll	1
671 2000	Calcium, granules, 25 g	1

The realisation that chemical reactions depend not on the mass of a substance but on the number of atoms marks the transition from alchemy to chemistry as a science. In that way, the molar mass can be used to carry out reactions with the right quantity of material.

In experiment C1.1.1.1, the molar mass of some base metals will be determined. In order to do so, those metals - magnesium, for example - will be reacted with acids.

$$Mg + 2\,H^{+} \rightarrow Mg^{2+} + H_2$$

Different metals of the same weight produce different quantities of hydrogen. When using the same quantity of material, the same quantities of hydrogen are produced. This way, the relative molar mass of the respective metals can be determined.

C1.1.1

DETERMINATION OF MOLAR MASS

C1.1.1.2
Determination of the molar mass of gases

Determination of the molar mass of gases (C1.1.1.2)

Cat. No.	Description	C1.1.1.2
379 07	Sphere with 2 stopcocks, glass, 1 l	1
SAP R313	Precision Balance Practum 313-1S	1
667 072	Support ring for round flask, 250 ml, cork	1
375 58	Hand vacuum pump	1
665 913	Gas syringe, 100 ml with 1-way stopcock	1
667 197	Silicone tubing, 4 mm diam., 1 m	1
604 434	Silicone tubing, 8 mm diam., 1 m	1
604 510	Tubing connector, 4...15 mm	2
667 186	Vacuum rubber tubing, 8 mm diam.	1
604 491	Vacuum tubes, 6 mm diam.	1
660 998	Minican pressurised gas canister, oxygen	1
661 000	Minican pressurised gas canister, nitrogen	1
660 980	Fine regulating valve for minican gas canisters	2
661 082	Stopcock grease, 60 g	1

At constant pressure and constant temperature, any gas occupies the same volume regardless of the type of atom or the composition. So if we know the volume, pressure and temperature, we can then determine the molar mass of gases. The measurement is conducted in experiment C1.1.1.2 with a glass sphere for weighing gases.

C1.1.2

STATES OF MATTER

C1.1.2.1
Melting ice, boiling water

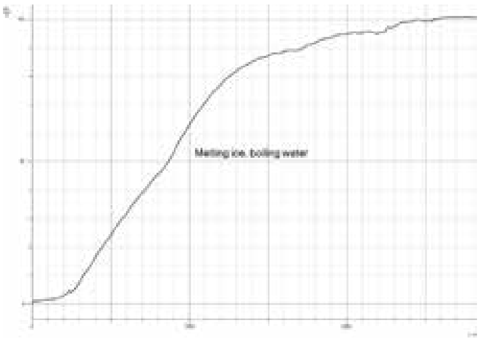
Melting ice, boiling water (C1.1.2.1)

Cat. No.	Description	C1.1.2.1
524 005W	Mobile-CASSY 2 WiFi	1
524 220	CASSY Lab 2	1
529 676	Temperature probe, NiCr-Ni, 1.5 mm, type K	1
664 105	Beaker, DURAN, 600 ml, squat	1
666 850	Stirring magnet, 15 mm x 5 mm diam.	1
666 8471	Magnetic stirrer with hotplate	1
666 523	Stand rod, 450 x 12 mm diam., M10 thread	1
666 555	Universal clamp 0...80 mm	1
301 09	Bosshead S	1
	additionally required: ice	

There are three states of matter: solid, liquid and gas. Solid materials have a stabile outer shape and a definite volume. Liquids have a definite volume but no longer have a solid shape. Gaseous materials have neither a shape nor a volume: they fill up any available space.

At constant pressure, materials transition from one state of matter to the next at a characteristic temperature. Those temperatures are known and listed as the melting point and boiling point.

Experiment C1.1.2.1 examines the behaviour of water at different temperatures. To that end, ice (solid water) is slowly heated until it melts and then evaporates. At the boiling point and the melting point, the temperature does not change until the substance has transitioned completely to the other state. The boiling point and melting point are easy to determine in this way.



Melting and boling curve of water

Brownian motion of smoke particles (C1.1.3.1)

C1.1.3

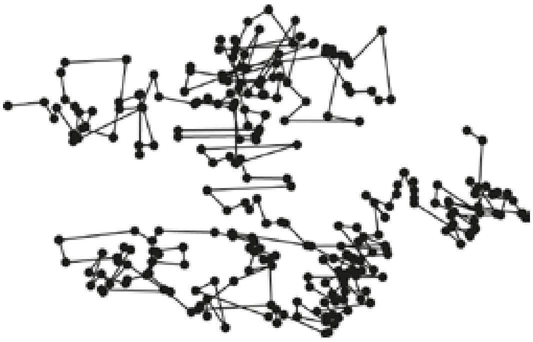
STRUCTURE OF MATTER

C1.1.3.1
Brownian motion of smoke particles

Cat. No.	Description	C1.1.3.1
MIK 5738870	Microscop EduLed FLArQ mono	1
372 51	Smoke chamber	1
450 60	Lamp housing with cable	1
450 521	Bulbs, 12 V/30 W, E14, set of 2	1
460 20	Condenser with diaphragm holder	1
521 210	Transformer 6/12 V	1
300 02	Stand base, V-shaped, small	1
665 958ET5	Disposable syringe, 10 ml, with Luer fitting, 5 pcs.	1
MIK 74708	BMS SyncCam 8Mp	1
	additionally required: incense cone or cigarette, pc or device for image transmission	1

Matter is everything that takes up space and has mass. We distinguish between pure substances and mixtures. Mixtures can be homogeneous or heterogeneous. Pure substances are elements and are made up entirely of the same type of atom. Each atom consists of a core, the nucleus, and a shell, the electron shell.

The speed and direction of a particle floating in a gas changes continuously. *J. Perrin* provided the explanation for this molecular motion, which was discovered by *R. Brown*: it is caused by the impacts of the gas molecules on the particle. The smaller the particle, the livelier the motion. It comprises a translational motion and a similarly changing rotation. In experiment C1.1.3.1, a microscope is used to observe the motion of smoke particles in air.



Schematic diagram of Brownian motion of molecules

Estimation of the size of oil molecules (C1.1.3.2)

C1.1.3

STRUCTURE OF MATTER

C1.1.3.2
Estimation of the size of oil molecules

Cat. No.	Description	C1.1.3.2
664 179	Crystallisation dish, 230 mm diam., 3500 ml	1
665 843	Burette clear glass, 10 ml, side stopcock	1
664 110	Beaker, DURAN, 50 ml, tall	1
665 751	Measuring cylinder 10 ml, with plastic base	1
665 754	Measuring cylinder 100 ml, with plastic base	1
300 02	Stand base, V-shaped, small	1
300 43	Stand rod, 75 cm, 12 mm diam.	1
301 09	Bosshead S	1
666 555	Universal clamp 0...80 mm	1
675 3410	Water, pure, 5 l	1
672 1240	Glycerinetrioleate, 100 ml	1
674 2220	Petroleum ether, 40...70 °C, 1 l	1
670 6920	Lycopodium spores, 25 g	1

One of the important questions in atomic physics is the question of the size of the atom. The study of the size of molecules provides experimentally easier access on a manageable magnitude. Experiment C1.1.3.2 uses simple means to estimate the size of molecules from the size of a patch of oil floating on the surface of water.

Determining the area A of the oil spot

Analysis of Rutherford scattering (C1.1.3.4)

C1.1.3

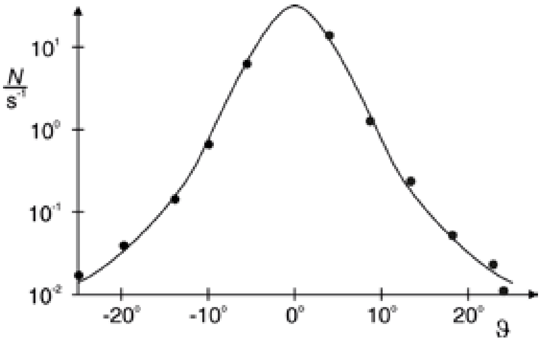
STRUCTURE OF MATTER

C1.1.3.4
Analysis of Rutherford scattering

Cat. No.	Description	C1.1.3.4
559 820Z	Am-241 preparation, 330 kBq	1
559 56	Rutherford scattering chamber	1
559 52	Aluminium foil in frame	1
559 931	Discriminator preamplifier	1
562 791	Plug-in power supply, 12 V AC	1
575 471	Counter S	1
378 73	Rotary-vane vacuum pump S 1.5	1
378 005	T-piece, DN 16 KF	1
378 040	Centering ring (adapter) DN 10/16	1
378 045	Centering ring DN 16 KF	1
378 050	Clamping ring, DN 10/16 KF	2
378 771	Air inlet valve, DN 10 KF	1
378 031	Hose nozzle, DN 16 KF	1
667 186	Vacuum rubber tubing, 8 mm diam.	1
501 01	BNC cable, 0.25 m	1
575 24	Screened cable, BNC/4 mm	1

The fact that an atom is "mostly empty" was confirmed by *Rutherford, Geiger* and *Marsden* in a momentous experiment. They let a parallel bundle of α-particles fall on a very thin sheet of gold foil. In so doing they found that the vast majority of α-particles pass through the gold foil almost without any deflection at all and only very few are deflected to any large degree. They concluded from this that atoms comprise a nearly massless, extended shell and a massive core concentrated practically at a point.

Experiment C1.1.3.4, carries out an observation with an Am-241-preparation in a vacuum chamber. Depending on the scatter angle ϑ the scatter rate $N(\vartheta)$ of the α-particles is measured with a Geiger-Müller tube.



Scattering rate N as a function of the scattering angle delta

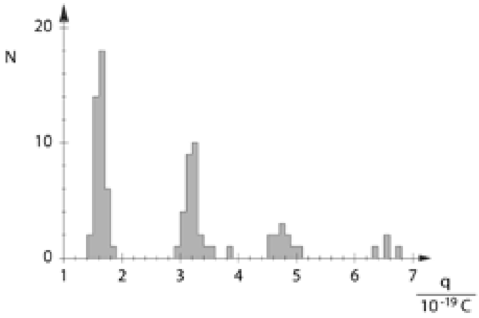
C1.1.3

STRUCTURE OF MATTER

C1.1.3.5
Determination of the elementary electric charge according to Millikan and proof of charge quantisation

Determination of the elementary electric charge according to Millikan and proof of charge quantisation (C1.1.3.5)

Cat. No.	Description	C1.1.3.5
559 412	Millikan apparatus	1
559 421	Millikan supply unit	1
313 033	Electronic time clock P	1
501 46	Connecting leads 19 A, 100 cm, red/blue, pair	3



The histogram reveals the qantum nature of the change

With his famous oil-drop method, R. A. Millikan succeeded in demonstrating the quantum nature of minute amounts of electricity in 1910. He caused charged oil droplets to be suspended in the vertical electric field of a plate capacitor and, on the basis of the radius *r* and the electric field *E*, determined the charge *q* of a suspended droplet:

$$q = \frac{4\pi}{3} \cdot r^3 \cdot \frac{\rho \cdot g}{E}$$

ρ: density of oil

g: gravitanional acceleration

He discovered that *q* only occurs as a whole multiple of an electron charge *e*.

In experiment C1.1.3.5, the electric field

$$E = \frac{U}{d}$$

d: plate spacing

is calculated from the voltage *U* on the plate condenser at which the oil droplet is observed floating straight. To determine the radius, the constant sinking velocity v_1 of the droplet is then measured with the electric field switched off. From the equilibrium between the force of gravity and Stokes' drag, it follows that

$$\frac{4\pi}{3} \cdot r^3 \cdot \rho \cdot g = 6\pi \cdot r \cdot \eta \cdot v_1$$

η: viscosity

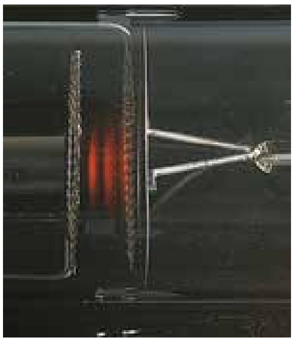
C1.1.3
STRUCTURE OF MATTER

C1.1.3.6
Franck-Hertz experiment

Franck-Hertz experiment (C1.1.3.6)

Cat. No.	Description	C1.1.3.6
555 870	Ne Franck-Hertz tube	1
555 871	Holder with socket and screen	1
555 872	Connecting cable for Ne Franck-Hertz tube	1
555 880	Franck-Hertz supply unit	1
524 013	Sensor-CASSY 2	1
524 220	CASSY Lab 2	1
501 46	Connecting leads 19 A, 100 cm, red/blue, pair	2
	additionally required: PC with Windows XP/Vista/7/8/10 (x86 or x64)	1

In 1914, J. Franck and G. Hertz reported observing discontinuous energy emission when electrons passed through mercury vapor, and the resulting emission of the ultraviolet spectral line (λ = 254 nm) of mercury. A few months later, Niels Bohr recognised that their experiment supported his model of the atom. The de-excitation of neon atoms can occur indirectly via intermediate states, with the emission of photons. In this process, the photons have a wavelength in the visible range between red and green. The emitted light can thus be observed with the naked eye. Between the grids G_1 and G_2 reddish luminous layers, clearly separated from one another, can be observed, and their number increases with increasing voltage. These are zones of high excitation density, in which the excited atoms emit spectral light.



Luminous layers between control electrode and acceleration grid

C1.1.3

STRUCTURE OF MATTER

C1.1.3.7
Recording emission spectra of a flame test

Recording emission spectra of a flame test (C1.1.3.7)

Cat. No.	Description	C1.1.3.7
467 251	Compact spectrometer, physics (spectral photometer)	1
460 251	Fibre holder	1
300 11	Saddle base	1
666 731	Gas igniter, mechanical	1
666 960	Powder spatula, stainless steel, 150 mm	1
667 089	Spotting tile	1
656 017	Teclu burner, universal	1
607 020	Safety gas hose with clamp 0.5 m	1
673 0840	Magnesia rods, 25 pieces	1
665 953	Dropping pipette, 7 x 150 mm, 10 pcs.	1
665 954	Rubber bulbs, 10 pcs	1
661 088	Salts for flame tests, set of 9	1
674 6950	Hydrochloric acid, 0.1 mol/l, 500 ml	1
	additionally required: PC with Windows XP/Vista/7/8/10 (x86 or x64)	1

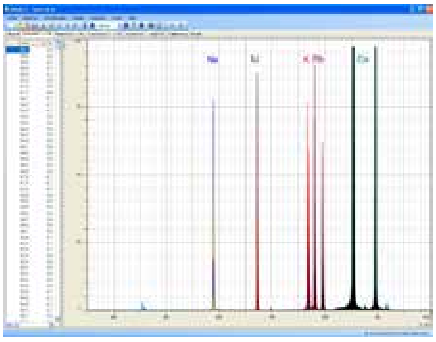
Spectral lines occur when electrons transition from higher to lower energy levels in the shell of excited atoms. The wavelength of the light emitted during the transition is determined by that energy differential:

$$\nu = \frac{E_2 - E_1}{h}$$

h: Planck's constant

Because the energies E_1 and E_2 can only take on discrete values, only photons with discrete frequencies are emitted or absorbed. Taken all together, the frequencies which occur are referred to as the spectrum of the atom. The arrangement of the spectral lines is characteristic for the element concerned.

Experiment C1.1.3.7 investigates flame colourations of metal salts. A compact spectrometer with a USB link to the computer makes it easy to record such transient events and to analyse the emission lines which are produced. Unlike in classical observation with the eye, lines in the IR range can also be identified, e.g. for potassium.



Emission spectra of different metal salts

C1.2.1

LAW OF CONSERVATION OF MASS

C1.2.1.1
Conservation of mass in the reaction of marble with acid

Conservation of mass in the reaction of marble with acid (C1.2.1.1)

Cat. No.	Description	C1.2.1.1
ADA HCB602H	Precision Balance, 600 g /0,01g, with USB interface	1
664 238	Erlenmeyer flask, DURAN, 250 ml, wide neck	1
664 043	Test tubes, Fiolax, 16 x 160 mm, set of 10	1
665 997	Graduated pipette 10 ml	1
666 003	Pipetting ball (Peleus ball)	1
667 0344	Tweezer, blunt, 145 mm	1
667 243	Rubber balloons, set of 10	1
362 04	Overflow vessel	1
602 953	Measuring cylinder, Boro 3.3, 100 ml, glass base	1
674 6900	Hydrochloric acid, 1 mol/l, 500 ml	1
673 2500	Marble, pcs., 250 g	1

The law of conservation of mass was formulated in 1789 by Antoine Laurent de Lavoisier: For a chemical reaction in a closed system, the sum of the masses of the starting materials is equal to the sum of the masses of the products.

Experiment C1.2.1.1 demonstrates that in a chemical reaction the total mass of the substances involved in the reaction remains unchanged. In the experiment, hydrochloric acid is pipetted into a test tube. Pieces of marble are introduced into a balloon. The reaction is started by tipping the pieces of marble into the acid. Although bubbles form, it can be observed that no mass is lost.

Synthesis of magnesium oxide (C1.2.2.1)

C1.2.2
LAW OF DEFINITE PROPORTIONS

C1.2.2.1
Synthesis of magnesium oxide

Cat. No.	Description	C1.2.2.1
666 9882	Combustion boat, glazed	1
664 077	Reaction tube, quartz, 300 x 20 mm dia., SB 19	1
667 286	Silicone stopper, one 7-mm hole, 16...21 mm Ø	2
665 914	Gas syringe, 100 ml with 3-way stopcock	2
666 714	Cartridge burner, DIN type	1
666 715	Cartridge	1
300 76	Laboratory stand II	2
666 731	Gas igniter, mechanical	1
ADA NBL124E	Analytical balance 120 g; 0,0001g, with USB interface	1
667 194	Silicone tubing 7 mm Ø, 1 m	1
667 197	Silicone tubing, 4 mm diam., 1 m	1
604 510	Tubing connector, 4...15 mm	1
666 4660	Adhesive magnetic board 300 mm	6
666 4661	Holder, magnetic, size 1, 9...11 mm	2
666 4665	Holder, magnetic, size 5, 30...32 mm	2
666 428	Panel frame C100, two-level, for CPS	1
441 531	Screen	1
300 02	Stand base, V-shaped, small	1
673 1000	Magnesium, ribbon, 25 g	1
674 6970	Hydrochloric acid, 0.5 mol/l, 500 ml	1
660 998	Minican pressurised gas canister, oxygen	1
660 980	Fine regulating valve for minican gas canisters	1

The law of definite proportions is one of the laws of proportion and a fundamental principle in chemistry. It is the basis for the concept of the mol, and stoichiometry would also be unthinkable without this law. Two substances always react with one another in equal (= constant) proportions, which means that there are fixed combination relationships. Developed in part through longsome analyses carried out by Berzelius at the beginning of the 19th century, this law made it possible to write reaction equations for the first time.

In experiment C1.2.2.1, the law of definite proportions is confirmed by the synthesis of magnesium oxide. Magnesium reacts with oxygen in a luminous reaction to magnesium oxide.

$$2\ Mg + O_2 \rightarrow 2\ MgO$$

The starting material magnesium and the product magnesium oxide can be weighed. In addition, the quantity of oxygen consumed is determined by measuring the volume. The results can be used to determine the mass ratio of oxygen to magnesium. Repeated tests can then show that it remains constant.

Analysis of copper(I) oxide and copper(II) oxide (C1.2.3.1_p)

C1.2.3

LAW OF MULTIPLE PROPORTIONS

C1.2.3.1_p
Analysis of copper(I) oxide and copper(II) oxide

Cat. No.	Description	C1.2.3.1_p
666 428	Panel frame C100, two-level, for CPS	1
666 4660	Adhesive magnetic board 300 mm	4
666 4659	Adhesive magnetic board 500 mm	1
666 4662	Holder, magnetic, size 2, 11...14 mm	3
666 4664	Holder, magnetic, size 4, 27...29 mm	1
666 4795	HydroStik PRO, CPS	1
666 4798	HydroFill PRO	1
664 077	Reaction tube, quartz, 300 x 20 mm dia., SB 19	1
664 086	U-Tube, 160 mm, 2 side taps, 2 SB 19	1
667 312	Glass connector, 2 x GL 18	1
664 800	Gas scrubber bottle, lower section, 200 ml	1
664 806	Glass tube insert with filter, ST 29/32	1
667 255	Rubber stopper, solid, 16...21 mm diam.	2
667 286	Silicone stopper, one 7-mm hole, 16...21 mm Ø	2
667 194	Silicone tubing 7 mm Ø, 1 m	1
667 197	Silicone tubing, 4 mm diam., 1 m	1
604 520	Connector with nipple	1
665 238	Glass nozzle 90°, 80 mm x 80 mm, 8 mm Ø	1
666 988	Combustion boat, not glazed, 80 x 12 mm	2
667 035	Crucible tongs 200 mm	1
667 016	Scissors, 200 mm, pointed	1
667 034	Tweezers, blunt, 200 mm	1
604 5672	Double microspatula, steel, 150 mm	1
666 968	Spoon-ended spatula, stainless steel, 180 mm	1
666 714	Cartridge burner, DIN type	2
666 724	Wide-flame attachment	2
300 76	Laboratory stand II	2
665 212	Glass stirring rod 200 x 8 mm Ø	1
664 925	Vacuum dessicator	1
ADA NBL124E	Analytical balance 120 g; 0,0001g, with USB interface	1
666 8036	Drying oven UNB 30 l	1
672 9320	Copper(I) oxide, 250 g	1
672 9500	Copper(II) oxide, powder, 50 g	1
672 7781	Silica gel with indicator, 500 g	1
672 1000	Glass wool, 10 g	1
671 8410	Iron wool, 200 g	1

The law of multiple proportions states that the ratio of the masses of two elements which combine to form different chemical compounds is always a whole number.

Experiment C1.2.3.1 determines the mass ratios of copper and oxygen in copper(I) oxide and copper(II) oxide. In these compounds, the elements copper and oxygen are combined with one another in different mass ratios. Those different ratios can be determined by quantitative reduction with hydrogen.

Electrolytic water decomposition according to Hoffmann (C1.3.1.1_p)

C1.3.1

WATER DECOMPOSITION

C1.3.1.1_p
Electrolytic water decomposition according to Hoffmann

C1.3.1.1_s
Electrolytic water decomposition according to Hoffmann using stand material

Cat. No.	Description	C1.3.1.1_p	C1.3.1.1_s
666 446	Electrolysis apparatus, CPS	1	
666 425	Panel frame C50, two-level, for CPS	1	
521 546	DC Power Supply 0...16 V/0...5 A	1	1
501 46	Connecting leads 19 A, 100 cm, red/blue, pair	1	1
602 953	Measuring cylinder, Boro 3.3, 100 ml, glass base	1	1
665 008	Funnel, PP, 50 mm diam.	1	1
602 004	Test tubes, DURAN, 20 x 180 mm, set of 100	1	1
656 017	Teclu burner, universal	1	1
607 020	Safety gas hose with clamp 0.5 m	1	1
666 731	Gas igniter, mechanical	1	1
661 083	Wooden turnings, 10 pieces	1	1
674 7920	Sulfuric acid, diluted, approx. 2 N (= 10 %), 500 ml	1	1
664 350	Water electrolysis apparatus		1

Water consists of hydrogen and oxygen, which are bound to one another in the ratio of 2:1. So the formula is H_2O. This formula can be derived from decomposition of water by electrolysis.

In experiment C1.3.1.1, water is analyzed by electrolysis in the Hoffmann voltameter. The transformation of electrical energy into chemical energy is demonstrated at the same time. First the gases generated – hydrogen and oxygen – can be determined qualitatively. Quantitative assessment of the quantities of gas generated can then be used to derive the chemical formula for the compound water.

$$2\,H_2O(l) \rightleftharpoons 2\,H_2\uparrow + O_2\uparrow$$

C1.3.2

WATER SYNTHESIS

C1.3.2.1_p
Qualitative water synthesis

C1.3.2.1_s
Qualitative water synthesis
using stand material

Qualitative water synthesis (C1.3.2.1_p)

Cat. No.	Description	C1.3.2.1_p	C1.3.2.1_s
375 56	Water jet pump	1	1
664 133	Beaker, Boro3.3, 1000 ml, squat	1	1
665 001	Funnel for gas collection	1	1
664 800	Gas scrubber bottle, lower section, 200 ml	1	1
664 805	Glass tube insert, ST 29/32	1	1
665 237	Glass nozzle straight, 8 mm Ø	1	1
664 093	U-tube, 160 x 22 mm, 2 side taps	1	1
666 425	Panel frame C50, two-level, for CPS	1	
666 4659	Adhesive magnetic board 500 mm	1	
666 4661	Holder, magnetic, size 1, 9...11 mm	1	
666 4662	Holder, magnetic, size 2, 11...14 mm	2	
666 4664	Holder, magnetic, size 4, 27...29 mm	1	
667 312	Glass connector, 2 x GL 18	1	
300 76	Laboratory stand II	1	1
667 257	Rubber stopper solid, 19...24 mm Ø	2	2
666 4795	HydroStik PRO, CPS	1	
666 4798	HydroFill PRO	1	1
667 197	Silicone tubing, 4 mm diam., 1 m	1	1
604 481	Rubber tubing, 1 m x 4 mm diam., DIN 12865	1	
672 9700	Copper(II) sulfate, dry, 50 g	1	1
675 3410	Water, pure, 5 l	1	1
671 8410	Iron wool, 200 g	1	1
300 02	Stand base, V-shaped, small		2
608 051	Stand tube, 750 mm, diam. 10 mm		2
301 09	Bosshead S		4

Cat. No.	Description	C1.3.2.1_p	C1.3.2.1_s
666 555	Universal clamp 0...80 mm		4
667 183	Rubber tubing, 1 m x 8 mm diam., DIN 12865		1
666 4796	HydroStik PRO		1
666 4797	Regulating valve		1

Water is available in large quantities on Earth, but it can also be synthesised in the laboratory. The synthesis of water is a complementary experiment to the electrolytic decomposition of water.

In experiment C1.3.2.1, hydrogen is burned. The resulting hydrogen oxide is collected in a U-tube. White copper(II)-sulfate or water detection test paper is used to prove that it is water.

$$2\,H_2 + O_2 \rightleftharpoons 2\,H_2O$$

Thermal anomaly of water (C1.3.3.1)

C1.3.3

PROPERTIES OF WATER

C1.3.3.1
Thermal anomaly of water

Cat. No.	Description	C1.3.3.1
667 505	Anomaly of water apparatus	1
666 8451	Magnetic stirrer	1
666 851	Stirring magnet 25 mm x 6 mm Ø, circular	1
602 725	Laboratory dish, 140 mm diam., 900 ml	1
665 009	Funnel PP 75 mm Ø	1
307 66	Tubing (rubber)	1
608 040	Stand rod, 60 cm, 12 mm diam.	1
666 555	Universal clamp 0...80 mm	2
301 09	Bosshead S	2
300 02	Stand base, V-shaped, small	1
524 005W	Mobile-CASSY 2 WiFi	1
529 676	Temperature probe, NiCr-Ni, 1.5 mm, type K	1
666 194	Protective sleeves for temperature probe, set of 5	1
602 011	Beaker, Boro 3.3, 400 ml, tall	1
666 966	Spoon-ended spatula, PP, 180 mm	1
ADA CB1001	Compact scale 1000 g; 0.1g	1
666 003	Pipetting ball (Peleus ball)	1
673 5700	Sodium chloride 250 g	1
	Additional required: permanet marker, crushed ice, ruler (30 cm)	

Water is necessary for life. This is because of the special properties of water as compared with other substances. Water is one of the few compounds which exists in nature in all three states of matter: solid (ice), liquid (water) and gas (water vapour).

Water has a density anomaly: up to a temperature of 4 °C, water has a negative coefficient of expansion , i.e. it shrinks when warmed. After passing through zero at 4 °C, the coefficient of expansion becomes positive. So the density of water reaches a maximum at 4 °C.

In experiment C1.3.3.1, the density maximum of water is proven by measuring its expansion in a vessel with a riser. Starting from room temperature, the complete setup is cooled down in an ice water bath to about 1 °C under constant stirring, or after cooling in a freezer, it is warmed slowly by the ambient temperature. The level h, in a riser with a cross-sectional area A is measured as a function of the water temperature ϑ. Because the change in volume relative to the total volume V_0 is small, the result obtained for density is

$$\rho(\vartheta)=\rho(0\ ^\circ\mathrm{C})\cdot\left(1-\frac{A}{V_0}\cdot h(\vartheta)\right).$$

The ion product of water (C1.3.3.2)

C1.3.3

PROPERTIES OF WATER

C1.3.3.2
The ion product of water

Cat. No.	Description	C1.3.3.2
664 4071	Electrochemistry demonstration unit, CPS	1
666 425	Panel frame C50, two-level, for CPS	1
666 472	Table for electrochemistry, CPS	1
664 401	Electrochemistry accessories set	1
665 754	Measuring cylinder 100 ml, with plastic base	1
602 023	Beaker, Boro 3.3, 150 ml, squat	1
675 3400	Water, pure, 1 l	1
673 8410	Sodium hydroxide solution, 0.1 mol/l, 500ml	1
674 6900	Hydrochloric acid, 1 mol/l, 500 ml	1

The conductivity of pure water is not zero, although there are no charged ions solved. This contradiction can be explained with the autoprotolysis of water. Two molecules of water react in an equilibrium reaction to a hydroxide and an hydronium ion. These charged particles lead to a measureable conductivity.

The ion product of water describes this equilibrium reation. The pH scale is based on it. In this experiment, the ion product of water is determined by setting up a galvanic element and using the Nernst equation.

Determination of the oxygen content of air (C1.4.1.1)

C1.4.1

THE COMPONENTS OF AIR

C1.4.1.1
Determination of the oxygen content of air

Cat. No.	Description	C1.4.1.1
664 0771	Reaction tube, quartz, 160 x 20 mm Ø, GL 18	1
664 079	Copper wire gauze roll 80 x 7.5 mm Ø	1
665 912	Gas syringe, 100 ml	1
665 914	Gas syringe, 100 ml with 3-way stopcock	1
665 936	Immersion tube manometer, after Schiele	1
666 714	Cartridge burner, DIN type	1
666 724	Wide-flame attachment	1
300 76	Laboratory stand II	1
666 4660	Adhesive magnetic board 300 mm	6
666 4665	Holder, magnetic, size 5, 30...32 mm	3
666 4661	Holder, magnetic, size 1, 9...11 mm	2
666 428	Panel frame C100, two-level, for CPS	1
667 312	Glass connector, 2 x GL 18	1

Air is a mixture of different gases. It essentially comprises nitrogen (78 %), oxygen (21 %), noble gases (1 %) and carbon dioxide (0.04 %). It also contains trace quantities of other gases. The component which is vital to us, oxygen, also participates in important reactions, e.g. in combustion and corrosion.

Experiment C1.4.1.1 determines the oxygen content of air. The determination of the oxygen content uses the fact that certain substances can react quantitatively with oxygen to form oxides. For this purpose, the oxygen of a defined volume of air is reacted with copper and removed from the gas space as copper oxide.

$$2\,Cu + O_2 \rightarrow 2\,CuO$$

From the resulting reduction in volume, the oxygen content of the original air can be easily calculated in per cent by volume. The gas remaining in the apparatus can be studied further: One can find out that it does not sustain combustion.

C1.4.1

THE COMPONENTS OF AIR

C1.4.1.2
Determination of the density of air

Determination of the density of air (C1.4.1.2)

Cat. No.	Description	C1.4.1.2
379 07	Sphere with 2 stopcocks, glass, 1 l	1
667 072	Support ring for round flask, 250 ml, cork	1
315 05	Single-pan suspension balance 311	1
375 58	Hand vacuum pump	1
661 082	Stopcock grease, 60 g	1

In experiment C1.4.1.2, a sphere of known volume with two stopcocks is used to determine the density of air. The mass of the enclosed air is determined from the measured difference between the total weight of the sphere filled with air and the empty weight of the evacuated sphere.

C1.4.2

PRODUCTION OF GASES

C1.4.2.1_p
Production of gases with a Kipp's apparatus, CPS version

C1.4.2.1_s
Production of gases with a Kipp's apparatus

Production of gases with a Kipp's apparatus, CPS version (C1.4.2.1_p)

Cat. No.	Description	C1.4.2.1_p	C1.4.2.1_s
665 648	Gas generator according to Maey	1	
666 425	Panel frame C50, two-level, for CPS	1	
666 4659	Adhesive magnetic board 500 mm	2	
666 4661	Holder, magnetic, size 1, 9...11 mm	1	
666 4663	Holder, magnetic, size 3, 18...22 mm	1	
666 4664	Holder, magnetic, size 4, 27...29 mm	2	
666 4665	Holder, magnetic, size 5, 30...32 mm	1	
667 312	Glass connector, 2 x GL 18	2	
604 501	PVC tubing, 7 mm diam., 1 m	1	1
664 800	Gas scrubber bottle, lower section, 200 ml	2	2
664 805	Glass tube insert, ST 29/32	2	2
665 914	Gas syringe, 100 ml with 3-way stopcock	1	1
664 043	Test tubes, Fiolax, 16 x 160 mm, set of 10	1	1
675 4800	Zinc, granulated, 100 g	1	1
674 6920	Hydrochloric acid, approx. 2 mol/l, 500ml	1	1
674 7860	Sulfuric acid, 95-98 %, 500 ml	1*	1*
666 714	Cartridge burner, DIN type	1*	1*
665 647	Gas generator according to Maey		1
666 6221	Experimental tray		1
666 623	Angle strip		1
301 01	Leybold multiclamp		3
301 27	Stand rod 50 cm, 10 mm Ø		3
301 09	Bosshead S		4
666 555	Universal clamp 0...80 mm		4

* additionally recommended

By reacting different chemicals, in most cases a liquid and a solid material, many different gases can be generated. The gases generated can then be used and studied in other experiments.

To purify the gases generated, wash bottles with H_2SO_4 as a desiccator, for example, can be added downstream. Appropriate reagents can also be used to demonstrate assay reactions.

Experiment C1.4.2.1 uses the gas generator according to Maey, the principle of which corresponds to that of the Kipp's apparatus for the production of hydrogen: zinc granules are added to a setup with frits. Diluted hydrochloric acid is added to the flask, which passes through the frits to reach the zinc. Hydrogen is generated there.

$$Zn + 2\,H^{+} \rightarrow Zn^{2+} + H_2$$

Other gases which can be generated in a similar way include: CO_2, H_2S and NO.

C1.4.2

PRODUCTION OF GASES

C1.4.2.2
Production of gases with a dropping funnel

Production of gases with a dropping funnel (C1.4.2.2)

Cat. No.	Description	C1.4.2.2
665 647	Gas generator according to Maey	1
665 649	Dropper funnel, 75 ml, 2 NS 29/32	1
666 6221	Experimental tray	1
666 623	Angle strip	1
301 01	Leybold multiclamp	3
301 27	Stand rod 50 cm, 10 mm Ø	3
301 09	Bosshead S	4
666 555	Universal clamp 0...80 mm	4
604 501	PVC tubing, 7 mm diam., 1 m	1
664 800	Gas scrubber bottle, lower section, 200 ml	2
664 805	Glass tube insert, ST 29/32	2
665 914	Gas syringe, 100 ml with 3-way stopcock	1
664 043	Test tubes, Fiolax, 16 x 160 mm, set of 10	1*
672 2520	Wooden turnings	1*
666 967	Spoon-ended spatula, stainless steel, 150 mm	1*
673 2200	Manganese(IV) oxide, 100 g	1*
675 3500	Hydrogen peroxide, 30 %, 250 ml	1*
674 7860	Sulfuric acid, 95-98 %, 500 ml	1*

* additionally recommended

In experiment C1.4.2.2, a dropping funnel is used and the solid is introduced into the flask. The reaction is controlled here by adding drops of a liquid and the gas can be drawn off via the stopcock on the side. In the production of oxygen, for example, hydrogen peroxide is dripped onto the catalyst manganese dioxide and decomposes into water and oxygen.

$$2\ H_2O_2 \xrightarrow{MnO} 2\ H_2O + O_2$$

This variant can be used to produce several other gases, including: O_2, NH_3, Cl_2, HCl, SO_2, NO_2, CO, C_2H_2 and CH_4.

C1.4.3

REACTIONS WITH GASES

C1.4.3.1
Hydrogen as a reducing agent

Hydrogen as a reducing agent (C1.4.3.1)

Cat. No.	Description	C1.4.3.1
664 0772	Reaction tube, quartz, 160 x 20 mm Ø	1
667 286	Silicone stopper, one 7-mm hole, 16...21 mm Ø	2
666 988	Combustion boat, not glazed, 80 x 12 mm	1
665 201	Glass tubes, 80 mm x 8 mm diam., set of 10 pieces	1
665 238	Glass nozzle 90°, 80 mm x 80 mm, 8 mm Ø	1
666 714	Cartridge burner, DIN type	1
666 724	Wide-flame attachment	1
604 481	Rubber tubing, 1 m x 4 mm diam., DIN 12865	1
667 198	Silicone tubing, 2 mm diam., 1 m	1
666 602	Base rail, 55 cm	1
301 27	Stand rod 50 cm, 10 mm Ø	2
666 615	Universal bosshead	3
301 09	Bosshead S	3
666 555	Universal clamp 0...80 mm	2
ADA NBL124E	Analytical balance 120 g; 0,0001g, with USB interface	1
664 800	Gas scrubber bottle, lower section, 200 ml	1
664 806	Glass tube insert with filter, ST 29/32	1
604 5672	Double microspatula, steel, 150 mm	1
666 4796	HydroStik PRO	1
666 4797	Regulating valve	1
666 4798	HydroFill PRO	1
672 9500	Copper(II) oxide, powder, 50 g	1
671 8410	Iron wool, 200 g	1
674 7860	Sulfuric acid, 95-98 %, 500 ml	1

Gases, too, can participate in chemical reactions. In most cases they are added in surplus and their properties enable complete penetration of the reaction space. Reactions with gases are easy to follow because the volume at constant pressure allows a simple determination of the quantity of material.

In experiment C1.4.3.1, copper oxide is reduced with hydrogen to form elementary copper. Hydrogen is a good reducing agent. Its ability to react applies not only to free oxygen but also to oxygen compounds. The metal is formed in this way when transforming a metal oxide (as in this experiment) with hydrogen.

C1.4.4

GAS LAWS

C1.4.4.1
Pressure-dependency of the volume of a gas at a constant temperature (Boyle-Mariotte's law)

Pressure-dependency of the volume of a gas at a constant temperature (Boyle-Mariotte's law) (C1.4.4.1)

Cat. No.	Description	C1.4.4.1
382 00	Gas thermometer	1
375 58	Hand vacuum pump	1
524 005W	Mobile-CASSY 2 WiFi	1
524 064	Pressure sensor S, ±2000 hPa	1
665 223ET10	Connector, T-shaped, 8 mm Ø, 10 pieces	1
300 02	Stand base, V-shaped, small	1
300 42	Stand rod, 47 cm, 12 mm diam.	1
301 11	Clamp with jaw clamp	2

In experiment C1.4.4.1 the Boyle-Mariotte law is confirmed by means of a gas thermometer. An air column is maintained at constant room temperature T. At an external pressure p_0, it has a volume of V_0 bounded by a mercury stopper. The pressure p in the air column is then reduced by evacuating air at the open end, and the increased volume V of the air column is determined for different pressure values p. The evaluation confirms the relationship $p\,V = p_0\,V_0 = const.$ (Boyle-Mariotte law).

C1.4.4

GAS LAWS

C1.4.4.2
Temperature-dependency of the volume of a gas at a constant pressure (Gay-Lussac's law)

Temperature-dependency of the volume of a gas at a constant pressure (Gay-Lussac's law) (C1.4.4.2)

Cat. No.	Description	C1.4.4.2
382 00	Gas thermometer	1
300 02	Stand base, V-shaped, small	1
300 42	Stand rod, 47 cm, 12 mm diam.	1
301 11	Clamp with jaw clamp	2
524 005W	Mobile-CASSY 2 WiFi	1
666 767	Hotplate, 1500 W, 180 mm Ø	1
664 103	Beaker, DURAN, 250 ml, squat	1
375 58	Hand vacuum pump	1

In experiment C1.4.4.2 Gay-Lussac's law is confirmed by means of a gas thermometer. The gas thermometer is placed in a water bath of a specific temperature which is allowed to gradually cool. The open end is subject to the ambient air pressure, so that the pressure in the air column is constant. The volume V of the air column is measured as a function of the temperature T of the water bath. The evaluation confirms the relationship $V \propto T$ for $p = const.$ (Gay-Lussac's law).

C1.4.4

GAS LAWS

C1.4.4.3
Temperature-dependency of the pressure of a gas at a constant volume (Amontons' law)

Temperature-dependency of the pressure of a gas at a constant volume (Amontons' law) (C1.4.4.3)

Cat. No.	Description	C1.4.4.3
382 00	Gas thermometer	1
300 02	Stand base, V-shaped, small	1
300 42	Stand rod, 47 cm, 12 mm diam.	1
301 11	Clamp with jaw clamp	2
524 005W	Mobile-CASSY 2 WiFi	1
524 064	Pressure sensor S, ±2000 hPa	1
666 767	Hotplate, 1500 W, 180 mm Ø	1
664 103	Beaker, DURAN, 250 ml, squat	1
375 58	Hand vacuum pump	1
665 223ET10	Connector, T-shaped, 8 mm Ø, 10 pieces	1

In experiment C1.4.4.3 Amontons' law is confirmed by means of a gas thermometer. The gas thermometer is placed in a water bath of a specific temperature which is allowed to gradually cool. Meanwhile the pressure p in the air column is constantly reduced by evacuating the air at the open end. The volume V of the air column remains constant as the temperature drops. This experiment measures the pressure p of the air column as a function of the temperature T of the water bath. The evaluation confirms the relationship $p \propto T$ for $V = const.$ (Amonton's law).

Extraction of copper from copper oxide (C1.5.1.1)

C1.5.1

EXTRACTION OF METALS

C1.5.1.1

Extraction of copper from copper oxide

Cat. No.	Description	C1.5.1.1
667 092	Mortar porcelain 70 mm Ø	1
608 360	Pestle, 54 mm long	1
666 502	Bunsen burner stand, 450 mm high	1
301 09	Bosshead S	1
666 555	Universal clamp 0...80 mm	1
667 050	Test tube rack, plastic, for 9 tubes, 18 mm Ø	1
664 043	Test tubes, Fiolax, 16 x 160 mm, set of 10	1
667 254	Rubber stopper, one 7-mm hole, 14...18 mm Ø	1
665 004	Funnel, Boro 3.3, 80 mm diam.	1
609 082	Folded filter 125mmØ Typ: 595	1
667 027	Tweezers, blunt, 130 mm	1
665 231	Angled tube 90°, 250/50 mm, 8 mm Ø	1
664 101	Beaker, DURAN, 100 ml, squat	2
666 962	Double-ended spatula, stainless steel, 150 mm	1
656 017	Teclu burner, universal	1
666 729	Safety gas hose, 1 m	1
666 683	Tripod, 26 cm x 14 cm diam.	1
666 685	Wire gauze 160 mm x 160 mm	1
ADA HCB602H	Precision Balance, 600 g /0,01g, with USB interface	1
672 9500	Copper(II) oxide, powder, 50 g	1
672 2490	Charcoal, small pieces, 500 g	1
672 1010	Glass wool, 100 g	1
671 2900	Calcium hydroxide, 50 g	1
675 3400	Water, pure, 1 l	1

Most of the ores found in nature are oxides and sulphides: e.g. magnetite (lodestone, Fe_3O_4), haematite (red iron oxide, Fe_2O_3), cassiterite (SnO_2), tenorite (CuO), cuprite (Cu_2O), pyrite (fool's gold, FeS_2) and sphalerite (ZnS). Reduction can be used to extract metals from oxide ores and from the metal oxides formed during the metallurgical process known as “roasting”.

In experiment C1.5.1.1, charcoal is the reducing agent to reduce tenorite (CuO) to elementary copper. When heated, the mixture of tenorite and pulverised charcoal produces red copper and carbon dioxide. A saturated calcium hydroxide solution is used to verify the presence of the carbon dioxide.

Conditions for iron corrosion (C1.5.3.1)

C1.5.3

CORROSION

C1.5.3.1
Conditions for iron corrosion

Cat. No.	Description	C1.5.3.1
665 936	Immersion tube manometer, after Schiele	1
667 054	Test tube rack, for 12 tubes, 32 mm diam.	1
664 045	Test tubes, Fiolax, 30 x 200 mm, set of 10	1
665 232	Angled tube 90°, 50/50 mm, 8 mm Ø	1
667 261	Rubber stopper, one 7-mm hole, 25...31 mm Ø	1
667 180	Rubber tubing 7 mm Ø, 1 m	1
300 02	Stand base, V-shaped, small	2
301 28	Stand rod, 450 x 10 Ø mm	2
301 09	Bosshead S	2
666 555	Universal clamp 0...80 mm	2
664 183	Petri dish, 100 x 20 mm, glass	1
667 0344	Tweezer, blunt, 145 mm	1
664 130	Beaker, Boro 3.3, 250 ml, squat	1
666 767	Hotplate, 1500 W, 180 mm Ø	1
666 962	Double-ended spatula, stainless steel, 150 mm	1
671 8410	Iron wool, 200 g	1
670 8200	Petroleum ether, 90...110 °C, 250 ml	1
309 42	Colouring, red, 10 g	1
672 1200	Glycerol, 99 %, 100 ml	1
	additionally required: tap water, mineral water	1

The term “corrosion” refers to the slow oxidation of metal surfaces under the influence of the surrounding medium. Corrosion (rust) destroys large quantities of iron and steel. Corrosion protection (rust protection) is an extremely important topic in the metal industry.

Experiment C1.5.3.1 examines the conditions under which ferrous metals corrode. Wads of iron wool are subjected to different conditions. In one test tube, boiled water is poured over the iron wool, in the second test tube the iron wool is left dry, and the third test tube is rinsed with tap water so that droplets remain in the tube. This test tube is connected to an immersion tube manometer filled with coloured water. The changes in the iron wool and the changes in the immersion tube manometer are observed. It can be seen that under the simultaneous action of water and oxygen on iron, corrosion forms and a measurable negative pressure builds up in the apparatus.

$$4\ Fe + 2\ H_2O + 3\ O_2 \rightarrow 4\ FeO(OH)$$

Experiments with the corrosion set (C1.5.3.2)

C1.5.3
CORROSION

C1.5.3.2
Experiments with the corrosion set

Cat. No.	Description	C1.5.3.2
664 3561	Corrosion set	1
531 94	AV meter	1
501 45	Connecting lead 19 A, 50 cm, red/blue, pair	1
501 861	Crocodile-clips, polished, set of 6	1
664 391ET4	Grindstones, set of 4	1
674 7920	Sulfuric acid, diluted, approx. 2 N (= 10 %), 500 ml	1
665 756	Measuring cylinder 500 ml, with plastic base	1
665 997	Graduated pipette 10 ml	1
666 003	Pipetting ball (Peleus ball)	1
665 212	Glass stirring rod 200 x 8 mm Ø	1

Experiment C1.5.3.2 demonstrates that every type of corrosion has its origin in chemical and electrochemical processes. Different metals generate an electric voltage when they are immersed in an electrically conductive medium at the same time, such as diluted sulfuric acid. The further apart the metals are in the electrochemical series the higher that voltage.

C1.5.3

CORROSION

C1.5.3.3
Electrochemical corrosion protection

Electrochemical corrosion protection (C1.5.3.3)

Cat. No.	Description	C1.5.3.3
664 4071	Electrochemistry demonstration unit, CPS	1
301 339	Stand bases, pair	1
664 401	Electrochemistry accessories set	1
667 7967	Compact Balance EMB200-2	1
665 795	Volumetric flask, Boro 3.3, 500 ml	1
665 793	Volumetric flask, Boro 3.3, 100 ml	1
665 953	Dropping pipette, 7 x 150 mm, 10 pcs.	1
665 954	Rubber bulbs, 10 pcs	1
665 008	Funnel, PP, 50 mm diam.	1
666 967	Spoon-ended spatula, stainless steel, 150 mm	1
673 5700	Sodium chloride 250 g	1
672 6100	Potassium ferrocyanide (III), 50 g	1
674 2500	Phenolphthaleine solution, 100 ml	1
673 1000	Magnesium, ribbon, 25 g	1

In experiment C1.5.3.3, the cathodic protection anode technique is used to prevent electrochemical corrosion. The method is based on the fact that the speed of electrochemical corrosion processes depends on the electrode potential. If that electrode potential is shifted externally, the corrosion can be inhibited or greatly restricted. In the experiment, a zinc electrode is used as a cathodic protection anode. The metal to be protected is conductively connected to a less noble metal; a corrosion element is formed in which the less noble metal (the cathodic protection anode) dissolves while the nobler metal remains protected.

Chemical corrosion protection (C1.5.3.4)

C1.5.3

CORROSION

C1.5.3.4
Chemical corrosion protection

Cat. No.	Description	C1.5.3.4
664 401	Electrochemistry accessories set	1
667 035	Crucible tongs 200 mm	1
664 043	Test tubes, Fiolax, 16 x 160 mm, set of 10	1
667 050	Test tube rack, plastic, for 9 tubes, 18 mm Ø	1
604 5661	Spatula, double ended, 185 mm	1
602 022	Beaker Boro 3.3, 100 ml, squat	2
602 740	Petri dish, 120 mm	1
665 9531	Dropping pipette 150 mm x 7 mm Ø	1
665 9541	Rubber bulb	1
666 711	Butane gas burner	1
672 6100	Potassium ferrocyanide (III), 50 g	1
673 5700	Sodium chloride 250 g	1
673 7410	Trisodium phosphate dodecahydrate, 250 g	1
675 3400	Water, pure, 1 l	1
674 6610	Nitric acid, 65%, 500 ml	1

Iron can be protected from corrosion using chemical processes. Then, the metal surface is treated chemically in a way, that a layer is formed that saves the metal. Especially passivation and phosphatation can be mentioned here.

In this experiment iron nails are corroded. The corrosion of iron is detected using Prussion blue. Treated and untreated nails are compared.

C1.6.2

THE OXYGEN GROUP

C1.6.2.1
Change of modification of sulphur

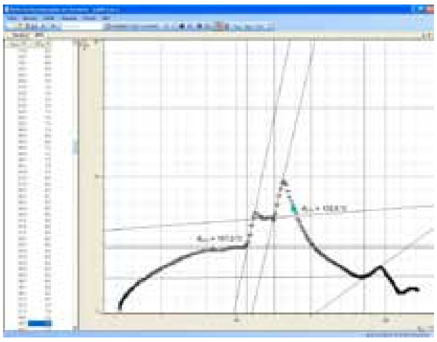
Change of modification of sulphur (C1.6.2.1)

Cat. No.	Description	C1.6.2.1
524 005W	Mobile-CASSY 2 WiFi	1
524 220	CASSY Lab 2	1
524 0673	NiCr-Ni adapter S, type K	1
529 676	Temperature probe, NiCr-Ni, 1.5 mm, type K	2
666 202	Heating block with 2 holes	1
666 203	Set of 20 glass tubes	1
666 8471	Magnetic stirrer with hotplate	1
666 523	Stand rod, 450 x 12 mm diam., M10 thread	1
301 09	Bosshead S	2
666 555	Universal clamp 0...80 mm	2
666 960	Powder spatula, stainless steel, 150 mm	1
667 092	Mortar porcelain 70 mm Ø	1
608 360	Pestle, 54 mm long	1
674 7610	Sulfur, sublimed, 500 g	1
670 2900	Aluminium oxide, 250 g	1
	additionally required: PC with Windows 7 or higher with WIFI or USB connection	1

The oxygen family is the 6th main group in the periodic table. Its elements are also known as “chalcogens”, i.e. ore generators. They include the non-metals oxygen and sulphur, the metalloids selenium and tellurium, and the metal polonium.

The elements of this group must acquire two electrons in order to achieve noble gas configuration. Alternatively, they can form two covalent bonds.

Experiment C1.6.2.1 takes a closer look at sulphur. Sulphur has the ability to form chains and rings, and that makes it the element with the most modifications. Those modification changes are studied by differential thermal analysis. For this purpose, a sample of sulphur is heated and its temperature is measured. During the modification changes, the temperature of the sample no longer increases as compared with a control substance. There is no measurable temperature increase until the modification change is complete.



Observing the change of modification of sulphur

C1.7.2

ACID STRENGTHS AND pH VALUES

C1.7.2.1
Determination of acidity (pKa value) by titration

Determination of acidity (pKa value) by titration (C1.7.2.1)

Cat. No.	Description	C1.7.2.1
524 005W	Mobile-CASSY 2 WiFi	1
524 220	CASSY Lab 2	1
524 0672	pH adapter S	1
667 4172	pH sensor with plastic shaft, BNC	1
607 105	Magnetic stirrer mini	1
666 851	Stirring magnet 25 mm x 6 mm Ø, circular	1
665 845	Burette, clear glass, 25 ml	1
666 559	Burette clamp for 1 burette, roller clamp	1
665 816	Burette filling funnel plastic, 35 mm Ø	1
300 02	Stand base, V-shaped, small	1
300 43	Stand rod, 75 cm, 12 mm diam.	1
301 26	Stand rod 25 cm, 10 mm Ø	1
300 11	Saddle base	1
301 09	Bosshead S	1
666 555	Universal clamp 0...80 mm	1
665 997	Graduated pipette 10 ml	1
666 003	Pipetting ball (Peleus ball)	1
664 130	Beaker, Boro 3.3, 250 ml, squat	1
661 243	Wash bottle PE 500 ml	1
661 082	Stopcock grease, 60 g	1
671 9560	Acetic acid, 0.1 mol/l, 500ml	1
673 8410	Sodium hydroxide solution, 0.1 mol/l, 500ml	1
674 2500	Phenolphthaleine solution, 100 ml	1
674 4640	Buffer solution pH 4.00, 250 ml	1
674 4670	Buffer solution pH 7.00, 250 ml	1

Cat. No.	Description	C1.7.2.1
675 3400	Water, pure, 1 l	1
	additionally required: PC with Windows 7 or higher with WIFI or USB connection	1

In experiment C1.7.2.1, the acidity (pK_a value) of acetic acid is determined. Between an acid HA and its base A^- the following equilibrium reaction takes place in an aqueous solution :

$$HA + H_2O \rightleftharpoons H_3O^+ + A^-$$

According to the law of mass action, the equilibrium position is described by the equilibrium constant K_a:

$$K = \frac{[H_3O^+]\cdot[A^-]}{[HA]\cdot[H_2O]}; K_a = K\cdot[H_2O] = \frac{[H_3O^+]\cdot[A^-]}{[HA]}$$

By analogy to the pH value, the pK_a value is given as the negative base 10 logarithm of the numerical value of K_a

$$pK_a = -\lg\frac{[H_3O^+]\times[A^-]}{[HA]}$$

The lower the value of pK_a, the higher the acidity. The pK_a value is numerically equal to the pH value of a solution when the protonated and non-protonated forms are present in equal concentration.

C1.7.2

ACID STRENGTHS AND pH VALUES

C1.7.2.2
Analysis of triprotic phosphoric acid by titration

Analysis of triprotic phosphoric acid by titration (C1.7.2.2)

Cat. No.	Description	C1.7.2.2
524 013	Sensor-CASSY 2	1
524 220	CASSY Lab 2	1
524 0672	pH adapter S	1
667 4172	pH sensor with plastic shaft, BNC	1
524 074	Timer S	1
337 4681	Drop counter	1
607 105	Magnetic stirrer mini	1
664 103	Beaker, DURAN, 250 ml, squat	2
665 997	Graduated pipette 10 ml	1
666 003	Pipetting ball (Peleus ball)	1
665 847	Burette, clear glass, 50 ml	1
665 816	Burette filling funnel plastic, 35 mm Ø	1
666 559	Burette clamp for 1 burette, roller clamp	1
300 02	Stand base, V-shaped, small	1
300 43	Stand rod, 75 cm, 12 mm diam.	1
300 11	Saddle base	1
301 26	Stand rod 25 cm, 10 mm Ø	1
301 09	Bosshead S	2
666 555	Universal clamp 0...80 mm	2
661 082	Stopcock grease, 60 g	1
674 3440	Phosphoric acid, 10 %, 100 ml	1
673 8421	Sodium hydroxide solution, 1 mol/l, 1 l	1
674 4640	Buffer solution pH 4.00, 250 ml	1
674 4670	Buffer solution pH 7.00, 250 ml	1
675 1600	Thymolphthalein solution, 0.1 %, 50 ml	1*

Cat. No.	Description	C1.7.2.2
	additionally required: PC with Windows XP/Vista/7/8/10 (x86 or x64)	1

* additionally recommended

Phosphoric acid is a triprotic acid. When dissolved in water, it first gives up one proton and dissociates to dihydrogen phosphate, i.e. it reacts like a monoprotic acid (see formula 1). The addition of sodium hydroxide, e.g. during titration, first leads to complete dissociation of the phosphoric acid into dihydrogen phosphate.

The second protolysis, i.e. the reaction to hydrogen phosphate (see formula 2), occurs only after a high pH value has been reached, approx. pH 9. The third protolysis requires a considerably higher pH value (see formula 3). In experiment C1.7.2.2, the first two protolysis steps of phosphoric acid are determined in an automatic titration.

1: $H_3PO_4 + H_2O \rightleftharpoons H_2PO_4^- + H_3O^+$
2: $H_2PO_4^- + H_2O \rightleftharpoons HPO_4^{2-} + H_3O^+$
3: $HPO_4^{2-} + H_2O \rightleftharpoons PO_4^{3-} + H_3O^+$

C1.7.3

SALTS AND IONIC COMPOUNDS

C1.7.3.1

Determination of the enthalpy of solution of salts

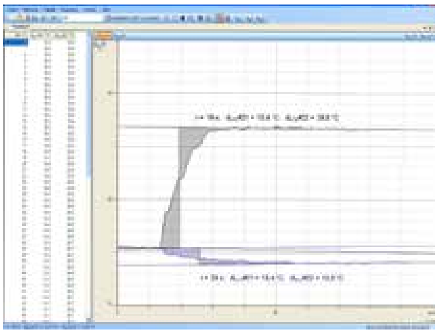
Determination of the enthalpy of solution of salts (C1.7.3.1)

Cat. No.	Description	C1.7.3.1
386 40	Glass calorimeter	1
524 005W	Mobile-CASSY 2 WiFi	1
524 220	CASSY Lab 2	1
529 676	Temperature probe, NiCr-Ni, 1.5 mm, type K	1
664 155	Watch glass dish 100 mm Ø	1
607 105	Magnetic stirrer mini	1
666 851	Stirring magnet 25 mm x 6 mm Ø, circular	3
300 11	Saddle base	1
301 26	Stand rod 25 cm, 10 mm Ø	1
301 09	Bosshead S	1
602 953	Measuring cylinder, Boro 3.3, 100 ml, glass base	1
667 7977	Electronic Balance 440-3N, 200 g : 0.01 g	1
666 968	Spoon-ended spatula, stainless steel, 180 mm	1
673 0510	Lithium chloride, 100 g	1
672 5210	Potassium chloride, 250 g	1
673 5710	Sodium chloride, 500 g	1
	additionally required: PC with Windows 7 or higher with WIFI or USB connection	1

Salts are chemical compounds made of ions. The positively charged cation is often a metal and the negatively charged anion is often a non-metal, as in the case of sodium chloride (table salt). In polar solvents such as water, salts dissolve forming hydrated ions.

When a salt is dissolved in water, it can heat the solution up or cool it down. Accordingly, the enthalpy of solution is either negative (heat generating) or positive (heat absorbing). For the dissolution of the crystal, the so-called lattice energy must be applied. In hydration, on the other hand, energy is released. Enthalpies of solution cannot be calculated with certainty, but rather must be determined experimentally.

Experiment C1.7.3.1 determines the enthalpy of solution of various chloride salts. For this purpose, the salts LiCl, KCl and NaCl are dissolved in the transparent demonstration Dewar flask. The enthalpy of solution can then be calculated from the temperature change.



The enthalpy of solution of different salts

C1.7.3

SALTS AND IONIC COMPOUNDS

C1.7.3.2
Determination of the solubility product of silver halides

Determination of the solubility product of silver halides (C1.7.3.2)

Cat. No.	Description	C1.7.3.2
524 005W	Mobile-CASSY 2 WiFi	1
664 137	Beaker, Boro3.3, 100 ml, tall	4
665 754	Measuring cylinder 100 ml, with plastic base	1
667 455	Salt bridge, 90 mm x 90 mm, 20 mm diam.	1
667 255	Rubber stopper, solid, 16...21 mm diam.	1
664 130	Beaker, Boro 3.3, 250 ml, squat	1
664 421	Plate electrodes, silver, 55 x 40 mm, set of 2	1
501 861	Crocodile-clips, polished, set of 6	1
501 44	Connecting leads, 19 A, 25 cm, red/blue, pair	1
667 7977	Electronic Balance 440-3N, 200 g : 0.01 g	1
666 963	Spoon-ended spatula, stainless steel, 120 mm	1
300 11	Saddle base	1
300 42	Stand rod, 47 cm, 12 mm diam.	1
301 09	Bosshead S	1
666 555	Universal clamp 0...80 mm	1
665 953	Dropping pipette, 7 x 150 mm, 10 pcs.	1
665 954	Rubber bulbs, 10 pcs	1
665 009	Funnel PP 75 mm Ø	1
674 8800	Silver nitrate solution, 0,1 mol/l, 250 ml	1
673 5740	Sodium chloride solution, approx. 1 M, 500 ml	1
672 4930	Potassium bromide solution, approx. 1 M, 250 ml	1
672 6620	Potassium iodide, 50 g	1
672 6800	Potassium nitrate, 100 g	1

In experiment C1.7.3.2, the solubility product of silver salts is determined. The solubility product is the product of the concentrations of cations and anions of an electrolyte in a saturated aqueous solution at constant temperature. In a saturated salt solution, a chemical equilibrium exists between the solid and the solution, i.e. just as many ions leave the ion lattice per unit time as enter it in the opposite sense. Using voltage measurements and the Nernst equation, the solubility products of the low solubility salts AgCl, AgBr and AgI are determined.

C2.4.2.1
Soxhlet extraction from leaves

For more information on this experience, see page 75.

C2 ORGANIC CHEMISTRY

Quantitative determination of carbon (C2.1.1.1)

C2.1.1

COMPOSITION OF ORGANIC COMPOUNDS

C2.1.1.1
Quantitative determination of carbon

C2.1.1.2
Quantitative determination of hydrogen

Cat. No.	Description	C2.1.1.1	C2.1.1.2
664 069	Reaction tube, quartz, 220 x 25 mm Ø, for butane combustion	1	1
665 374	Drying tube, 1 GL 18 and 1 GL 25, 120 mm x 30 mm diam.	2	2
665 914	Gas syringe, 100 ml with 3-way stopcock	2	2
656 017	Teclu burner, universal	1	1
666 724	Wide-flame attachment	1	1
666 729	Safety gas hose, 1 m	1	1
666 603	Base rail, 95 cm	1	1
666 609	Stand tube, 45 cm, Ø 10 mm	4	4
666 615	Universal bosshead	4	4
301 09	Bosshead S	5	5
666 555	Universal clamp 0...80 mm	4	3
301 72	Universal clamp, 0...120 mm	1	1
666 962	Double-ended spatula, stainless steel, 150 mm	1	1
665 994	Graduated pipette 1 ml	1	1
666 003	Pipetting ball (Peleus ball)	1	1
667 180	Rubber tubing 7 mm Ø, 1 m	1	1
604 481	Rubber tubing, 1 m x 4 mm diam., DIN 12865	1	1
665 004	Funnel, Boro 3.3, 80 mm diam.	1	1
604 510	Tubing connector, 4...15 mm	1	1
661 000	Minican pressurised gas canister, nitrogen	1	1
660 989	Minican pressurised gas canister, n-Butane	1	1
660 980	Fine regulating valve for minican gas canisters	1	1
667 034	Tweezers, blunt, 200 mm	1	1
672 9410	Copper(II) oxide, wire form, 250 g	1	1

Cat. No.	Description	C2.1.1.1	C2.1.1.2
671 2410	Calcium chloride, granulated, 250 g	1	1
674 4310	1-Propanol, 250 ml	1	1
672 1010	Glass wool, 100 g	1	1
665 918	Gas syringe holder		1
SAP R213	Precision Balance Practum 213-1S		1

In order to determine the chemical composition of organic compounds, a quantitative elementary analysis is conducted. Combustion analysis is also still used today for the determination of carbon and hydrogen.

In experiment C2.1.1.1, the carbon content of an organic compound is determined quantitatively. In a combustion analysis, the substance is passed over glowing copper(II) oxide at approx. 800 °C - 900 °C. The carbon is converted to CO_2 and the hydrogen is converted to H_2O. The CO_2 gas generated is collected in a gas syringe and the volume is measured.

In experiment C2.1.1.2, the hydrogen content of an organic compound is determined quantitatively. Here, too, the combustion analysis is carried out, whereby the carbon is converted to CO_2 and the hydrogen is converted to H_2O. The water content is determined from the difference in the weight of the drying tube, and the share of hydrogen is determined from the water content.

Thermal analysis of hydrocarbons (C2.1.2.1)

C2.1.2

HYDROCARBONS

C2.1.2.1
Thermal analysis of hydrocarbons

Cat. No.	Description	C2.1.2.1
666 428	Panel frame C100, two-level, for CPS	1
666 460	Combustion chamber with filament, CPS	1
666 4660	Adhesive magnetic board 300 mm	2
666 4664	Holder, magnetic, size 4, 27...29 mm	4
665 914	Gas syringe, 100 ml with 3-way stopcock	2
666 468	Blank panel, 300 mm, CPS	1
666 467	Blank panel, 200 mm, CPS	1
726 21	Equipment platform, 350 mm	1
501 45	Connecting lead 19 A, 50 cm, red/blue, pair	1
521 551	AC/DC power supply 0...24 V/0...10 A	1
660 987	Minican pressurised gas canister, methane	1
660 988	Minican pressurised gas canister, ethane	1
660 980	Fine regulating valve for minican gas canisters	1
667 194	Silicone tubing 7 mm Ø, 1 m	1
604 510	Tubing connector, 4...15 mm	1
667 197	Silicone tubing, 4 mm diam., 1 m	1
664 042	Test tubes, Fiolax, 16 x 160 mm, set of 100	1
667 052	Test tube rack, for 12 tubes, 18 mm diam., 6 drying pegs	1
656 016	Bunsen burner, universal	1
666 729	Safety gas hose, 1 m	1

Hydrocarbons are compounds which contain only carbon and hydrogen. A differentiation is made between alkanes, alkenes and alkynes. Alkanes are saturated hydrocarbons. Each C atom forms four single bonds. Unsaturated hydrocarbon compounds have multiple bonds. Alkenes have at least one double bond, alkynes one triple bond. Hydrocarbons can occur in short or long chains. Open chains or branches are found, and they can also comprise ring-shaped molecules.

In order to determine the number of hydrogen atoms as compared with the number of carbon atoms, hydrocarbons can be separated into their elements by thermal decomposition. With gaseous hydrocarbons, this can be done with a filament in a combustion chamber. There the gas is split into hydrogen and carbon black (soot). The ratio of hydrogen to carbon in the compound can be derived directly from the increase in gas volume. In experiment C2.1.2.1, the gases methane and ethane are studied in this way.

Oxidation of propanol (C2.2.2.1)

C2.2.2

OXIDATION REACTIONS

C2.2.2.1
Oxidation of propanol

Cat. No.	Description	C2.2.2.1
666 602	Base rail, 55 cm	1
664 0771	Reaction tube, quartz, 160 x 20 mm Ø, GL 18	1
664 078	Copper wire, gauze roll, 60 x 10 mm diam.	1
667 313	Glass connector, 1 GL 18, with glass olive	2
665 9351	Woulff's bottle with manometer	1
667 312	Glass connector, 2 x GL 18	1
667 186	Vacuum rubber tubing, 8 mm diam.	1
375 56	Water jet pump	1
666 555	Universal clamp 0...80 mm	2
301 09	Bosshead S	2
666 615	Universal bosshead	2
666 609	Stand tube, 45 cm, Ø 10 mm	2
664 051	Test tube, with side arm, Boro 3.3, 20 x 180 mm, SB 19	2
667 256	Rubber stopper, one 7-mm hole, 16...21 mm Ø	2
665 231	Angled tube 90°, 250/50 mm, 8 mm Ø	2
666 714	Cartridge burner, DIN type	1
666 724	Wide-flame attachment	1
664 114	Beaker, DURAN, 400 ml, tall	2
300 76	Laboratory stand II	1
666 963	Spoon-ended spatula, stainless steel, 120 mm	1
664 442	Evaporating dish, 80 mm diam.	1
667 035	Crucible tongs 200 mm	1
608 010	Tripod, 24 cm x 14 cm diam.	1
666 685	Wire gauze 160 mm x 160 mm	1
661 083	Wooden turnings, 10 pieces	1

Cat. No.	Description	C2.2.2.1
667 026	Tweezers, pointed, 130 mm	1
672 1010	Glass wool, 100 g	1
672 1210	Glycerin, 99 %, 250 ml	1
674 4400	2-Propanol, 250 ml	1
672 9710	Copper(II) sulfate, dry, 250 g	1
	additionally required: cold water I ice I hot water (60 °C)	

Oxidation and reduction reactions also occur in organic chemistry. These involve oxygen transfer reactions, e.g. the oxidation of alcohols to carboxylic acids, or hydrogen transfer reactions, in which, technically, a hydride ion (H^-) is transferred. But redox reactions can also occur radically or via displacement or addition-elimination mechanisms.

In experiment C2.2.2.1, acetone is produced. To do so, the secondary alcohol 2-propanol is oxidised to 2-propanone (acetone). The oxidising agent used is copper oxide (CuO), which at high temperature gives off oxygen to reducing materials. Continuous air supply immediately re-oxidises the metal copper, however. In order to provide the largest possible Cu-CuO surface area, an anoxidised, rolled up copper mesh is used.

The automated Blue Bottle Experiment - a reversible redox reaction (C2.2.2.2)

C2.2.2

OXIDATION REACTIONS

C2.2.2.2 The automated Blue Bottle Experiment - a reversible redox reaction

Cat. No.	Description	C2.2.2.2
524 013	Sensor-CASSY 2	1
524 220	CASSY Lab 2	1
524 069	Immersion photometer S	1
666 425	Panel frame C50, two-level, for CPS	1
666 438	Woulff's bottle with manometer, CPS	1
667 3095	Screw cap, GL 45, with hole	1
667 3107	Silicone seal GL 45/26, 10 pcs	1
666 482	Aeration pump, controllable, CPS	1
501 44	Connecting leads, 19 A, 25 cm, red/blue, pair	1
667 7977	Electronic Balance 440-3N, 200 g : 0.01 g	1
664 157	Watch glass dish 125 mm Ø	2
666 966	Spoon-ended spatula, PP, 180 mm	2
666 003	Pipetting ball (Peleus ball)	1
665 996	Graduated pipette, 5 ml	1
665 756	Measuring cylinder 500 ml, with plastic base	1
604 501	PVC tubing, 7 mm diam., 1 m	1
604 460	Hose clamp, 8...12 mm	1
602 347	Laboratory bottle, 500 ml, GL 45 thread	1
673 2920	Methylene blue solution, 100 ml	1
673 6800	Sodium hydroxide, pellets, 100 g	1
672 1100	D(+)-Glucose, 100 g	1
675 3400	Water, pure, 1 l	1
	additionally required: PC with Windows XP/Vista/7/8/10 (x86 or x64)	1

The blue bottle experiment is a model experiment for a organic redox system. The redox indicator methylene blue is reduced by glucose to its colourless form which is then oxidised by air to form again the coloured version. The air is led into solution by a pump. Additional glucose in solution will then reduce it to its colourless form. The process is reversible. In this experiment a automated version with a two-point control system is used.

The calorific value of coal (C2.3.1.1)

C2.3.1

ORGANIC COMPOUNDS AS FUELS

C2.3.1.1
The calorific value of coal

C2.3.1.3
The calorific value of fuel oil

Cat. No.	Description	C2.3.1.1	C2.3.1.3
666 429	Calorimeter for solids and liquids, CPS	1	1
666 819	Stirring top, with GL 32 screw thread	1	1
666 428	Panel frame C100, two-level, for CPS	1	1
666 4660	Adhesive magnetic board 300 mm	2	2
666 4664	Holder, magnetic, size 4, 27...29 mm	4	4
664 800	Gas scrubber bottle, lower section, 200 ml	4	4
664 805	Glass tube insert, ST 29/32	4	4
665 392	Joint clip plastic, ST 29/32	4	
667 312	Glass connector, 2 x GL 18	3	3
301 312	Console	1	1
726 21	Equipment platform, 350 mm	1	1
521 231	Low-voltage power supply 3/6/9/12 V	1	1
524 013	Sensor-CASSY 2	1	1
524 220	CASSY Lab 2	1	1
524 0673	NiCr-Ni adapter S, type K	1	1
529 676	Temperature probe, NiCr-Ni, 1.5 mm, type K	1	1
667 183	Rubber tubing, 1 m x 8 mm diam., DIN 12865	1	1
604 510	Tubing connector, 4...15 mm	1	1
667 197	Silicone tubing, 4 mm diam., 1 m	1	1
521 536	DC Power Supply 2 x 0...16 V/2 x 0...5 A	1	1
501 45	Connecting lead 19 A, 50 cm, red/blue, pair	3	3
667 7977	Electronic Balance 440-3N, 200 g : 0.01 g	1	1
ADA HCB3001	Precision Balance, 3000 g / 0,1 g	1	1
667 092	Mortar porcelain 70 mm Ø	1	
608 360	Pestle, 54 mm long	1	
660 998	Minican pressurised gas canister, oxygen	1	1
660 980	Fine regulating valve for minican gas canisters	1	1
674 9340	Anthracite coal, pieces, 100 g	1	
673 8420	Sodium hydroxide solution, 1 mol/l, 500 ml	1	1
674 7850	Sulfuric acid, 95-98 %, 250 ml	1	1
661 082	Stopcock grease, 60 g	1	1
665 953	Dropping pipette, 7 x 150 mm, 10 pcs.		1
665 954	Rubber bulbs, 10 pcs		1
672 1740	Heating oil, 250 ml		1
	additionally required: PC with Windows XP/Vista/7/8/10 (x86 or x64)	1	1

In experiment C2.3.1.1, coal is burned and the heat of combustion is determined with a calorimeter. The calorimeter completely surrounds the sides and top of the combustion chamber. The hot combustion gases generated are fed through a double glass coil and give off their energy to the environment (the glass element and the bath liquid) in the form of heat. In this way, the heat of combustion can be determined using the total heat capacity of the calorimeter.

In experiment C2.3.1.3 the heating value of fuel oil is determined with a demonstration calorimeter.

Fractionated petroleum distillation with a bubble tray column (C2.3.2.1)

C2.3.2

FROM CRUDE OIL TO PETROLEUM PRODUCT

C2.3.2.1
Fractionated petroleum distillation with a bubble tray column

Cat. No.	Description	C2.3.2.1
666 447	Crude oil distillation, bubble tray column, CPS	1
666 425	Panel frame C50, two-level, for CPS	1
524 013	Sensor-CASSY 2	1
524 220	CASSY Lab 2	1
524 0673	NiCr-Ni adapter S, type K	2
529 676	Temperature probe, NiCr-Ni, 1.5 mm, type K	4
666 6533	Heating mantle, 500 ml, adjustable	1
300 75	Laboratory stand I	1
666 659	Clamp for heating mantle	1
666 194	Protective sleeves for temperature probe, set of 5	1
665 755	Measuring cylinder 250 ml, with plastic base	1
604 501	PVC tubing, 7 mm diam., 1 m	3
604 460	Hose clamp, 8...12 mm	3
664 241	Erlenmeyer flask, 100 ml, narrow neck, SB 19	3
667 281	Assorted cork stoppers, set of 100	3
661 0771	Warning labels, GHS	1
661 081	Aluminium, foil, 1 roll	1
667 026	Tweezers, pointed, 130 mm	1
608 311	Evaporating dish, 72 ml, 77 mm diam.	3
661 083	Wooden turnings, 10 pieces	1
674 5840	Crude oil, artificial, 1 L	1
661 091	Boiling stones 100 g	1
661 082	Stopcock grease, 60 g	1
672 1200	Glycerol, 99 %, 100 ml	1
	additionally required: PC with Windows XP/Vista/7/8/10 (x86 or x64)	1

The organic chemical industry is largely based on the raw materials crude oil and natural gas. Those raw materials were formed a long time ago from biomass through biochemical and geochemical processes. Based on its origin, crude oil is classified as a fossil fuel together with natural gas and coal.

These fuels and raw materials cannot be used directly in their natural condition. First they must be refined by various physical and chemical processes. This is done in so-called oil refineries, where different processes are used in order to produce from the crude oil the desired mineral oil products and primary chemicals for the chemical industry.

Crude oil is first separated into different fractions by fractionated distillation. Individual substances cannot be isolated in this way, because the boiling points are very close to one another. Rather, the objective here is to collect hydrocarbons of certain boiling point ranges.

In chemical engineering, crude oil is distilled in bubble tray columns. This process is simulated in experiment C2.3.2.1. The system is fitted with two bubble trays so multiple fractions can be extracted simultaneously.

C2.3.2

FROM CRUDE OIL TO PETROLEUM PRODUCT

C2.3.2.3
Catalytic cracking

Catalytic cracking (C2.3.2.3)

Cat. No.	Description	C2.3.2.3
665 338	Distillation bridge after Claisen	1
664 301	Round-bottom flask, 250 ml, ST 19/26	1
664 300	Round-bottom flask, 100 ml, ST 19/26	1
664 105	Beaker, DURAN, 600 ml, squat	1
667 072	Support ring for round flask, 250 ml, cork	1
665 391	Joint clip, plastic, ST 19/26	2
665 237	Glass nozzle straight, 8 mm Ø	1
665 255	Three-way valve, T-shaped, ST nozzles	1
665 914	Gas syringe, 100 ml with 3-way stopcock	1
667 256	Rubber stopper, one 7-mm hole, 16...21 mm Ø	1
666 161	Chemical thermometer, -10...+250 °C/1 K	1
666 6522	Heating Mantle, 250 ml	1
300 76	Laboratory stand II	2
666 4660	Adhesive magnetic board 300 mm	6
666 4662	Holder, magnetic, size 2, 11...14 mm	2
666 4663	Holder, magnetic, size 3, 18...22 mm	2
666 4661	Holder, magnetic, size 1, 9...11 mm	1
666 4665	Holder, magnetic, size 5, 30...32 mm	1
666 428	Panel frame C100, two-level, for CPS	1
664 153	Watch glass dish 60 mm Ø	2
661 083	Wooden turnings, 10 pieces	1
664 043	Test tubes, Fiolax, 16 x 160 mm, set of 10	1
667 052	Test tube rack, for 12 tubes, 18 mm diam., 6 drying pegs	1*
604 170	Powder funnel d=65mm	1
665 997	Graduated pipette 10 ml	1
666 003	Pipetting ball (Peleus ball)	1
665 754	Measuring cylinder 100 ml, with plastic base	1
661 082	Stopcock grease, 60 g	1
674 0800	Paraffine, thick, 100 ml	1
674 1980	Bead catalyst, 100 g	1
671 8410	Iron wool, 200 g	1
672 1210	Glycerin, 99 %, 250 ml	1

* additionally recommended

Distillation can only extract materials which are naturally present in the crude oil to start with. Because the share of petrol in the crude oil is insufficient to cover the need, however, conversion processes (modification processes) have been developed. They include, along with thermal cracking, also the catalytic cracking which is carried out in experiment C2.3.2.3. Here, paraffin oil is cracked in the heat of a bead catalyst and the gaseous and liquid fractions are collected.

Boiling range distribution of petrol (C2.3.3.1)

C2.3.3

PROPERTIES OF PETROCHEMICAL PRODUCTS

C2.3.3.1
Boiling range distribution of petrol

C2.3.3.2
Boiling range distribution and fractionated distillation of petroleum

Cat. No.	Description	C2.3.3.1	C2.3.3.2
524 005W	Mobile-CASSY 2 WiFi	1	1
524 220	CASSY Lab 2	1	1
529 676	Temperature probe, NiCr-Ni, 1.5 mm, type K	1	1
665 338	Distillation bridge after Claisen	1	1
664 301	Round-bottom flask, 250 ml, ST 19/26	1	1
667 072	Support ring for round flask, 250 ml, cork	1	1
665 391	Joint clip, plastic, ST 19/26	1	
604 501	PVC tubing, 7 mm diam., 1 m	2	1
604 460	Hose clamp, 8...12 mm	2	2
665 754	Measuring cylinder 100 ml, with plastic base	1	1
667 305	Screw cap, GL 18, with hole	1	1
667 295	Silicone gaskets, GL 18/8, set of 10	1	1
666 194	Protective sleeves for temperature probe, set of 5	1	1
666 6523	Heating Mantle, 250 ml, adjustable	1	1
300 76	Laboratory stand II	1	2
666 4659	Adhesive magnetic board 500 mm	2	2
666 4662	Holder, magnetic, size 2, 11...14 mm	2	2
666 4663	Holder, magnetic, size 3, 18...22 mm	2	2
666 425	Panel frame C50, two-level, for CPS	1	1
661 091	Boiling stones 100 g	1	1
670 8200	Petroleum ether, 90...110 °C, 250 ml	1	
670 8210	Petroleum ether, 100...140 °C, 500 ml	1	
661 082	Stopcock grease, 60 g	1	1
665 354	Delivery adapter after Bredt (quadruple)		1
664 300	Round-bottom flask, 100 ml, ST 19/26		4
665 397	Joint clip metal, ST 19/26		2
667 071	Support ring for round flask, 100 ml, cork		4
667 227	Glass stopper for ST 19/26		4
661 0771	Warning labels, GHS		1
664 131	Beaker Boro 3.3, 400 ml, squat		1
661 081	Aluminium, foil, 1 roll		1
664 153	Watch glass dish 60 mm Ø		4
665 997	Graduated pipette 10 ml		1
666 002	Pipetting aid		1
313 12	Digital stop-watch		1
674 5840	Crude oil, artificial, 1 L		1
	additionally required: PC with Windows 7 or higher with WIFI or USB connection	1	1

The petrol fraction is subdivided into several subgroups, so-called special petrols. Petrol benzene boils between 40 °C and 70 °C, for example, and regular petrol boils between 65 °C and 90 °C. In experiment C2.3.3.1, a boiling point analysis is carried out on petrol. For this purpose, different petrol fractions are heated in a distillation apparatus in order to determine the boiling range.

In a fractionated distillation of crude oil, fractions of different boiling ranges can be separated. In experiment C2.3.3.2, a fractionated distillation of crude oil is carried out and the fractions are characterised according to their boiling points.

Synthesis and use of indigo (C2.4.1.1)

C2.4.1

SYNTHESIS OF ORGANIC COMPOUNDS

C2.4.1.1
Synthesis and use of indigo

Cat. No.	Description	C2.4.1.1
664 246	Erlenmeyer flask, DURAN, 100 ml, wide neck	1
665 212	Glass stirring rod 200 x 8 mm Ø	1
665 162	Büchner funnel, 70 mm diam.	1
661 031	Round filter, Type 595, 70 mm diam., 100 pcs.	1
665 060	Rubber collars, set of 7	1
664 866	Suction flask, 500 ml, glass	1
666 967	Spoon-ended spatula, stainless steel, 150 mm	1
665 751	Measuring cylinder 10 ml, with plastic base	1
665 996	Graduated pipette, 5 ml	1
666 003	Pipetting ball (Peleus ball)	1
664 101	Beaker, DURAN, 100 ml, squat	1
667 7977	Electronic Balance 440-3N, 200 g : 0.01 g	1
375 56	Water jet pump	1
667 186	Vacuum rubber tubing, 8 mm diam.	1
673 9390	2-Nitrobenzaldehyde, 5 g	1
670 0410	Acetone, 1 l	1
673 8420	Sodium hydroxide solution, 1 mol/l, 500 ml	1
671 9711	Ethanol, absolute, 500 ml	1
	additionally required: white cotton cloth	1

The synthesis of new compounds is a major branch of organic chemistry. Because carbon and the heteroatoms oxygen, nitrogen and sulphur can be linked together in so many different combinations, the number of compounds characterised increases year after year. Every synthesis of a new compound consists of carrying out a chemical reaction and subsequently purifying the reaction mixture.

Indigo, a dye, can be produced in a simple organic synthesis. In so doing, o-nitrobenzaldehyde reacts with acetone in a condensation reaction to form isatin. That dimerises into finished indigo. Indigo is not water soluble and can simply be filtered out after the reaction. In experiment C2.4.1.1, this reaction is carried out and the finished indigo is used as a dye.

Soxhlet extraction from leaves (C2.4.2.1)

C2.4.2

EXTRACTION AS A PURIFICATION PROCESS

C2.4.2.1

Soxhlet extraction from leaves

Cat. No.	Description	C2.4.2.1
665 453	Extraction unit after Soxhlet	1
665 422	Counter-flow coller after Dimroth	1
664 301	Round-bottom flask, 250 ml, ST 19/26	1
665 391	Joint clip, plastic, ST 19/26	1
665 392	Joint clip plastic, ST 29/32	1
666 6523	Heating Mantle, 250 ml, adjustable	1
300 76	Laboratory stand II	1
300 01	Stand base, V-shaped, large	1
300 43	Stand rod, 75 cm, 12 mm diam.	1
666 555	Universal clamp 0...80 mm	2
301 09	Bosshead S	2
667 193	PVC tubing, 7 mm diam., 1 m	2
604 460	Hose clamp, 8...12 mm	2
661 050	Extraction thimbles, 80 x 26 mm diam., 25 pieces	1
667 027	Tweezers, blunt, 130 mm	1
602 954	Measuring cylinder, Boro 3.3, 250 ml, glass base	1
661 167	Narrow-neck bottle, amber glass, 250 ml	1
665 005	Funnel, Boro 3.3, 100 mm diam.	1
671 9720	Ethanol, denaturated, 1 l	1
661 082	Stopcock grease, 60 g	1
661 091	Boiling stones 100 g	1
	additionally required: leaves, dry, fine powder	1

The term "extraction" refers to the process of dissolving out individual substances from the extraction material, a liquid or solid mixture of substances. For this it takes a suitable solvent – the extraction agent – in which ideally only the substance to be dissolved out (the extract) dissolves.

When low solubility or insoluble solids are to be extracted, then a Soxhlet extraction is carried out as in experiment C2.4.2.1. In this case the vapourised solvent condenses on a chiller and drips onto the extraction material in a filter sleeve. It collects in the extraction space, draws the extract out of the extraction material, and is automatically drawn into the flask. From there the solvent evaporates once again (without extract).

C2.4.2

EXTRACTION AS A PURIFICATION PROCESS

C2.4.2.2
Extracting pigments from leaf extract

Extracting pigments from leaf extract (C2.4.2.2)

Cat. No.	Description	C2.4.2.2
665 123	Separating funnel, 250 ml, ungraduated	1
300 01	Stand base, V-shaped, large	1
300 42	Stand rod, 47 cm, 12 mm diam.	1
301 09	Bosshead S	1
666 573	Stand ring with stem 100 mm Ø	1
667 180	Rubber tubing 7 mm Ø, 1 m	1
667 016	Scissors, 200 mm, pointed	1
664 103	Beaker, DURAN, 250 ml, squat	1
665 997	Graduated pipette 10 ml	1
666 003	Pipetting ball (Peleus ball)	1
610 061	Safety gloves, neoprene, medium	1
	additionally required: Cooking oil, leaf extract from experiment C2.4.2.1	1

The solvent extraction of a substance is a simple liquid-liquid extraction. In this case the extraction material is shaken with the extraction agent in a closed vessel, the separatory funnel. The liquids must not be miscible! The substance to be extracted goes over to the extraction agent. In experiment C2.4.2.2 this technique is illustrated by the solvent extraction of a leaf extract with oil.

C2.4.2

DISTILLATION AS A PURIFICATION PROCESS

C2.4.3.1
Distillation of red wine

Distillation of red wine (C2.4.3.1)

Cat. No.	Description	C2.4.3.1
524 005W	Mobile-CASSY 2 WiFi	1
524 220	CASSY Lab 2	1
529 676	Temperature probe, NiCr-Ni, 1.5 mm, type K	1
665 338	Distillation bridge after Claisen	1
664 301	Round-bottom flask, 250 ml, ST 19/26	1
664 300	Round-bottom flask, 100 ml, ST 19/26	1
665 391	Joint clip, plastic, ST 19/26	2
604 501	PVC tubing, 7 mm diam., 1 m	2
604 460	Hose clamp, 8...12 mm	2
667 305	Screw cap, GL 18, with hole	1
667 295	Silicone gaskets, GL 18/8, set of 10	1
666 194	Protective sleeves for temperature probe, set of 5	1
666 6522	Heating Mantle, 250 ml	1
300 76	Laboratory stand II	1
666 4659	Adhesive magnetic board 500 mm	2
666 4662	Holder, magnetic, size 2, 11...14 mm	2
666 4663	Holder, magnetic, size 3, 18...22 mm	2
666 425	Panel frame C50, two-level, for CPS	1
602 954	Measuring cylinder, Boro 3.3, 250 ml, glass base	1
661 082	Stopcock grease, 60 g	1
661 091	Boiling stones 100 g	1
608 311	Evaporating dish, 72 ml, 77 mm diam.	1
672 2520	Wooden turnings	1
	additionally required: PC with Windows 7 or higher with WIFI or USB connection	1

Distillation is a purification process for separating fluids from one another. It relies on the different volatilities and boiling points of the components.

In distillation, the liquid mixture is heated and the vapours are re-cooled. The composition of the vapours differs from that of the liquid, and the same also applies then to the condensate.

If the boiling points are far enough apart, then mixtures can be separated by simple distillation. This is the case, for example, in the distillation of red wine in experiment C2.4.3.1. Ethanol boils at 78 °C and water boils at 100 °C. Here CASSY is used to track the temperature curve in computerised form.

C2.4.3

DISTILLATION AS A PURIFICATION PROCESS

C2.4.3.3

Purification of a substance with water vapour distillation

Purification of a substance with water vapour distillation (C2.4.3.3)

Cat. No.	Description	C2.4.3.3
666 4659	Adhesive magnetic board 500 mm	2
666 4662	Holder, magnetic, size 2, 11...14 mm	1
666 4663	Holder, magnetic, size 3, 18...22 mm	2
666 6522	Heating Mantle, 250 ml	1
665 338	Distillation bridge after Claisen	1
664 300	Round-bottom flask, 100 ml, ST 19/26	1
664 301	Round-bottom flask, 250 ml, ST 19/26	1
665 391	Joint clip, plastic, ST 19/26	2
666 425	Panel frame C50, two-level, for CPS	1
666 161	Chemical thermometer, -10...+250 °C/1 K	1
300 76	Laboratory stand II	1
604 501	PVC tubing, 7 mm diam., 1 m	2
604 460	Hose clamp, 8...12 mm	4
667 295	Silicone gaskets, GL 18/8, set of 10	1
661 091	Boiling stones 100 g	1
661 082	Stopcock grease, 60 g	1
	additionally required: one lemon or orange	1

In experiment C2.4.3.3, water vapour distillation is used to isolate fragrance and flavouring substances from crushed plant parts. The readily volatile fragrance and flavouring substances are carried away by the hot steam. In addition, the water solubility of these essential oils is temperature dependent. They dissolve in the hot water in the receiver flask. During cooling in the distillation unit, the water and essential oil separate again. In this way, the oil can be easily separated from the solvent water.

C2.4.4

COLUMN CHROMATOGRAPHY AS A PURIFICATION PROCESS

C2.4.4.1

Separation of a leaf extract with column chromatography

Separation of a leaf extract with column chromatography (C2.4.4.1)

Cat. No.	Description	C2.4.4.1
665 592	Chromatography column, 235 x 20 mm diam.	1
665 073	Dropping funnel, 75 ml, ST 29	1
664 101	Beaker, DURAN, 100 ml, squat	2
602 012	Beaker, Boro 3.3, 600 ml, tall	1
667 092	Mortar porcelain 70 mm Ø	1
667 091	Pestle 88 mm	1
665 005	Funnel, Boro 3.3, 100 mm diam.	1
661 038	Round filter, Type 595, 150 mm diam., 100 pcs.	1
661 161	Narrow-neck glass bottle, amber glass, 100 ml	1
602 347	Laboratory bottle, 500 ml, GL 45 thread	1
665 754	Measuring cylinder 100 ml, with plastic base	1
665 756	Measuring cylinder 500 ml, with plastic base	1
665 217	Glass stirring rod, 500 mm x 8 mm diam., set of 10	1
667 7977	Electronic Balance 440-3N, 200 g : 0.01 g	1
665 025	Powder funnel, 100 mm diam., plastic	1
661 0771	Warning labels, GHS	1
667 050	Test tube rack, plastic, for 9 tubes, 18 mm Ø	1
664 043	Test tubes, Fiolax, 16 x 160 mm, set of 10	1
667 253	Rubber stopper solid, 14...18 mm Ø	9
666 966	Spoon-ended spatula, PP, 180 mm	1
665 953	Dropping pipette, 7 x 150 mm, 10 pcs.	1
666 584	Filtration stand for two funnels	1
665 954	Rubber bulbs, 10 pcs	1
300 02	Stand base, V-shaped, small	1
300 42	Stand rod, 47 cm, 12 mm diam.	1

Cat. No.	Description	C2.4.4.1
301 09	Bosshead S	2
666 555	Universal clamp 0...80 mm	2
670 8200	Petroleum ether, 90...110 °C, 250 ml	1
672 1000	Glass wool, 10 g	1
674 8210	Sea sand, purified, 1 kg	1
670 0410	Acetone, 1 l	1
661 0581	Silica gel, 35-70 mesh, 1 kg	1
661 0821	Stopcock grease (grease stick)	1
	additionally required: green leaves, dry or fresh	1

After a synthesis, the resulting reaction mixture is often separated by means of column chromatography. Often used is a solid-liquid adsorption chromatography, which takes advantage of the different polarities of the individual compounds.

The process of chromatography was developed by Tsvet on leaf pigments at the beginning of the 20th century. Although ridiculed at first, the technique has since become one the most important methods in organic chemistry. In experiment C2.4.4.1, a leaf extract is produced and separated into its components by means of column chromatography.

C2.4.4

COLUMN CHROMATOGRAPHY AS A PURIFICATION PROCESS

C2.4.4.2
Separation of petroleum by means of column chromatography

Separation of petroleum by means of column chromatography (C2.4.4.2)

Cat. No.	Description	C2.4.4.2
665 592	Chromatography column, 235 x 20 mm diam.	1
665 073	Dropping funnel, 75 ml, ST 29	1
665 005	Funnel, Boro 3.3, 100 mm diam.	1
665 754	Measuring cylinder 100 ml, with plastic base	1
667 7977	Electronic Balance 440-3N, 200 g : 0.01 g	1
665 025	Powder funnel, 100 mm diam., plastic	1
661 0771	Warning labels, GHS	1
666 966	Spoon-ended spatula, PP, 180 mm	1
300 02	Stand base, V-shaped, small	1
300 42	Stand rod, 47 cm, 12 mm diam.	1
301 09	Bosshead S	1
666 555	Universal clamp 0...80 mm	1
670 0410	Acetone, 1 l	1
661 0581	Silica gel, 35-70 mesh, 1 kg	
661 0821	Stopcock grease (grease stick)	1
665 563	Miniature separation tank	8
661 242	Wash bottle, PE, 250 ml	1
664 130	Beaker, Boro 3.3, 250 ml, squat	1
602 283	Bottle clear glass wide treath w. cap, 5	1
665 997	Graduated pipette 10 ml	1
666 003	Pipetting ball (Peleus ball)	1
602 022	Beaker Boro 3.3, 100 ml, squat	1
672 1810	n-Heptane, 250 ml	1
672 2210	n-Hexane, 250 ml	1
675 2100	Toluene, 250 ml	1

Cat. No.	Description	C2.4.4.2
673 2700	Methanol, 250 ml	1
671 6590	Dichloromethane, 500 ml	1
670 2900	Aluminium oxide, 250 g	1
674 5840	Crude oil, artificial, 1 L	1

Crude oil is a liquid mixture of many organic substances. The aromatic substances in the crude oil can be separated on aluminium oxide by means of column chromatography. This is carried out in experiment C2.4.4.2. Using column chromatography, however, it is also possible to assay the different compound classes in crude oil fractions.

C3 ANALYTICAL CHEMISTRY

Determination of the density of gases (C3.1.1.1)

C3.1.1

PROPERTIES OF GASES

C3.1.1.1
Determination of the density of gases

Cat. No.	Description	C3.1.1.1
379 07	Sphere with 2 stopcocks, glass, 1 l	1
667 072	Support ring for round flask, 250 ml, cork	1
SAP R313	Precision Balance Practum 313-1S	1
375 58	Hand vacuum pump	1
665 913	Gas syringe, 100 ml with 1-way stopcock	1
661 000	Minican pressurised gas canister, nitrogen	1
660 998	Minican pressurised gas canister, oxygen	1
660 980	Fine regulating valve for minican gas canisters	1
604 481	Rubber tubing, 1 m x 4 mm diam., DIN 12865	1
667 183	Rubber tubing, 1 m x 8 mm diam., DIN 12865	1
604 510	Tubing connector, 4...15 mm	2
661 082	Stopcock grease, 60 g	1

A gas is a collection of molecules which are separated by great distances from one another and are in chaotic motion. It completely fills any volume which is available to it. In so doing, it always has the same volume, regardless of which gas it is. Because of the large molecular distances, gases are highly compressible.

Density (σ) is defined as mass (m) per unit volume (V):

$$\sigma = \frac{V}{m}$$

In experiment C3.1.1.1, a sphere of known volume with two stopcocks is used to determine the density of various gases. The mass of the enclosed air is determined from the measured difference between the total weight of the sphere filled with gas and the empty weight of the evacuated sphere.

Determination of viscosity with the falling ball viscometer according to Höppler (C3.1.2.1)

C3.1.2

PROPERTIES OF LIQUIDS

C3.1.2.1
Determination of viscosity with the falling ball viscometer according to Höppler

Cat. No.	**Description**	**C3.1.2.1**
665 906	Höppler falling ball viscometer	1
313 27	Hand-held stop-watch, 60s/0.2s	1
666 7681	Circulation thermostat SC 100-S5P	1
667 194	Silicone tubing 7 mm Ø, 1 m	2
OHC R221	Compact Balance CR221, 220 g : 0.1 g	1
602 022	Beaker Boro 3.3, 100 ml, squat	5
604 5682	Powder spatula, steel, 185 mm	1
666 8451	Magnetic stirrer	1
666 850	Stirring magnet, 15 mm x 5 mm diam.	1
674 6060	D(+)-Sucrose, 250 g	1
675 3410	Water, pure, 5 l	2

Liquid particles glide easily alongside one another. A liquid conforms to the shape of the vessel in which it is placed. All objects which are heavier than the liquid sink into it unimpeded. The surface of liquids always remains horizontal. Liquids cannot be compressed.

When a substance (gas, liquid or solid) deforms, it opposes the change in form by a resistance which is generally referred to as its viscosity. If one liquid layer moves at constant speed in a direction parallel to a second layer, then a force friction acts between the two layers. The friction converts the energy of motion into heat. For this reason, the viscosity of a substance is a measure of the internal friction. The viscosity of a substance determines how well or poorly it flows in a pipe (e.g. blood through a vein) and how much resistance it exerts against a solid body moving in it.

Viscosity is highly temperature dependant. Experiment C3.1.2.1 studies the dependence of the viscosity on concentration in concentrated sugar solutions at room temperature.

C3.1.2

PROPERTIES OF LIQUIDS

C3.1.2.2
Measurement of surface tension using the „break-away“ method

Measurement of surface tension using the „break-away“ method (C3.1.2.2)

Cat. No.	Description	C3.1.2.2
367 46	Surface tension determination device	1
664 175	Crystallisation dish, 95 mm diam., 300 ml	1
314 111	Precision dynamometer, 0.1 N	1
311 53	Vernier callipers	1
300 76	Laboratory stand II	1
300 02	Stand base, V-shaped, small	1
300 43	Stand rod, 75 cm, 12 mm diam.	1
301 08	Clamp with hook	1
671 9740	Ethanol, denaturated, 250 ml	1
675 3400	Water, pure, 1 l	1

Liquid particles glide easily alongside one another. A liquid conforms to the shape of the vessel in which it is placed. All objects which are heavier than the liquid sink into it unimpeded. The surface of liquids always remains horizontal. Liquids cannot be compressed.

Surface tension is a property of the surface (boundary layer) between a fluid and a gas, such as air. The surface of a liquid behaves like a stretched elastic film. This effect is the reason that water droplets form, for example, and helps make it possible for certain insects to walk on the water or for a coin to "swim" on the water.

Experiment C3.1.2.2 determines the surface tension of water and ethanol. Here it will be shown that water is characterised by a particularly high surface tension as compared with other liquids. (Published value for water: 0.073 Nm^{-1}, for ethanol: 0.022 $Nm^{-1<}$)

C3.1.2

PROPERTIES OF LIQUIDS

C3.1.2.3
Determination of density according to Mohr-Westphal

C3.1.2.4
Determination of density with the pycnometer

Determination of density with the pycnometer (C3.1.2.4)

Cat. No.	Description	C3.1.2.3	C3.1.2.4
362 025	Plumb bob	1	
315 011	Hydrostatic balance	1	
315 31	Set of weights, 10 mg to 200 g	1	
382 21	Stirring thermometer -10...+110 °C	1	1
665 754	Measuring cylinder 100 ml, with plastic base	2	2
671 9720	Ethanol, denaturated, 1 l	1	1
666 145	Gay-Lussac pycnometer, 50 ml		1
667 7977	Electronic Balance 440-3N, 200 g : 0.01 g		1

Experiment C3.1.2.3 provides a plummet for determining the of density of liquids. The measurement task is to determine the density of ethanol-water mixtures. Using the plummet, the density is determined from the buoyancy that a body of known volume experiences in the liquid under examination.

Experiment C3.1.2.4 provides a pycnometer according to Gay-Lussac for determining the of density of liquids. The measurement task is to determine the density of ethanol-water mixtures. The pycnometer is a bulb-shaped bottle into which the liquid under study is filled for weighing. The volume capacity of the pycnometer is determined by weighing with a liquid of known density (e.g. water).

Determination of the melting point of salicylic acid (C3.1.3.1)

C3.1.3

PROPERTIES OF SOLIDS

C3.1.3.1
Determination of the melting point of salicylic acid

Cat. No.	Description	C3.1.3.1
667 500	Melting point determination apparatus	1
661 085	Melting point detection tubes, set of 100	1
667 306	Silicone gaskets, GL 18/6, set of 10	1
666 161	Chemical thermometer, -10...+250 °C/1 K	1
666 8471	Magnetic stirrer with hotplate	1
666 854	Stirring magnet, 50 mm x 8 mm diam.	1
666 523	Stand rod, 450 x 12 mm diam., M10 thread	1
666 555	Universal clamp 0...80 mm	1
301 09	Bosshead S	1
602 725	Laboratory dish, 140 mm diam., 900 ml	1
664 154	Watch glass dish 80 mm Ø	1
604 5682	Powder spatula, steel, 185 mm	1
665 009	Funnel PP 75 mm Ø	1
656 017	Teclu burner, universal	1
667 187	Safety gas hose with end clamp, 1 m	1
674 0820	Paraffin, thick, 1 l	1
674 6210	Salicylic acid, 100 g	1

The solid state of a substance is defined as featuring a definite, nearly temperature-independent volume and stable shape. All substances which meet those criteria are known as solids.

In experiment C3.1.3.1, the thiele tube is used to determine the melting point of salicylic acid. The melting point is, along with the boiling point, a characteristic property of every substance. The melting point determination apparatus is filled with paraffin and fitted with a thermometer. A melting point tube is filled with the substance to be assayed. The tube is inserted with the open side into the device in a way that it is positioned alongside the thermometer. The melting point is determined by slow heating in the water bath.

C3.1.3

PROPERTIES OF SOLIDS

C3.1.3.4
Determination of the density of solids

Determination of the density of solids (C3.1.3.4)

Cat. No.	Description	C3.1.3.4
667 7977	Electronic Balance 440-3N, 200 g : 0.01 g	1
362 04	Overflow vessel	1
590 08	Measuring cylinder 100 ml	1
300 76	Laboratory stand II	1
309 48	Fishing line	1
674 7560	Sulfur, Pcs., 500 g	1
309 42	Colouring, red, 10 g	1*

* additionally recommended

Experiment C3.1.3.4 determines the density of irregularly shaped solid bodies. Weighing is coupled with a measurement of volume. The volume of the bodies are determined by the volume of liquid which the bodies displace from an overflow vessel.

Gas chromatographical analysis of cigarette lighter gas (butane gas) (C3.2.1.1_p)

C3.2.1

GAS CHROMATOGRAPHY

C3.2.1.1_p
Gas chromatographical analysis of cigarette lighter gas (butane gas)

C3.2.1.1_s
Gas chromatographical analysis of cigarette lighter gas (butane gas) using stand material

Cat. No.	**Description**	**C3.2.1.1_p**	**C3.2.1.1_s**
665 580	Gas chromatograph LD 1	1	1
665 582	Hydrocarbon sensor	1	1
665 5831	Separation column silicone OV101	1	1
665 588	Base panel for gas chromatograph LD 1, CPS	1	
524 005W	Mobile-CASSY 2 WiFi	1	1
524 0036	Holder for Mobile-CASSY 2, CPS	1	
524 220	CASSY Lab 2	1	1
666 425	Panel frame C50, two-level, for CPS	1	
666 4660	Adhesive magnetic board 300 mm	1	
662 2861	Aquarium pump, 100 l/h	1	1
664 814	Bubble counter, with flash back valve	1	1
665 957	Disposable syringe, 1 ml, with Luer fitting	1	1
665 955	Disposable syringe, 5 ml, with Luer fitting	1	1
665 960	Cannula, 0.45 diam., 10 pcs., with Luer fitting	1	1
501 45	Connecting lead 19 A, 50 cm, red/blue, pair	1	1
666 503	Base plate for bunsen stand, 130 x 210 mm	1	1
666 523	Stand rod, 450 x 12 mm diam., M10 thread	1	1
666 555	Universal clamp 0...80 mm	1	1
301 09	Bosshead S	1	1
665 589	Septa, silicone, 13 mm diam., 10 pcs.	1	1
667 197	Silicone tubing, 4 mm diam., 1 m	1	1
660 980	Fine regulating valve for minican gas canisters	1	1
660 988	Minican pressurised gas canister, ethane	1	1
660 989	Minican pressurised gas canister, n-Butane	1	1
	additionally required: cigarette lighter(s)	1	

In use all around the world today, gas chromatography is a method for analyzing chemical substances and mixtures. Especially useful for identifying the components of gaseous hydrocarbons, e.g. natural gas, it can also be used to study volatile substances such as fragrances or alcohols. Substances are separated in a two-phase system comprising a stationary phase - the separation column with column material - and a mobile phase - the carrier gas. Samples are introduced into the carrier gas stream and travel along the column at different speeds depending on polarity, which makes it possible to separate them.

Cigarette lighter gas is a mixture of different gaseous hydrocarbons. They can be easily separated by gas chromatography techniques. The stationary phase is silicone oil OV-101 on silica gel. Air is used as the mobile phase. The proportions of the individual hydrocarbons in the gas mixture is different in every cigarette lighter - depending on the source of the natural gas. This is studied in experiment C3.2.1.1.

C3.2.1

GAS CHROMATOGRAPHY

C3.2.1.2_p
Gas chromatographical separation of alcohols - effect of temperature

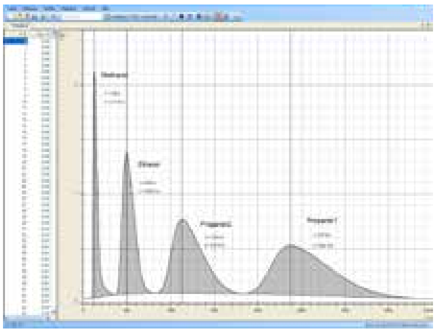
C3.2.1.2_s
Gas chromatographical separation of alcohols - effect of temperature using stand material

Gas chromatographical separation of alcohols - effect of temperature (C3.2.1.2_p)

Cat. No.	Description	C3.2.1.2_p	C3.2.1.2_s
524 005W	Mobile-CASSY 2 WiFi	1	1
524 220	CASSY Lab 2	1	1
665 580	Gas chromatograph LD 1	1	1
665 582	Hydrocarbon sensor	1	1
665 584	Separation column with Porapak P	1	1
662 2861	Aquarium pump, 100 l/h	1	1
664 814	Bubble counter, with flash back valve	1	1
602 013	Beaker, Boro 3.3, 800 ml, tall	2	2
300 76	Laboratory stand II	1	1
607 5025	Magnetic stirrer with hotplate	1	1
666 851	Stirring magnet 25 mm x 6 mm Ø, circular	1	1
382 21	Stirring thermometer -10...+110 °C	1	1
665 957	Disposable syringe, 1 ml, with Luer fitting	1	1
665 960	Cannula, 0.45 diam., 10 pcs., with Luer fitting	1	1
501 45	Connecting lead 19 A, 50 cm, red/blue, pair	1	1
666 425	Panel frame C50, two-level, for CPS	1	
666 4660	Adhesive magnetic board 300 mm	1	
524 0036	Holder for Mobile-CASSY 2, CPS	1	
665 588	Base panel for gas chromatograph LD 1, CPS	1	
665 589	Septa, silicone, 13 mm diam., 10 pcs.	1	1
667 197	Silicone tubing, 4 mm diam., 1 m	1	1
673 2700	Methanol, 250 ml	1	1
671 9700	Ethanol, absolute, 250 ml	1	1
671 9740	Ethanol, denaturated, 250 ml	1	1
674 4310	1-Propanol, 250 ml	1	1

Cat. No.	Description	C3.2.1.2_p	C3.2.1.2_s
674 4400	2-Propanol, 250 ml	1	1
666 503	Base plate for bunsen stand, 130 x 210 mm		1
666 523	Stand rod, 450 x 12 mm diam., M10 thread		1
666 555	Universal clamp 0...80 mm		1
301 09	Bosshead S		1
	additionally required: PC with Windows 7 or higher with WiFi or USB connection	1	1

A gas chromatograph can be used to separate not only gaseous substances, but also volatile liquids. Only the gaseous part is separated, however. In such cases, the separation column and the carrier gas can be warmed if necessary. In experiment C3.2.1.2, the gas chromatographic analysis of an alcohol mixture is carried out.



Chromatogram of the analysis of different alcohols

Absorption spectra of pigments on a screen (C3.3.1.1)

C3.3.1

SPECTROMETRY

C3.3.1.1
Absorption spectra of pigments on a screen

C3.3.1.2
Recording of absorption spectra with a spectrometer

Cat. No.	Description	C3.3.1.1	C3.3.1.2
460 03	Lens in frame, f=100 mm	1	1
466 05	Direct vision prism	1	
466 04	Holder for direct vision prism	1	
477 33	Cuvette made of optical glass 45 x 12,5 x 102,5 mm	1	1
460 25	Prism table	1	1
441 53	Screen, translucent	1	
450 60	Lamp housing with cable	1	1
450 521	Bulbs, 12 V/30 W, E14, set of 2	1	1
460 20	Condenser with diaphragm holder	1	1
521 210	Transformer 6/12 V	1	1
460 310	Optical bench, S1 profile, 1 m	1	1
460 311	Clamp rider with clamp 45/65	5	4
667 7977	Electronic Balance 440-3N, 200 g : 0.01 g	1	1
602 023	Beaker, Boro 3.3, 150 ml, squat	5	
665 212	Glass stirring rod 200 x 8 mm Ø	1	
665 753	Measuring cylinder 50 ml, with plastic base	1	
665 953	Dropping pipette, 7 x 150 mm, 10 pcs.	1	
665 954	Rubber bulbs, 10 pcs	1	
661 243	Wash bottle PE 500 ml	1	
671 8700	Iron(III) chloride-6-hydrate, 50 g	1	1
673 2900	Methylene blue, 1 g	1	1*
675 2550	Universal Indicator, 50 ml	1	1
309 42	Colouring, red, 10 g	1	1
675 3400	Water, pure, 1 l	1	
673 8400	Sodium hydroxide solution, diluted, aprox. 2 M, 500 ml	1	

Cat. No.	Description	C3.3.1.1	C3.3.1.2
467 251	Compact spectrometer, physics (spectral photometer)		1
460 251	Fibre holder		1
665 997	Graduated pipette 10 ml		1
666 003	Pipetting ball (Peleus ball)		1
604 5672	Double microspatula, steel, 150 mm		1
664 103	Beaker, DURAN, 250 ml, squat		1
602 043	Beaker, DURAN, 150 ml, squat		6
665 754	Measuring cylinder 100 ml, with plastic base		1
	additionally required: PC with Windows XP/Vista/7/8/10 (x86 or x64)		1

* additionally recommended

In experiment C3.3.1.1, the light from a lamp is separated out into its spectrum with a direct vision prism. That light is then projected through coloured liquids and compared with the continuous spectrum of the light from the lamp. The original continuous spectrum with the different spectral colours disappears. Only the colour components of the liquid remain visible.

In experiment C3.3.1.2, the solution of a dye is exposed to the light from a lamp. For the absorption spectrum, the light passing through the coloured solution is recorded with a spectrometer. The absorption spectrum is compared with the continuous spectrum of the light from the lamp.

C3.3.1

SPECTROMETRY

C3.3.1.3
Recording of a fluorescence spectrum with a spectrometer

Recording of a fluorescence spectrum with a spectrometer (C3.3.1.3)

Cat. No.	Description	C3.3.1.3
664 470	Rectangular cuvette cell, glass, 10 x 10 mm	2
467 252	Compact spectrometer, complete	1
458 100	Halogen spotlight, 12 V/20 W	1
562 791	Plug-in power supply, 12 V AC	1
300 02	Stand base, V-shaped, small	1
301 26	Stand rod 25 cm, 10 mm Ø	1
301 11	Clamp with jaw clamp	1
604 5672	Double microspatula, steel, 150 mm	1
602 022	Beaker Boro 3.3, 100 ml, squat	1
664 130	Beaker, Boro 3.3, 250 ml, squat	1
665 754	Measuring cylinder 100 ml, with plastic base	1
665 996	Graduated pipette, 5 ml	1
666 003	Pipetting ball (Peleus ball)	1
665 953	Dropping pipette, 7 x 150 mm, 10 pcs.	1
665 954	Rubber bulbs, 10 pcs	1
309 42	Colouring, red, 10 g	1
672 0110	Fluoresceine, 25 g	1
671 9740	Ethanol, denaturated, 250 ml	1
675 3400	Water, pure, 1 l	1
	additionally required: PC with Windows 7 or higher with WIFI or USB connection	1

The impression of colour observed when looking through liquids is created by the part of the white light which is transmitted („passed through"). Every coloured substance absorbs at characteristic wavelengths. In this way, a characteristic spectrum can be created for a dye.

In experiment C3.3.1.3, a solution of the fluorescent dye fluorescein is exposed to the light from a lamp. For this purpose, the spectrometer is arranged at a right angle to the lamp. In this way, the fluorescence spectrum of the dye can be recorded. This can be compared with the absorption spectrum from experiment C3.3.1.2.

Spectra of a mixture of different-colourd substances (C3.3.1.4)

C3.3.1

SPECTROMETRY

C3.3.1.4
Spectra of a mixture of different-colourd substances

Cat. No.	Description	C3.3.1.4
467 252	Compact spectrometer, complete	1
604 5672	Double microspatula, steel, 150 mm	1
667 7977	Electronic Balance 440-3N, 200 g : 0.01 g	1
664 103	Beaker, DURAN, 250 ml, squat	1
665 754	Measuring cylinder 100 ml, with plastic base	1
309 42	Colouring, red, 10 g	1
673 2920	Methylene blue solution, 100 ml	1
665 793	Volumetric flask, Boro 3.3, 100 ml	5
675 3410	Water, pure, 5 l	1
661 243	Wash bottle PE 500 ml	1
664 474	Rectangular cuvette cell, polystyrene, 10 x 10 mm	1

To determine the concentration of a dye in a solution with other dyes, the solution must be separated and the concentrations of the individual dyes must be determined. A look at the spectra of the dye mixture and the individual dyes can show whether such a separation is necessary. This method is carried out in experiment C3.3.1.4.

C3.3.2

PHOTOMETRY

C3.3.2.1
The Beer-Lambert law

The Beer-Lambert law (C3.3.2.1)

Cat. No.	Description	C3.3.2.1
524 005W	Mobile-CASSY 2 WiFi	1
524 220	CASSY Lab 2	1
524 069	Immersion photometer S	1
666 2605	Holder for immersion photometer S	1
665 793	Volumetric flask, Boro 3.3, 100 ml	1
665 792	Volumetric flask, Boro 3.3, 50 ml	1
664 045	Test tubes, Fiolax, 30 x 200 mm, set of 10	1
665 997	Graduated pipette 10 ml	3
666 003	Pipetting ball (Peleus ball)	1
667 054	Test tube rack, for 12 tubes, 32 mm diam.	1
667 7977	Electronic Balance 440-3N, 200 g : 0.01 g	1
672 9600	Copper(II) sulfate-5-hydrate, 100 g	1
670 3600	Ammonia solution, 25 %, 250 ml	1
675 3400	Water, pure, 1 l	1
	additionally required: PC with Windows 7 or higher with WIFI or USB connection	1

The intensity of light diminishes when it passes through a coloured solution. Photometric measurements make use of this fact to determine the concentration of such a solution. For this purpose, the transmittance T of the solution is measured, i.e. the ratio of the intensity of the transmitted light I to the intensity of light exposure I_0.

$$T = \frac{I}{I_0}$$

The extinction or absorption of the solution, i.e. the number of light quanta absorbed, is proportional to the concentration. Transmission and extinction have the following relationship:

$$E = \log_{10}\left(\frac{I_0}{I}\right) = -\log_{10}\left(\frac{I}{I_0}\right) = -\log_{10}(T)$$

If the extinction of a solution is measured, its concentration can be calculated from the result. That relationship is expressed by the Beer-Lambert law. Along with the concentration c of a solution, the extinction also depends on the thickness d of the layer and on the substance-specific extinction coefficient ε.

$$E = \log_{10}\left(\frac{I_0}{I}\right) = \varepsilon \cdot c \cdot d$$

In experiment C3.3.2.1, a dilution series is used to study the proportional relationship between extinction and concentration and to determine the extinction coefficient of blue copper tetraammine.

Determination of the refractive index with the refractometer (C3.3.3.1)

C3.3.3

REFRACTOMETRY

C3.3.3.1
Determination of the refractive index with the refractometer

Cat. No.	Description	C3.3.3.1
667 359	Laboratory refractometer	1
667 7977	Electronic Balance 440-3N, 200 g : 0.01 g	1
602 022	Beaker Boro 3.3, 100 ml, squat	2
665 997	Graduated pipette 10 ml	2
666 002	Pipetting aid	1
665 953	Dropping pipette, 7 x 150 mm, 10 pcs.	1
665 954	Rubber bulbs, 10 pcs	1
661 251	Flip-flap glass, 20 ml	10
661 243	Wash bottle PE 500 ml	1
671 9720	Ethanol, denaturated, 1 l	1
667 3551	Peltier-Thermostat PT30	1*
307 70	Tubing 8 mm Ø, 1 m, plastic	2*

* additionally recommended

Every liquid has a characteristic refractive index n_D . The refractive index of a mixture of two liquids is determined by the refractive index of the individual liquids and by their proportion in the mixture. If the refractive indices of the individual liquids are known, then their mixing proportion in a solution can be determined. The refractive index is measured with a refractometer.

The refractometer is also useful for determining the Brix value (mass for the soluble solids or sugar content). In experiment C3.3.3.1, the refractometer is used to determine the mass fraction w in % in a solution by measuring the refractive index. (w = the mass of the components / the mass of the mixture. To express the result in percent, the number is multiplied by 100). For this purpose, solutions with different mass fractions of a substance are prepared. In this way, a sample with unknown mass fraction can be determined.

Rotation of the polarisation plane through sugar solutions (C3.3.4.1)

C3.3.4

POLARIMETRY

C3.3.4.1
Rotation of the polarisation plane through sugar solutions

Cat. No.	Description	C3.3.4.1
657 591	Polarimeter	1
OHC R221	Compact Balance CR221, 220 g : 0.1 g	1
666 963	Spoon-ended spatula, stainless steel, 120 mm	1
665 793	Volumetric flask, Boro 3.3, 100 ml	3
664 153	Watch glass dish 60 mm Ø	3
665 009	Funnel PP 75 mm Ø	3
664 137	Beaker, Boro3.3, 100 ml, tall	3
672 1100	D(+)-Glucose, 100 g	1
672 0700	D(-)-Fructose, 50 g	1
674 6050	D(+)-Sucrose, 100 g	1

The term 'optical activity' refers to the property of some materials which rotate the polarisation plane of linearly polarised light as it passes through a substance. The angle of rotation α depends on the molecular structure and the concentration of the dissolved substance, on the distance that the light travels through the solution, and on the wavelength of the light.

Experiment C3.3.4.1 demonstrates that optically active substances can rotate the plane of a linerally polarised beam of light by a specific value. For a given cuvette length *d*, the angle of rotation α of an optically active solution is proportional to the concentration *c* of the solution.

To determine the concentration *c* of the solution, the following expression applies:

$$c = \frac{\alpha}{l \cdot [\alpha]}$$

specific rotation: $[\alpha]$ (°· ml/g · dm)

The angle of rotation is given as a positive (+) value when the polarisation plane of the light directed toward the observer rotates clockwise (to the right). Counterclockwise rotation is referred to as rotation to the left and expressed as a negative number, hence preceded by a minus sign (-).

C3.4.3

NUCLEAR MAGNETIC RESONANCE SPECTROSCOPY (NMR SPECTROSCOPY)

C3.4.3.1

Nuclear magnetic resonance (NMR) on water, polystyrene, glycerine and Teflon

Nuclear magnetic resonance (NMR) on water, polystyrene, glycerine and Teflon (C3.4.3.1)

Cat. No.	Description	C3.4.3.1
514 602	NMR supply unit	1
514 606	NMR probe	1
562 11	U-core with yoke	1
562 131	Coil, 480 turns, 10 A	2
521 546	DC Power Supply 0...16 V/0...5 A	1
575 304	Digital storage oscilloscope 70 MHz two-channel	1
501 02	BNC cable, 1 m	2
524 005W	Mobile-CASSY 2 WiFi	1*
524 0381	Combi B sensor S	1*
501 11	Extension cable, 15 pin	1*
500 621	Safety connecting lead 50 cm, red	1
500 641	Safety connecting lead, 100 cm, red	1
500 642	Safety connecting lead, 100 cm, blue	1

* additionally recommended

In a magnetic field *B*, the magnetic moment of a nucleus associated with nuclear spin *I* takes on the following energy states:

$$E_\mathrm{m} = -g_\mathrm{I} \cdot \mu_\mathrm{K} \cdot m \cdot B \quad \text{with} \quad m = -I, \; -I+1, \; \ldots, \; I$$

$$\mu_\mathrm{K} = 5.051 \cdot 10^{-27} \, \frac{\mathrm{J}}{\mathrm{T}}: \text{ nuclear magneton}$$

g_I: g factor of nucleus

A high-frequency magnetic field with frequency *f* projected perpendicular to that magnetic field excites transitions between neighbouring energy states when they meet the resonance conditions:

$$h \cdot \nu = E_{m+1} - E_m$$

h: Planck's constant

This phenomenon is the basis for nuclear magnetic resonance (NMR). Nuclei with an uneven number of protons are active here. The exact resonance frequency of a nucleus depends on the type of the atom and on its chemical surroundings. Along with the outer magnetic field *B*, a local, inner field also affects every nucleus. This is generated by the nuclei in the immediate proximity. In this way, NMR is useful for analyzing structures.

In experiment C3.4.3.1, nuclear magnetic resonance is demonstrated on polystyrene, glycerine and Teflon. The position, width and intensity of the resonance lines are evaluated.

Electron spin resonance on DPPH (C3.4.4.1)

C3.4.3

ELECTRON SPIN RESONANCE SPECTROSCOPY

C3.4.4.1
Electron spin resonance on DPPH

Cat. No.	Description	C3.4.4.1
514 55	ESR basic unit	1
514 571	ESR supply unit	1
555 604	Pair of Helmholtz coils	1
575 304	Digital storage oscilloscope 70 MHz two-channel	1
501 02	BNC cable, 1 m	2
300 11	Saddle base	3
501 23	Connecting lead, 32 A, 25 cm, black	1
501 25	Connecting lead, 32 A, 50 cm, red	1
501 26	Connecting lead, 32 A, 50 cm, blue	1

In experiment C3.4.4.1, electron spin resonance is demonstrated on diphenylpicrylhydrazyl (DPPH). DPPH is a radical in which a free electron occurs on a nitrogen atom. In the experiment, the resonance frequencies can be predefined continuously between 13 and 130 MHz. The aim of the assessment is to determine the g factor.

C3.5.1

POTENTIOMETRIC AND ACID-BASE TITRATIONS

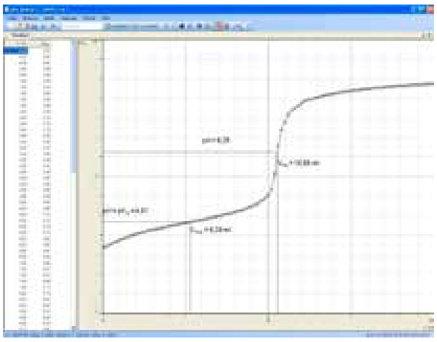
C3.5.1.1
Determination of acid concentration by titration with drop counter

Determination of acid concentration by titration with drop counter (C3.5.1.1)

Cat. No.	Description	C3.5.1.1
524 013	Sensor-CASSY 2	1
524 220	CASSY Lab 2	1
524 0672	pH adapter S	1
667 4172	pH sensor with plastic shaft, BNC	1
524 074	Timer S	1
337 4681	Drop counter	1
607 105	Magnetic stirrer mini	1
604 592	Stirring magnet, PTFE, oval, l = 40 mm, 20 mm diam.	1
664 103	Beaker, DURAN, 250 ml, squat	2
665 997	Graduated pipette 10 ml	1
666 003	Pipetting ball (Peleus ball)	1
665 845	Burette, clear glass, 25 ml	1
665 816	Burette filling funnel plastic, 35 mm Ø	1
666 559	Burette clamp for 1 burette, roller clamp	1
300 02	Stand base, V-shaped, small	1
300 42	Stand rod, 47 cm, 12 mm diam.	1
300 11	Saddle base	1
300 41	Stand rod, 25 cm, 12 mm Ø	1
666 543	Double, crossed boss head, 0...16 mm	2
666 555	Universal clamp 0...80 mm	2
673 8420	Sodium hydroxide solution, 1 mol/l, 500 ml	1
674 4640	Buffer solution pH 4.00, 250 ml	1
674 4670	Buffer solution pH 7.00, 250 ml	1
	additionally required: balsamic vinegar or other dark coloured vinegar	1

The classic technique for determining the exact quantity of a substance in solution (quantitative analysis) is titration. Here a reagent is slowly added in drops with a burette until the equivalence point is reached, i.e. the point at which the substance under investigation has reacted completely. In manual titrations, that point is made visible by means of a detection reagent, but it can also be measured by means of instrumentation.

In experiment C3.5.1.1, the acid concentration of balsamic vinegar is determined. Due to the dark colour, coloured indicators cannot be used here. Rather, the pH is measured continuously. This is done with a pH electrode. pH electrodes are potentiometric electrodes which respond ion-selectively only to changes in the potential of protons. The measured potential is then converted to a pH value. In the experiment, a complete titration curve of the titration of balsamic vinegar with sodium hydroxide is recorded using a drop counter.



Titration curve of vinegar

C3.5.1

POTENTIOMETRIC AND ACID-BASE TITRATIONS

C3.5.1.3
Potentiometric titration of iron(II) ions

Potentiometric titration of iron(II) ions (C3.5.1.3)

Cat. No.	Description	C3.5.1.3
524 005W	Mobile-CASSY 2 WiFi	1
524 220	CASSY Lab 2	1
524 0672	pH adapter S	1
667 416	Single-rod redox probe BNC	1
ADA NBL124E	Analytical balance 120 g; 0,0001g, with USB interface	1
607 105	Magnetic stirrer mini	1
664 103	Beaker, DURAN, 250 ml, squat	2
300 42	Stand rod, 47 cm, 12 mm diam.	1
300 02	Stand base, V-shaped, small	1
665 997	Graduated pipette 10 ml	1
666 003	Pipetting ball (Peleus ball)	1
665 845	Burette, clear glass, 25 ml	1
665 816	Burette filling funnel plastic, 35 mm Ø	1
666 559	Burette clamp for 1 burette, roller clamp	1
666 543	Double, crossed boss head, 0...16 mm	2
666 551	Universal clamp 0...40 mm	2
671 9100	Iron(II) sulfate-7-hydrate, 100 g	1
672 7000	Potassium permanganate, 100 g	1
674 7920	Sulfuric acid, diluted, approx. 2 N (= 10 %), 500 ml	1
674 4670	Buffer solution pH 7.00, 250 ml	1
674 6900	Hydrochloric acid, 1 mol/l, 500 ml	1*
675 3500	Hydrogen peroxide, 30 %, 250 ml	1*
	additionally required: PC with Windows 7 or higher with WIFI or USB connection	1

* additionally recommended

In experiment C3.5.1.3, a potentiometric titration is performed in order to measure the concentration of iron(II) ions. In the process, the iron(II) ions are oxidised with potassium permanganate.

$$5\ Fe^{2+} + MnO_4^- + 8\ H^+ \rightleftharpoons 5\ Fe^{3+} + Mn^{2+} + 4\ H_2O$$

The change in the potential of the solution during the titration corresponds here to the change in pH in an acid-base titration.

Conductometric titration of a hydrochloric acid solution (C3.5.2.1_p)

C3.5.2

CONDUCTOMETRIC TITRATIONS

C3.5.2.1_p
Conductometric titration of a hydrochloric acid solution

C3.5.2.1_s
Conductometric titration of a hydrochloric acid solution using stand material

Cat. No.	Description	C3.5.2.1_p	C3.5.2.1_s
666 425	Panel frame C50, two-level, for CPS	1	
666 4659	Adhesive magnetic board 500 mm	2	
666 4662	Holder, magnetic, size 2, 11...14 mm	3	
524 0036	Holder for Mobile-CASSY 2, CPS	1	
524 005W	Mobile-CASSY 2 WiFi	1	1
524 220	CASSY Lab 2	1	1
524 0671	Conductivity adapter S	1	1
529 670	Conductivity sensor	1	1
607 105	Magnetic stirrer mini	1	1
604 592	Stirring magnet, PTFE, oval, l = 40 mm, 20 mm diam.	1	1
664 103	Beaker, DURAN, 250 ml, squat	1	1
665 975	Bulb pipette, 10 ml, one mark	1	1
666 003	Pipetting ball (Peleus ball)	1	1
665 845	Burette, clear glass, 25 ml	1	1
665 816	Burette filling funnel plastic, 35 mm Ø	1	1
300 76	Laboratory stand II	1	
674 6950	Hydrochloric acid, 0.1 mol/l, 500 ml	1	1
673 8410	Sodium hydroxide solution, 0.1 mol/l, 500ml	1	1
666 559	Burette clamp for 1 burette, roller clamp		1
300 02	Stand base, V-shaped, small		1
300 42	Stand rod, 47 cm, 12 mm diam.		1
666 543	Double, crossed boss head, 0...16 mm		1
666 555	Universal clamp 0...80 mm		1
	additionally required: PC with Windows 7 or higher with WIFI or USB connection	1	1

In conductometric titrations, the equivalence point is determined by measuring the conductivity. This technique relies on the fact that dissolved salts dramatically increase the conductivity of a solution. Acid-base titrations or precipitation titrations can be tracked conductometrically.

In experiment C3.5.2.1, an acid-base titration is performed in which a hydrochloric acid solution is titrated with sodium hydroxide. Because hydronium ions and hydroxide ions have very high conductivity, the equivalence point is easy to determine. During the titration, the conductivity falls at first because more and more hydronium ions are neutralised.

$$H_3O^+ + OH^- \rightleftharpoons 2\,H_2O$$

Beginning exactly from the equivalence point, it starts to rise again because then there is a surplus of hydroxide ions.

C3.5.2

CONDUCTOMETRIC TITRATIONS

C3.5.2.2

Conductometric titration of a hydrochloric acid solution with pH measurement

Conductometric titration of a hydrochloric acid solution with pH measurement (C3.5.2.2)

Cat. No.	Description	C3.5.2.2
524 013	Sensor-CASSY 2	1
524 220	CASSY Lab 2	1
524 0671	Conductivity adapter S	1
529 670	Conductivity sensor	1
524 0672	pH adapter S	1
667 4172	pH sensor with plastic shaft, BNC	1
607 105	Magnetic stirrer mini	1
604 592	Stirring magnet, PTFE, oval, l = 40 mm, 20 mm diam.	1
664 103	Beaker, DURAN, 250 ml, squat	1
665 754	Measuring cylinder 100 ml, with plastic base	1
665 975	Bulb pipette, 10 ml, one mark	1
666 003	Pipetting ball (Peleus ball)	1
665 845	Burette, clear glass, 25 ml	1
665 816	Burette filling funnel plastic, 35 mm Ø	1
666 559	Burette clamp for 1 burette, roller clamp	1
300 02	Stand base, V-shaped, small	1
666 523	Stand rod, 450 x 12 mm diam., M10 thread	1
300 11	Saddle base	1
300 41	Stand rod, 25 cm, 12 mm Ø	1
666 543	Double, crossed boss head, 0...16 mm	2
666 555	Universal clamp 0...80 mm	2
674 6950	Hydrochloric acid, 0.1 mol/l, 500 ml	1
673 8410	Sodium hydroxide solution, 0.1 mol/l, 500ml	1
674 4640	Buffer solution pH 4.00, 250 ml	1
674 4670	Buffer solution pH 7.00, 250 ml	1

Cat. No.	Description	C3.5.2.2
	additionally required: PC with Windows XP/Vista/7/8/10 (x86 or x64)	1

In conductometric titrations, the equivalence point is determined by measuring the conductivity. This technique relies on the fact that dissolved salts dramatically increase the conductivity of a solution. Acid-base titrations or precipitation titrations can be tracked conductometrically.

In experiment C3.5.2.2, along with conductivity, the change in pH is also traced. It becomes clear that the two measurement methods determine the same equivalence point. This is attributable to the fact that the same chemical process is measured in different ways.

C3.5.2

CONDUCTOMETRIC TITRATIONS

C3.5.2.3
Conductometric titration using the Electrochemistry demonstration unit


Conductometric titration using the Electrochemistry demonstration unit (C3.5.2.3)

Cat. No.	Description	C3.5.2.3
664 4071	Electrochemistry demonstration unit, CPS	1
666 425	Panel frame C50, two-level, for CPS	1
666 472	Table for electrochemistry, CPS	1
664 401	Electrochemistry accessories set	1
665 212	Glass stirring rod 200 x 8 mm Ø	1
665 997	Graduated pipette 10 ml	1
666 003	Pipetting ball (Peleus ball)	1
665 843	Burette clear glass, 10 ml, side stopcock	1
665 816	Burette filling funnel plastic, 35 mm Ø	1
300 02	Stand base, V-shaped, small	1
300 42	Stand rod, 47 cm, 12 mm diam.	1
666 559	Burette clamp for 1 burette, roller clamp	1
675 3400	Water, pure, 1 l	1
674 6900	Hydrochloric acid, 1 mol/l, 500 ml	1
673 8421	Sodium hydroxide solution, 1 mol/l, 1 l	1
674 2500	Phenolphthalein solution, 100 ml	1*

* additionally recommended

In experiment C3.5.2.3 a conductivity titration is carried out using the electrochemistry demonstration unit. The reaction takes place in an electrolysis cell while two nickel electrodes are used for measuring the electrical potential differences.

C3.5.3

REDOX TITRATIONS

C3.5.3.2 Manganometric determination of iron(II) ions

Manganometric determination of iron(II) ions (C3.5.3.2)

Cat. No.	Description	C3.5.3.2
524 005W	Mobile-CASSY 2 WiFi	1
524 220	CASSY Lab 2	1
524 0672	pH adapter S	1
667 416	Single-rod redox probe BNC	1
667 7977	Electronic Balance 440-3N, 200 g : 0.01 g	1
607 105	Magnetic stirrer mini	1
664 103	Beaker, DURAN, 250 ml, squat	2
300 42	Stand rod, 47 cm, 12 mm diam.	1
300 02	Stand base, V-shaped, small	1
665 997	Graduated pipette 10 ml	1
666 003	Pipetting ball (Peleus ball)	1
665 845	Burette, clear glass, 25 ml	1
665 816	Burette filling funnel plastic, 35 mm Ø	1
666 559	Burette clamp for 1 burette, roller clamp	1
666 543	Double, crossed boss head, 0...16 mm	1
666 555	Universal clamp 0...80 mm	1
671 9100	Iron(II) sulfate-7-hydrate, 100 g	1
672 7000	Potassium permanganate, 100 g	1
674 7920	Sulfuric acid, diluted, approx. 2 N (= 10 %), 500 ml	1
674 4670	Buffer solution pH 7.00, 250 ml	1
674 6900	Hydrochloric acid, 1 mol/l, 500 ml	1*
675 3500	Hydrogen peroxide, 30 %, 250 ml	1*
	additionally required: PC with Windows 7 or higher with WIFI or USB connection	1

* additionally recommended

In redox titrations, a redox reaction takes place as an assay reaction. Similar to the pH indicator in acid-base titrations, the equivalence point is determined with redox indicators. Oxidation or reduction makes them change their colour at a specific "endpoint potential". Similar to the pH electrode, a redox electrode is used in the instrumental titration.

Manganometry requires no redox indicator because a potassium manganate solution is used as a reference solution. It has a deep violet colour and serves as an oxidising agent. In experiment C3.5.3.2, an iron(II) solution is titrated with a potassium permanganate solution.

$$5\,Fe^{2+} + MnO_4^- + 8\,H^+ \rightleftharpoons 5\,Fe^{3+} + Mn^{2+} + 4\,H_2O$$

The endpoint is reached when the solution retains a constant violet colour. At the same time, a redox electrode is used to measure the potential of the solution.

Determination of water contents with indicator reagents and immersion photometer (C3.6.1.1)

C3.6.1

WATER ANALYTICS

C3.6.1.1
Determination of water contents with indicator reagents and immersion photometer

Cat. No.	Description	C3.6.1.1
524 069	Immersion photometer S	1
666 2605	Holder for immersion photometer S	1
524 005W	Mobile-CASSY 2 WiFi	1
666 2600	Photometry - reagent set 1 (with storage case and accessories)	1
666 961	Double-ended microspatula, stainless steel, 185 mm	1
664 043	Test tubes, Fiolax, 16 x 160 mm, set of 10	1
667 050	Test tube rack, plastic, for 9 tubes, 18 mm Ø	1
665 997	Graduated pipette 10 ml	1
666 003	Pipetting ball (Peleus ball)	1
667 031	Test tube holder 20 mm Ø	1
656 016	Bunsen burner, universal	1
607 025	Safety gas hose 1.5 m	1
674 7860	Sulfuric acid, 95-98 %, 500 ml	1

The determination of water quality plays a role in many areas today. Not only drinking water and mineral water are analyzed, but, for example, also swimming pools and lakes. Chemical and biological analyses can be carried out. In chemical water analytics, various ingredients are assayed. The concentrations of these substances indicate the quality of the water.

In experiment C3.6.1.1, water samples are tested for several ingredients, e.g. phosphate, ammonium or nitrate. These are photometric assays. The chemical basis for this relies on the fact that the ingredient to be identified forms a coloured compound or turbidity with the reagents added. At an appropriate wavelength, the extinction of the colour or turbidity created in this way is directly proportional to the concentration of the ingredient.

C3.6.2

AIR ANALYTICS

C3.6.2.1
Continuous measurement of carbon dioxide concentration in the classroom

Continuous measurement of carbon dioxide concentration in the classroom (C3.6.2.1)

Cat. No.	Description	C3.6.2.1
524 013	Sensor-CASSY 2	1
524 220	CASSY Lab 2	1
524 083	CO_2 sensor S	1
501 11	Extension cable, 15 pin	1*
524 0673	NiCr-Ni adapter S, type K	1
529 676	Temperature probe, NiCr-Ni, 1.5 mm, type K	2
	additionally required: PC with Windows XP/Vista/7/8/10 (x86 or x64)	1

* additionally recommended

The air all around us contains mainly nitrogen and oxygen. But the other substances, the ones which occur in significantly lower concentrations - in the ppm range (ppm = parts per million) or even less - are precisely the ones which can be harmful to humans. These are studied in air analyses.

One of the challenges here is the low concentration of the substances. In addition, the analysis of gases requires more complex instrumentation and is less easily accessible than the analysis of liquids.

In this context, it is worthwhile to study the interiors of classrooms or seminar rooms, where it is particularly important to maintain optimal air conditions, in order to facilitate the learning process.

In experiment C3.6.2.1, the carbon dioxide concentration in the classroom is studied for a period of one week. At the same time, the temperature is measured at two positions, e.g. on the radiator and in the classroom. In a room full of people, the CO_2 concentration rises rapidly above 1 %, and simply letting some air in can hardly lower it to the value in the atmosphere.

Analysis of cigarette smoke (C3.6.2.2)

C3.6.2

AIR ANALYTICS

C3.6.2.2
Analysis of cigarette smoke

Cat. No.	Description	C3.6.2.2
665 914	Gas syringe, 100 ml with 3-way stopcock	1
667 312	Glass connector, 2 x GL 18	1
666 313	Testing tube for NO_x, 0.5...50 ppm, set of 10	1
666 319	Testing tube for CO, 0.5...7.0 %, set of 10	1
666 314	Testing tube for SO_2, 1...25 ppm, set of 10	1
667 015	Glass file, triganular	1
313 27	Hand-held stop-watch, 60s/0.2s	1
	additionally required: cigarettes	1

Smoke from cigarette tobacco contains not only nicotine, but also many toxic substances, including nitrogen oxides, tar and formaldehyde. In experiment C3.6.2.2, cigarette smoke is analyzed for various airborne toxic substances. In so doing, different cigarette brands and strengths can be compared.

C3.6.4

FOOD ANALYTICS

C3.6.4.2
Determination of the content of phosphoric acid in a cola drink

Determination of the content of phosphoric acid in a cola drink (C3.6.4.2)

Cat. No.	Description	C3.6.4.2
524 005W	Mobile-CASSY 2 WiFi	1
524 220	CASSY Lab 2	1
524 0672	pH adapter S	1
529 672	pH sensor, BNC	1
664 131	Beaker Boro 3.3, 400 ml, squat	2
664 130	Beaker, Boro 3.3, 250 ml, squat	1
665 845	Burette, clear glass, 25 ml	1
666 559	Burette clamp for 1 burette, roller clamp	1
301 09	Bosshead S	2
666 555	Universal clamp 0...80 mm	1
607 105	Magnetic stirrer mini	1
300 02	Stand base, V-shaped, small	1
300 11	Saddle base	1
301 26	Stand rod 25 cm, 10 mm Ø	1
301 27	Stand rod 50 cm, 10 mm Ø	1
661 243	Wash bottle PE 500 ml	1
673 8410	Sodium hydroxide solution, 0.1 mol/l, 500ml	1
674 4640	Buffer solution pH 4.00, 250 ml	1
674 4670	Buffer solution pH 7.00, 250 ml	1
	additionally required: Cola beverage	1

As an applied science, food analytics forms the basis for the study and assessment of the quality and safety of food.

Phosphoric acid is added to cola in order to heighten the sensation of thirst, as a preservative, and to cover up the sugary taste. In experiment C3.6.4.2, phosphoric acid is titrated with sodium hydroxide. When titrating cola, the first two buffer stages are also clearly recognisable, just as in the titration of phosphoric acid. (It is generally impossible to titrate the third stage in these diluted solutions.) The second stage becomes indistinct in the presence of other ingredients. The phosphoric acid content of the cola beverage can be determined with the first stage.

X-ray fluorescence analysis of chemical composition (C3.6.5.1)

C3.6.5

MATERIAL ANALYTICS

C3.6.5.1
X-ray fluorescence analysis of chemical composition

C3.6.5.2
The chemical composition of a brass specimen

Cat. No.	Description	C3.6.5.1	C3.6.5.2
554 800	X-ray apparatus	1	1
554 861	X-ray tube, Mo	1	1
554 831	Goniometer	1	1
559 938	X-ray energy detector	1	1
554 848	Set of target alloys	1	1
524 013	Sensor-CASSY 2	1	1
524 058	MCA box	1	1
524 220	CASSY Lab 2	1	1
501 02	BNC cable, 1 m	1	1
554 844	Set of targets for K-line fluorescence		1
554 846	Set of targets for L-line fluorescence		1
	additionally required: PC with Windows XP/Vista/7/8/10 (x86 or x64)	1	1

X-ray fluorescence is a method for the non-destructive analysis of the chemical composition of an alloy. Under exposure to X-rays, each of the individual elements emits characteristic X-ray fluorescence, which identifies the element like a fingerprint.

In experiment C3.6.5.1, four alloys are analyzed by means of X-ray fluorescence and the composition is determined qualitatively. The alloys are chrome-nickel steel, two brass alloys and a rare earth magnet.

In experiment C3.6.5.2, the composition of a brass alloy is analyzed quantitatively. The weight percents of each component are calculated from the strength of the X-ray fluorescence.

C4 PHYSICAL CHEMISTRY

Catalytic oxidation of tartaric acid with hydrogen peroxide (C4.1.1.1)

C4.1.1

CATALYSIS

C4.1.1.1
Catalytic oxidation of tartaric acid with hydrogen peroxide

Cat. No.	Description	C4.1.1.1
524 013	Sensor-CASSY 2	1
524 220	CASSY Lab 2	1
524 0672	pH adapter S	1
667 4172	pH sensor with plastic shaft, BNC	1
524 0673	NiCr-Ni adapter S, type K	1
529 676	Temperature probe, NiCr-Ni, 1.5 mm, type K	1
664 130	Beaker, Boro 3.3, 250 ml, squat	1
667 7977	Electronic Balance 440-3N, 200 g : 0.01 g	1
665 997	Graduated pipette 10 ml	1
666 003	Pipetting ball (Peleus ball)	1
666 961	Double-ended microspatula, stainless steel, 185 mm	1
666 8451	Magnetic stirrer	1
666 850	Stirring magnet, 15 mm x 5 mm diam.	1
666 859	Stirring bar retriever	1
666 502	Bunsen burner stand, 450 mm high	1
301 09	Bosshead S	2
666 555	Universal clamp 0...80 mm	2
664 152	Watch glass dish 40 mm Ø	1
672 6710	Potassium sodium tartrate, 250 g	1
675 3500	Hydrogen peroxide, 30 %, 250 ml	1
672 8000	Cobalt(II) chloride-6-hydrate, 25 g	1
	additionally required: PC with Windows XP/Vista/7/8/10 (x86 or x64)	1

The rate of a reaction is defined as the change in concentration over time. For the reaction

$$A + B \rightleftharpoons C$$

therefore, the following applies:

$$v_A = -\frac{d[A]}{dt}; v_B = -\frac{d[B]}{dt}; v_C = \frac{d[C]}{dt} .$$

One challenge in analyses of this type is to continuously measure the concentration of one of the participants in the reaction.This is possible with reactions in which one or more participants in the reaction change colour or oxidation level, or in which salts form (increase in conductivity).

Apart from elevating the concentration and temperature, the rate of reactions can also be increased by the addition of catalysts. Because catalysts are not consumed in a reaction, a small amount is already enough to enable the conversion of large quantities of the reacting substances.

In experiment C4.1.1.1, hydrogen peroxide is used to convert tartaric acid oxidatively to CO_2 and H_2O under catalysis. The catalyst cobalt(II) chloride hexahydrate speeds up the reaction, but does not participate in the transformation and remains unchanged once the process has been completed. The reaction is monitored by measuring the redox potential and the temperature.

C4.1.2

REACTION ORDERS

C4.1.2.1
Hydrolysis of tertiary butyl chloride

Hydrolysis of tertiary butyl chloride (C4.1.2.1)

Cat. No.	Description	C4.1.2.1
524 005W	Mobile-CASSY 2 WiFi	1
524 220	CASSY Lab 2	1
524 0671	Conductivity adapter S	1
529 670	Conductivity sensor	1
607 105	Magnetic stirrer mini	1
664 103	Beaker, DURAN, 250 ml, squat	1
300 11	Saddle base	1
301 26	Stand rod 25 cm, 10 mm Ø	1
301 09	Bosshead S	1
666 555	Universal clamp 0...80 mm	1
665 754	Measuring cylinder 100 ml, with plastic base	1
665 994	Graduated pipette 1 ml	1
666 003	Pipetting ball (Peleus ball)	1
671 1450	Tertiary butyl chloride, 100 ml	1
670 0400	Acetone, 250 ml	1
	additionally required: PC with Windows 7 or higher with WIFI or USB connection	1

The reaction order can be used to test hypotheses about the stepwise course of reactions. The reaction order must be determined experimentally. In order to do so, a diagram is drawn showing of the rate of reaction versus the respective concentration. If the resulting curve is a straight line, then it represents a first-order reaction. A parabola indicates a second-order reaction.

In experiment C4.1.2.1, the hydrolysis of tertiary butylchloride (2-chloro-2-methylpropane) generates tertiary butanol and hydrochloric acid (HCl). In this protolysis reaction, HCl forms hydronium and chloride ions, which cause a strong increase in conductivity:

$$(CH_3)_3\text{-Cl} + 2\,H_2O \rightarrow (CH_3)_3C\text{-OH} + H_3O^+ + Cl^-$$

C4.1.2

REACTION ORDERS

C4.1.2.2
Determination of the reaction order of the reaction of malachite green with hydroxide ions

Determination of the reaction order of the reaction of malachite green with hydroxide ions (C4.1.2.2)

Cat. No.	Description	C4.1.2.2
524 005W	Mobile-CASSY 2 WiFi	1
524 220	CASSY Lab 2	1
607 105	Magnetic stirrer mini	1
664 103	Beaker, DURAN, 250 ml, squat	3
300 11	Saddle base	1
666 555	Universal clamp 0...80 mm	1
666 003	Pipetting ball (Peleus ball)	1
524 069	Immersion photometer S	1
666 851	Stirring magnet 25 mm x 6 mm Ø, circular	1
665 756	Measuring cylinder 500 ml, with plastic base	1
665 755	Measuring cylinder 250 ml, with plastic base	1
665 753	Measuring cylinder 50 ml, with plastic base	1
ADA NBL124E	Analytical balance 120 g; 0,0001g, with USB interface	1
604 5651	Spoon-ended spatula, Nickel, 120 mm, 20 mm	1
665 793	Volumetric flask, Boro 3.3, 100 ml	1
665 997	Graduated pipette 10 ml	1
602 347	Laboratory bottle, 500 ml, GL 45 thread	1
300 41	Stand rod, 25 cm, 12 mm Ø	1
666 543	Double, crossed boss head, 0...16 mm	1
661 243	Wash bottle PE 500 ml	1
673 1670	Malachite green, 25 g	1
671 9720	Ethanol, denaturated, 1 l	1
673 6800	Sodium hydroxide, pellets, 100 g	1
675 3400	Water, pure, 1 l	1
	additionally required: PC with Windows 7 or higher with WIFI or USB connection	1

The change in conductivity and the concentration of the butylchloride are used to determine the reaction order.

In Experiment C4.1.2.2 malachite green is bleached using sodium hydroxide solution. This bleaching can be followed with an immersion photometer. This way, the half time, the reaction order and, based on these data, the reaction rate constant can be determined.

C4.1.3

INFLUENCING THE RATE OF REACTION

C4.1.3.1
Reaction of malachite green with hydroxide ions

Reaction of malachite green with hydroxide ions (C4.1.3.1)

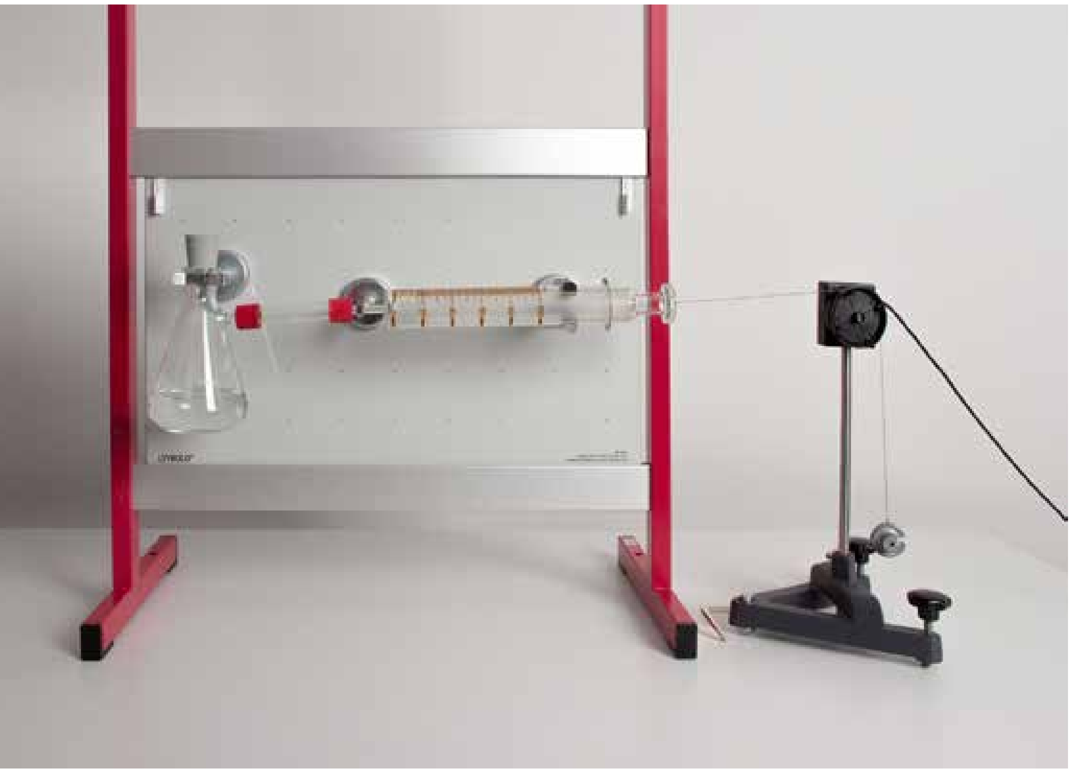
Cat. No.	Description	C4.1.3.1
524 069	Immersion photometer S	1
524 005W	Mobile-CASSY 2 WiFi	1
524 220	CASSY Lab 2	1
607 105	Magnetic stirrer mini	1
666 851	Stirring magnet 25 mm x 6 mm Ø, circular	4
664 103	Beaker, DURAN, 250 ml, squat	4
665 756	Measuring cylinder 500 ml, with plastic base	1
665 755	Measuring cylinder 250 ml, with plastic base	1
665 753	Measuring cylinder 50 ml, with plastic base	1
667 7991	Analytical balance, 210 g : 0,0001 g	1
604 5651	Spoon-ended spatula, Nickel, 120 mm, 20 mm	1
665 793	Volumetric flask, Boro 3.3, 100 ml	1
665 997	Graduated pipette 10 ml	1
666 003	Pipetting ball (Peleus ball)	1
602 347	Laboratory bottle, 500 ml, GL 45 thread	1
300 11	Saddle base	1
300 41	Stand rod, 25 cm, 12 mm Ø	1
666 543	Double, crossed boss head, 0...16 mm	1
666 555	Universal clamp 0...80 mm	1
661 243	Wash bottle PE 500 ml	1
673 1670	Malachite green, 25 g	1
671 9720	Ethanol, denaturated, 1 l	1
673 6800	Sodium hydroxide, pellets, 100 g	1
675 3400	Water, pure, 1 l	1

Cat. No.	Description	C4.1.3.1
	additionally required: PC with Windows 7 or higher with WIFI or USB connection	1

The rate of a reaction can be affected by many parameters. These include the temperature and the concentration of the substance involved. The choice of solvent can also play a role.

Reactions in which a participant in the reaction changes colour are a suitable choice if one wishes to observe the course of a reaction. Such reactions are easy to track photometrically, because the decrease and increase in the extinction rate can be directly converted mathematically into concentration changes.

In experiment C4.1.3.1, the reaction of malachite green with hydroxide ions is monitored with an immersion photometer in a glass beaker. Blue-green at first, the solution loses colour when sodium hydroxide is added. This simple system makes it possible to investigate how the rate of reaction is affected by temperature, concentration and the choice of solvent.



Concentration and reaction rate: Magnesium in strong and weak acids (C4.1.3.3)

C4.1.3

INFLUENCING THE RATE OF REACTION

C4.1.3.2
Reaction rate and degree of division: marble in hydrochloric acid

C4.1.3.3
Concentration and reaction rate: Magnesium in strong and weak acids

Cat. No.	Description	C4.1.3.2	C4.1.3.3
524 220	CASSY Lab 2	1	1
ADA HCB602H	Precision Balance, 600 g /0,01g, with USB interface	1	
664 137	Beaker, Boro3.3, 100 ml, tall	4	
673 2500	Marble, pcs., 250 g	1	
674 6920	Hydrochloric acid, approx. 2 mol/l, 500ml	1	
524 005W	Mobile-CASSY 2 WiFi		1
524 082	Rotary motion sensor S		1
300 02	Stand base, V-shaped, small		1
666 4659	Adhesive magnetic board 500 mm		2
666 425	Panel frame C50, two-level, for CPS		1
524 0036	Holder for Mobile-CASSY 2, CPS		1
666 4661	Holder, magnetic, size 1, 9...11 mm		1
666 4664	Holder, magnetic, size 4, 27...29 mm		1
666 4665	Holder, magnetic, size 5, 30...32 mm		1
665 912	Gas syringe, 100 ml		1
602 110	Erlenmeyer flask, DURAN with side outlet, 250 ml, wide, ST 29/32		1
667 312	Glass connector, 2 x GL 18		1
667 260	Rubber stopper solid, 25...31 mm Ø		1
309 48	Fishing line		1
340 85	Weights, each 50 g, set of 6		1
665 754	Measuring cylinder 100 ml, with plastic base		1
671 9590	Acetic acid, 1 mol/l, 1 l		1
674 6900	Hydrochloric acid, 1 mol/l, 500 ml		1
673 1000	Magnesium, ribbon, 25 g		1

Cat. No.	Description	C4.1.3.2	C4.1.3.3
	additionally required: PC with Windows XP/Vista/7/8/10 (x86 or x64)	1	

If marble (calcium carbonate) is put into hydrochloric acid, it dissolves. This produces carbon dioxide and calcium chloride. Carbon dioxide is released. The reaction mixture therefore becomes lighter.

In experiment C4.1.3.2 the reaction is carried out on a balance and recorded with CASSY Lab 2. If different degrees of fragmentation of marble are used, the influence of the degree of fragmentation on the reaction rate can be examined.

When in contact with acids, ignoble metals such as magnesium dissolve to form hydrogen. If the hydrogen is collected in a time-resolved manner, this reaction can be observed very easily.

In experiment C4.1.3.3 the hydrogen is collected with a piston sampler. The recording is done with CASSY, in that a displacement transducer registers the movement of the piston sampler. In this way the reaction speed can be quickly compared with different acids, e.g. hydrochloric acid and acetic acid.

C4.2.1

LAW OF MASS ACTION

C4.2.1.1
Influencing the equilibrium

Influencing the equilibrium (C4.2.1.1)

Cat. No.	Description	C4.2.1.1
664 268	Flat-bottom flask, DURAN, 250 ml, wide neck	2
664 249	Erlenmeyer flask, Boro 3.3, 100 ml, narrow neck	2
664 131	Beaker Boro 3.3, 400 ml, squat	1
666 850	Stirring magnet, 15 mm x 5 mm diam.	1
607 105	Magnetic stirrer mini	1
666 962	Double-ended spatula, stainless steel, 150 mm	1
666 003	Pipetting ball (Peleus ball)	1
665 996	Graduated pipette, 5 ml	1
665 998	Graduated pipette 25 ml	1
665 754	Measuring cylinder 100 ml, with plastic base	1
661 243	Wash bottle PE 500 ml	1
667 7977	Electronic Balance 440-3N, 200 g : 0.01 g	1
671 8710	Iron(III) chloride-6-hydrate, 250 g	1
672 7400	Potassium thiocyanate, 100 g	1

One of the most important laws in chemistry is the law of mass action. It provides insight into the mechanism of chemical reactions while also offering the chemist the ability to affect a chemical reaction in a way that favours the creation of specifically intended molecules. The law of mass action states that in a chemical reaction the concentration of the starting materials remains in an absolutely constant proportion to the concentration of the final materials.

Experiment C4.2.1.1 studies the chemical equilibrium of the reaction of thiocyanate with iron. The chemical equilibrium is a dynamic equilibrium in which the starting materials and final products are present alongside one another in the reaction mixture. Under equilibrium conditions, exactly so many parts react in one direction as back in the opposite direction. In so doing, the concentrations of the participants in the reaction remain constant and their quotient is expressed as the equilibrium constant K. By adding one of the substances involved, a new equilibrium is established.

For the reaction being investigated here

$$Fe^{3+} + 3\ SCN^- \rightleftharpoons Fe(SCN)_3$$

the equilibrium constant can be calculated as follows:

$$\frac{[Fe(SCN)_3]}{[Fe^{3+}]\cdot[SCN^-]^3} = K$$

C4.2.2

PROTOLYSIS EQUILIBRIUM

C4.2.2.1
Determination of the acidity constant of bromothymol blue

Determination of the acidity constant of bromothymol blue (C4.2.2.1)

Cat. No.	Description	C4.2.2.1
467 252	Compact spectrometer, complete	1
664 470	Rectangular cuvette cell, glass, 10 x 10 mm	2
665 996	Graduated pipette, 5 ml	1
666 003	Pipetting ball (Peleus ball)	1
602 345	Laboratory bottle, 100 ml, GL 45 thread	5
665 754	Measuring cylinder 100 ml, with plastic base	2
602 782	Glass rod, 200 mm, diam. 5 mm	2
667 7977	Electronic Balance 440-3N, 200 g : 0.01 g	1
667 4781	Digital pH-Meter 201	1
674 4600	Buffer solution set, 250 ml	1
671 0800	Bromothymol blue solution, 0.1 %, 50 ml	1
674 6950	Hydrochloric acid, 0.1 mol/l, 500 ml	1
673 8410	Sodium hydroxide solution, 0.1 mol/l, 500ml	1
673 6710	Disodium hydrogen phosphate, 250 g	1
673 6010	Sodium dihydrogenphosphate, 250 g	1
664 137	Beaker, Boro3.3, 100 ml, tall	1
661 243	Wash bottle PE 500 ml	1
675 3400	Water, pure, 1 l	1
	additionally required: PC with Windows XP/Vista/7/8/10 (x86 or x64)	1

The reaction of acids (AH) with water - protolysis - is an equilibrium reaction.

$$AH + H_2O \rightleftharpoons A^- + H_3O^+$$

The equilibrium constant K_a, also known as the acid dissociation constant, is a measure of the strength of an acid.

$$K=\frac{[H_3O^+]\cdot[A^-]}{[HA]\cdot[H_2O]};K_a=K\cdot[H_2O]=\frac{[H_3O^+]\cdot[A^-]}{[HA]}$$

It indicates the magnitude of the ratio between the protonated and non-protonated form of the acid. In most cases, however, the pK_a value, i.e. the negative base 10 logarithm of the acid dissociation constant, is given.

In experiment C4.2.2.1, the pH-dependent colour of the indicator bromothymol blue is used to determine the pKa value of the dye. The colouration enables the simultaneous determination of the concentration of the protonated (yellow) and non-protonated (blue) form of the indicator, with which, in turn, the Henderson-Hasselbalch equation.

$$pH = pKs + \log_{10}\left(\frac{[A^-]}{[HA]}\right)$$

can be used to compute the pKa value.

C4.2.3

COMPLEX EQUILIBRIUM

C4.2.3.1
Determination of the complex disintegration constant of Silver diamine complex.

Determination of the complex disintegration constant of Silver diamine complex. (C4.2.3.1)

Cat. No.	Description	C4.2.3.1
524 005W	Mobile-CASSY 2 WiFi	1
664 137	Beaker, Boro3.3, 100 ml, tall	1
665 754	Measuring cylinder 100 ml, with plastic base	1
667 455	Salt bridge, 90 mm x 90 mm, 20 mm diam.	1
667 255	Rubber stopper, solid, 16...21 mm diam.	1
664 130	Beaker, Boro 3.3, 250 ml, squat	1
664 421	Plate electrodes, silver, 55 x 40 mm, set of 2	1
501 861	Crocodile-clips, polished, set of 6	1
501 44	Connecting leads, 19 A, 25 cm, red/blue, pair	1
667 7977	Electronic Balance 440-3N, 200 g : 0.01 g	1
300 11	Saddle base	1
300 42	Stand rod, 47 cm, 12 mm diam.	1
301 09	Bosshead S	1
666 555	Universal clamp 0...80 mm	1
665 953	Dropping pipette, 7 x 150 mm, 10 pcs.	1
665 954	Rubber bulbs, 10 pcs	1
665 009	Funnel PP 75 mm Ø	1
674 8800	Silver nitrate solution, 0,1 mol/l, 250 ml	1
670 3600	Ammonia solution, 25 %, 250 ml	1

Complex compounds consist of a central atom, usually a metal, around which ligands are coordinated. These ligands can be exchanged more or less easily. Ligand exchange reactions are equilibrium reactions. In stable complexes, the equilibrium lies on the side of the starting materiel, the starting complex. In instable compleses the equilibrium lies on the side of the products.

The silver diamine complex consits of a central silver ion around which ammonia is coordinated as a ligand. The diamine-silver complex arises when ammonia is added to a silver salt solution. Then, the water ligands are replaced by ammonia ligands at the hydrated silver ion because the ammo-nia ligands have a stronger bond. In this experiment, the complex formation constant is determined.

C4.3.1

ENTHALPY OF CHEMICAL REACTIONS

C4.3.1.1
Differentiating between endothermic and exothermic reactions

Differentiating between endothermic and exothermic reactions (C4.3.1.1)

Cat. No.	Description	C4.3.1.1
524 005W	Mobile-CASSY 2 WiFi	1
529 676	Temperature probe, NiCr-Ni, 1.5 mm, type K	1
300 02	Stand base, V-shaped, small	1
301 27	Stand rod 50 cm, 10 mm Ø	1
301 09	Bosshead S	2
666 555	Universal clamp 0...80 mm	2
664 043	Test tubes, Fiolax, 16 x 160 mm, set of 10	1
667 053	Test tube rack, for 10 tubes, 22 mm diam.	1
667 031	Test tube holder 20 mm Ø	1
604 5682	Powder spatula, steel, 185 mm	1
656 017	Teclu burner, universal	1
667 187	Safety gas hose with end clamp, 1 m	1
666 733	Piezoelectric gas igniter	1
661 243	Wash bottle PE 500 ml	1
672 9600	Copper(II) sulfate-5-hydrate, 100 g	1
675 3400	Water, pure, 1 l	1

Every chemical reaction is characterised by a transformation of material. That transformation is closely connected with an energy transformation and/or energy change. In this way, heat energy is either consumed or heat is created, i.e. the reaction proceeds endothermically or exothermically.

In experiment C4.3.1.1, copper(II) sulfate in the pentahydrate form and in the anhydrous form is used to demonstrate the principle of endothermic and exothermic reactions. Here the reaction of copper(II) sulfate-5-hydrate under high heat to anhydrous copper(II) sulfate represents the endothermic reaction. The anhydrous copper(II) sulfate obtained in this way reacts in turn with water while generating heat, thereby demonstrating an exothermic reaction.

$$\underset{\text{(blue)}}{CuSO_4 \times 5\,H_2O} \rightleftharpoons \underset{\text{(white)}}{CuSO_4} + 5\,H_2O$$

Determination of the heat of combustion of benzoic acid (C4.3.3.1_p)

C4.3.3

CALORIMETRY

C4.3.3.1_p
Determination of the heat of combustion of benzoic acid

C4.3.3.1_s
Determination of the heat of combustion of benzoic acid using stand material

Cat. No.	Description	C4.3.3.1_p	C4.3.3.1_s
666 429	Calorimeter for solids and liquids, CPS	1	
666 428	Panel frame C100, two-level, for CPS	1	
666 4660	Adhesive magnetic board 300 mm	2	
666 4664	Holder, magnetic, size 4, 27...29 mm	4	
664 800	Gas scrubber bottle, lower section, 200 ml	4	4
664 805	Glass tube insert, ST 29/32	4	4
665 392	Joint clip plastic, ST 29/32	4	4
667 312	Glass connector, 2 x GL 18	3	
301 312	Console	1	
726 21	Equipment platform, 350 mm	1	
524 013	Sensor-CASSY 2	1	1
524 220	CASSY Lab 2	1	1
524 0673	NiCr-Ni adapter S, type K	1	1
529 676	Temperature probe, NiCr-Ni, 1.5 mm, type K	1	1
667 183	Rubber tubing, 1 m x 8 mm diam., DIN 12865	1	1
667 197	Silicone tubing, 4 mm diam., 1 m	1	1
604 510	Tubing connector, 4...15 mm	1	1
521 536	DC Power Supply 2 x 0...16 V/2 x 0...5 A	1	1
521 231	Low-voltage power supply 3/6/9/12 V	1	1
666 819	Stirring top, with GL 32 screw thread	1	1
501 45	Connecting lead 19 A, 50 cm, red/blue, pair	3	3
660 998	Minican pressurised gas canister, oxygen	1	1
660 980	Fine regulating valve for minican gas canisters	1	1
ADA HCB3001	Precision Balance, 3000 g / 0,1 g	1	1
667 7977	Electronic Balance 440-3N, 200 g : 0.01 g	1	1

Cat. No.	Description	C4.3.3.1_p	C4.3.3.1_s
608 360	Pestle, 54 mm long	1	1
667 092	Mortar porcelain 70 mm Ø	1	1
670 8300	Benzoic acid, 50 g	1	1
673 8420	Sodium hydroxide solution, 1 mol/l, 500 ml	1	1
674 7850	Sulfuric acid, 95-98 %, 250 ml	1	1
667 325	Calorimeter for solids and liquids		1
666 603	Base rail, 95 cm		1
301 09	Bosshead S		8
666 615	Universal bosshead		4
301 72	Universal clamp, 0...120 mm		2
666 555	Universal clamp 0...80 mm		5
301 27	Stand rod 50 cm, 10 mm Ø		4
	additionally required: PC with Windows XP/Vista/7/8/10 (x86 or x64)	1	1

In experiment C4.3.3.1, the temperature rise in the demonstration calorimeter is measured while burning benzoic acid. The substance is weighed before and after the combustion process. The combustion takes place in an oxygen atmosphere, whereby ignition is initiated by a filament. The energy released is calculated using either a previously determined heat capacity of the filled calorimeter or the individual theoretical values of the heat capacities of the glass jacket and calorimeter liquid. The quantity of heat Q is calculated according to the following formula:

$$Q = \Delta T \times (m_k \times C_k + m(\mathrm{H_2O}) \times C(\mathrm{H_2O}))$$

C4.3.3

CALORIMETRY

C4.3.3.3
Determination of the enthalpy of neutralisation of acids and alkali solutions

Determination of the enthalpy of neutralisation of acids and alkali solutions (C4.3.3.3)

Cat. No.	Description	C4.3.3.3
524 005W	Mobile-CASSY 2 WiFi	1
524 220	CASSY Lab 2	1
529 676	Temperature probe, NiCr-Ni, 1.5 mm, type K	1
607 105	Magnetic stirrer mini	1
666 850	Stirring magnet, 15 mm x 5 mm diam.	1
602 023	Beaker, Boro 3.3, 150 ml, squat	3
665 753	Measuring cylinder 50 ml, with plastic base	2
300 11	Saddle base	1
301 26	Stand rod 25 cm, 10 mm Ø	1
301 09	Bosshead S	1
673 8400	Sodium hydroxide solution, diluted, aprox. 2 M, 500 ml	1
673 8420	Sodium hydroxide solution, 1 mol/l, 500 ml	1
674 6920	Hydrochloric acid, approx. 2 mol/l, 500ml	1
674 6900	Hydrochloric acid, 1 mol/l, 500 ml	1
671 9550	Acetic acid, dil., approx. 2 mol/l, 500 ml	1
	additionally required: PC with Windows 7 or higher with WIFI or USB connection	1

The term ‚calorimetry' refers to the measurement of quantities of heat which are linked to biological, chemical or physical processes. They can be both exothermic and endothermic. Quantities of heat are determined by means of calorimeters.

When strong acids and strong alkalis react with one another, energy is given off to the surroundings in the form of heat - the so-called ‚heat of neutralisation'.

In experiment C4.3.3.3, measured quantities of hydrochloric acid and sodium hydroxide at the same temperature are neutralised together. The temperature increase ΔT is measured and from that result the quantity of heat Q_P is calculated:

$$Q_P = \Delta T \times \left(C_{H_2O} \times m + C_k\right)$$

From the quantity of heat, the following equation can be used to calculate the molar heat of neutralisation $\Delta_R H_m$:

$$\Delta_R H_m = \frac{Q_P}{n}$$

C4.3.3

CALORIMETRY

C4.3.3.4
Determination of enthalpy of mixing

Determination of enthalpy of mixing (C4.3.3.4)

Cat. No.	Description	C4.3.3.4
524 005W	Mobile-CASSY 2 WiFi	1
524 220	CASSY Lab 2	1
386 40	Glass calorimeter	1
529 676	Temperature probe, NiCr-Ni, 1.5 mm, type K	1
664 155	Watch glass dish 100 mm Ø	1
607 105	Magnetic stirrer mini	1
666 850	Stirring magnet, 15 mm x 5 mm diam.	1
300 11	Saddle base	1
301 26	Stand rod 25 cm, 10 mm Ø	1
301 09	Bosshead S	1
602 951	Measuring cylinder, Boro 3.3, 25 ml, glass base	1
665 994	Graduated pipette 1 ml	1
665 997	Graduated pipette 10 ml	1
666 003	Pipetting ball (Peleus ball)	1
670 0430	Acetone, 500 ml	1
675 3400	Water, pure, 1 l	1
	additionally required: PC with Windows 7 or higher with WIFI or USB connection	1

When two substances A and B are mixed together without initiating a chemical reaction, heats of mixing are released or consumed. If the mixing process takes place at constant pressure, the heat of mixing is equal to the enthalpy of mixing.

The cause of the enthalpy of mixing lies in the differences of the interaction energies of the similar molecules in the pure components along with the interaction energy between the different types of molecules in the mixture. If the interaction between similar molecules is stronger than between dissimilar ones, the mixing requires energy, so the solution cools down. In the opposite case, the solution warms up.

Experiment C4.3.3.4 determines the enthalpy of mixing of two solutions with different concentrations and measures the heat of mixing released.

Ion transport in liquids (C4.4.1.1)

C4.4.1

CONDUCTIVITY AND IONS

C4.4.1.1
Ion transport in liquids

Cat. No.	Description	C4.4.1.1
664 091	Double U-tube, 160 mm, with 2 G4 filters	1
664 369	Platinum leaf rod electrodes, set of 2	1
664 4071	Electrochemistry demonstration unit, CPS	1
501 44	Connecting leads, 19 A, 25 cm, red/blue, pair	1
666 425	Panel frame C50, two-level, for CPS	1
666 472	Table for electrochemistry, CPS	1
590 02	Small clip plug	2
664 243	Erlenmeyer flask 250 ml, narrow neck, SB 29	1
665 754	Measuring cylinder 100 ml, with plastic base	1
602 022	Beaker Boro 3.3, 100 ml, squat	1
664 130	Beaker, Boro 3.3, 250 ml, squat	1
664 133	Beaker, Boro3.3, 1000 ml, squat	1
665 217	Glass stirring rod, 500 mm x 8 mm diam., set of 10	1
604 5682	Powder spatula, steel, 185 mm	1
ADA CB501	Compact scale 500 g : 0.1 g	1
670 4900	Ammonium sulfate, 250 g	1
672 7000	Potassium permanganate, 100 g	1
672 9600	Copper(II) sulfate-5-hydrate, 100 g	1
670 3650	Ammonia solution, diluted, 2 mol/l, 500 ml	1
675 3500	Hydrogen peroxide, 30 %, 250 ml	1
675 3400	Water, pure, 1 l	1
665 004	Funnel, Boro 3.3, 80 mm diam.	1
666 584	Filtration stand for two funnels	1
661 066	Folded filter	1

Unlike solids, in which current is transported via electrons (1st order conductor), liquids can transport charges only via ions (2nd order conductor). The conductivity depends on both the number and the mobility of the ions present in the solution.

Conductivity relies on the migration of ions in the electric field. Anions (negative) migrate to the positive pole, cations (positive) migrate to the negative pole. In experiment C4.4.1.1, this migration is observed directly. The coloured anion permanganate (MnO_4^-) and the coloured cation copper tetraammine ($(Cu(NH_3)_4^{2+})$) are used for this purpose. In this way, the direction of migration and the magnitude of the speed can be determined.

Determination of migration velocity of permanganate ions (C4.4.1.2)

C4.4.1

CONDUCTIVITY AND IONS

C4.4.1.2
Determination of migration velocity of permanganate ions

Cat. No.	Description	C4.4.1.2
664 4071	Electrochemistry demonstration unit, CPS	1
664 401	Electrochemistry accessories set	1
666 425	Panel frame C50, two-level, for CPS	1
666 472	Table for electrochemistry, CPS	1
665 754	Measuring cylinder 100 ml, with plastic base	1
664 101	Beaker, DURAN, 100 ml, squat	4
382 21	Stirring thermometer -10...+110 °C	1
664 153	Watch glass dish 60 mm Ø	1
604 5682	Powder spatula, steel, 185 mm	1
666 8471	Magnetic stirrer with hotplate	1
602 725	Laboratory dish, 140 mm diam., 900 ml	1
667 7977	Electronic Balance 440-3N, 200 g : 0.01 g	1
672 6800	Potassium nitrate, 100 g	1
672 7000	Potassium permanganate, 100 g	1
670 1600	Agar-Agar, 50 g	1
674 6900	Hydrochloric acid, 1 mol/l, 500 ml	1
675 3500	Hydrogen peroxide, 30 %, 250 ml	1
LDS 00001	Stopwatch, digital	1
	additionally required: ruler	1

In a solution ions migrate toward the oppositely charged pole. The speed of migration depends on many factors, including the size and hydration of the ions. Experiment C4.4.1.2 determines the speed of migration of permanganate ions.

Determination of specific conductivity (C4.4.1.3)

C4.4.1

CONDUCTIVITY AND IONS

C4.4.1.3
Determination of specific conductivity

Cat. No.	Description	C4.4.1.3
664 4071	Electrochemistry demonstration unit, CPS	1
664 401	Electrochemistry accessories set	1
666 425	Panel frame C50, two-level, for CPS	1
666 472	Table for electrochemistry, CPS	1

The conductivity of a solution depends on the type and quantity of the dissolved ions. Every type of ion has a specific conductivity κ, which is the reciprocal of the specific resistance ς. The conductivity depends on the length of the conductor (electrode distance) l and on the cross-sectional area of the electrodes q according to the following formula:

$$\kappa = \frac{1}{\varsigma} = \frac{1}{R} \cdot \frac{l}{q}$$

Experiment C4.4.1.3 determines the specific conductivity of tap water. The effect of electrode distance on conductivity can also be investigated.

C4.4.1

CONDUCTIVITY AND IONS

C4.4.1.4_p
Electrolytic dissociation: Dependence of conductivity on electrolyte concentration

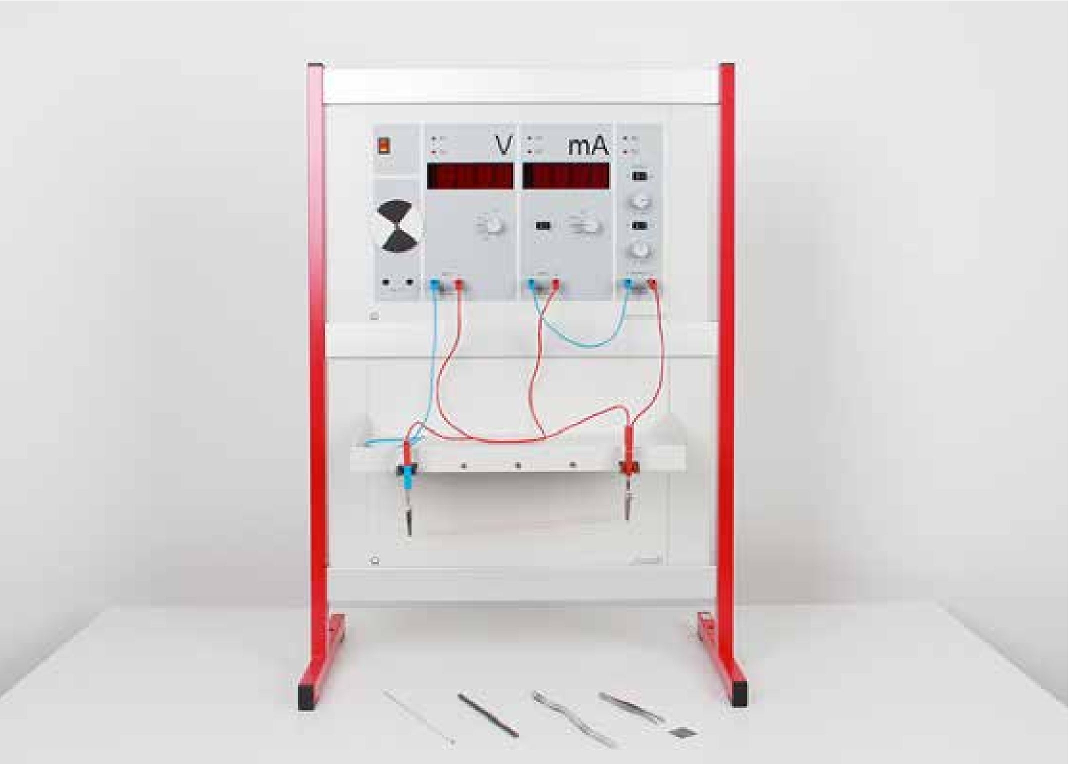
C4.4.1.4_s
Electrolytic dissociation: Dependence of conductivity on electrolyte concentration using stand material

Electrolytic dissociation: Dependence of conductivity on electrolyte concentration (C4.4.1.4_p)

Cat. No.	**Description**	**C4.4.1.4_p**	**C4.4.1.4_s**
664 4071	Electrochemistry demonstration unit, CPS	1	
666 425	Panel frame C50, two-level, for CPS	1	
666 472	Table for electrochemistry, CPS	1	
664 401	Electrochemistry accessories set	1	
665 752	Measuring cylinder 25 ml, with plastic base	1	
665 212	Glass stirring rod 200 x 8 mm Ø	1	
671 9500	Acetic acid, 99%-100%, 250 ml	1	
675 3400	Water, pure, 1 l	1	
524 005W	Mobile-CASSY 2 WiFi		1
524 220	CASSY Lab 2		1
524 0671	Conductivity adapter S		1
529 670	Conductivity sensor		1
665 792	Volumetric flask, Boro 3.3, 50 ml		1
665 845	Burette, clear glass, 25 ml		2
664 103	Beaker, DURAN, 250 ml, squat		2
607 105	Magnetic stirrer mini		1
666 851	Stirring magnet 25 mm x 6 mm Ø, circular		1
ADA NBL124E	Analytical balance 120 g; 0,0001g, with USB interface		1
300 02	Stand base, V-shaped, small		1
300 43	Stand rod, 75 cm, 12 mm diam.		1
301 09	Bosshead S		1
666 555	Universal clamp 0...80 mm		1
666 559	Burette clamp for 1 burette, roller clamp		1
665 816	Burette filling funnel plastic, 35 mm Ø		1

Cat. No.	**Description**	**C4.4.1.4_p**	**C4.4.1.4_s**
671 9560	Acetic acid, 0.1 mol/l, 500ml		1
672 5200	Potassium chloride, 100 g		1
	additionally required: PC with Windows 7 or higher with WIFI or USB connection		1

The conductivity of a solution is concentration-dependent. A distinction is drawn between strong and weak electrolytes. While strong electrolytes are completely dissociated, the dissociation of weak electrolytes is highly concentration-dependent. In experiment C4.4.1.4, this behaviour is investigated in potassium chloride and acetic acid, and among other things the equivalent conductivity is determined.



Conductivity of solids (C4.4.1.5)

C4.4.1

CONDUCTIVITY AND IONS

C4.4.1.5
Conductivity of solids

C4.4.1.6
Temperature-dependency of the conductivity of solids

Cat. No.	Description	C4.4.1.5	C4.4.1.6
664 4071	Electrochemistry demonstration unit, CPS	1	1
666 425	Panel frame C50, two-level, for CPS	1	1
666 472	Table for electrochemistry, CPS	1	1
590 02	Small clip plug	2	2
664 401	Electrochemistry accessories set	1	1
666 714	Cartridge burner, DIN type		1

In solids, current is transported by electrons. Only substances that have free electrons can conduct electricity (1st order conductor). In metals the electrons are in a cloud around the atomic nucleus and can easily move from one atomic nucleus to the next. They therefore conduct electric current. In experiment C4.4.1.5 different metals and non-metals are examined for their conductivity.

Conductivity in solids depends on the mobility of the electrons contained. This mobility is temperature-dependent. Semiconductors, e.g. silicon, have a special position here. They only conduct electricity at higher temperatures. Conductors such as iron, on the other hand, lose their good conductivity at higher temperatures. In experiment C4.4.1.6 the conductivity of iron and silicon is measured at different temperatures.

Conductivity of aqueous solutions (C4.4.1.7)

C4.4.1

CONDUCTIVITY AND IONS

C4.4.1.7
Conductivity of aqueous solutions

Cat. No.	Description	C4.4.1.7
664 4071	Electrochemistry demonstration unit, CPS	1
666 425	Panel frame C50, two-level, for CPS	1
666 472	Table for electrochemistry, CPS	1
664 401	Electrochemistry accessories set	1
665 950	Pasteur pipettes, 250 pcs.	1
665 954	Rubber bulbs, 10 pcs	1
675 3400	Water, pure, 1 l	1
670 3650	Ammonia solution, diluted, 2 mol/l, 500 ml	1
671 9570	Acetic acid, 0.1 mol/l, 1 l	1
674 6960	Hydrochloric acid, 0.1 mol/l, 1 l	1
673 8410	Sodium hydroxide solution, 0.1 mol/l, 500ml	1
673 5710	Sodium chloride, 500 g	1
674 6060	D(+)-Sucrose, 250 g	1

Liquids can also conduct electricity. A basic requirement for this is the presence of charged particles (ions), e.g. salts dissolved in water. In experiment C4.4.1.7 different liquids and solutions are examined for their conductivity. Solutions that can conduct the electric current are called electrolytes. In the additional part, strong electrolytes are distinguished from weak electrolytes.

C4.4.1

CONDUCTIVITY AND IONS

C4.4.1.8
Conductivity of melts

Conductivity of melts (C4.4.1.8)

Cat. No.	Description	C4.4.1.8
664 4071	Electrochemistry demonstration unit, CPS	1
666 425	Panel frame C50, two-level, for CPS	1
666 472	Table for electrochemistry, CPS	1
664 401	Electrochemistry accessories set	1
590 02	Small clip plug	2
666 4662	Holder, magnetic, size 2, 11...14 mm	1
608 231	Crucible porcelain, 30 ml	1
666 714	Cartridge burner, DIN type	1
666 688	Wire triangle with clay sleeves 60 mm	1
666 683	Tripod, 26 cm x 14 cm diam.	1
529 676	Temperature probe, NiCr-Ni, 1.5 mm, type K	1
524 005W	Mobile-CASSY 2 WiFi	1
ADA CB1001	Compact scale 1000 g; 0.1g	1
661 044	Weighing paper, 100 sheets	1
673 0500	Lithium chloride, 25 g	1
672 5200	Potassium chloride, 100 g	1

Liquids conduct electricity when ions are present. Salts should therefore conduct electricity when they are present in liquid form, i.e. as a melt. In experiment C4.4.1.8, a salt mixture is melted and its conductivity measured. We use a mixture of lithium chloride and potassium chloride because, due to the eutectic, it has a melting point of only 355 °C.

The electrochemical series (C4.4.3.1_p)

C4.4.3

ELECTROCHEMICAL POTENTIALS

C4.4.3.1_p
The electrochemical series

C4.4.3.1_s
The electrochemical series using stand material

Cat. No.	Description	C4.4.3.1_p	C4.4.3.1_s
664 4071	Electrochemistry demonstration unit, CPS	1	
664 401	Electrochemistry accessories set	1	
666 425	Panel frame C50, two-level, for CPS	1	
666 472	Table for electrochemistry, CPS	1	
667 7977	Electronic Balance 440-3N, 200 g : 0.01 g	1	1
665 754	Measuring cylinder 100 ml, with plastic base	1	1
602 032	Beaker, DURAN, 150 ml, tall	4	
665 212	Glass stirring rod 200 x 8 mm Ø	1	1
672 9600	Copper(II) sulfate-5-hydrate, 100 g	1	1
675 5410	Zinc sulfate-7-hydrate, 250 g	1	1
674 8610	Silver nitrate, 25 g	1	1
670 9650	Lead nitrate solution, approx. 1 M, 500 ml	1*	1*
671 9110	Iron(II) sulfate-7-hydrate, 250 g	1	1
524 005W	Mobile-CASSY 2 WiFi		1
602 010	Beaker, Boro 3.3, 150 ml, tall		7
667 455	Salt bridge, 90 mm x 90 mm, 20 mm diam.		1
667 255	Rubber stopper, solid, 16...21 mm diam.		1
501 45	Connecting lead 19 A, 50 cm, red/blue, pair		1
501 861	Crocodile-clips, polished, set of 6		1
300 11	Saddle base		1
300 41	Stand rod, 25 cm, 12 mm Ø		1
301 09	Bosshead S		1
666 555	Universal clamp 0...80 mm		1
604 5682	Powder spatula, steel, 185 mm		1
672 6800	Potassium nitrate, 100 g		1

Cat. No.	Description	C4.4.3.1_p	C4.4.3.1_s
675 3400	Water, pure, 1 l		1
591 53	Plate electrodes copper 76 x 40 mm, set of 10		1
591 54	Plate electrodes, zinc, 76 x 40 mm, set of 10		1
664 421	Plate electrodes, silver, 55 x 40 mm, set of 2		1
591 55	Plate electrodes, iron, 76 x 40 mm, set of 10		1
591 56	Plate electrodes, nickel, 76 x 40 mm, set of 5		1*
591 591	Plate electrodes lead 76 x 40 mm, set of 2		1*

* additionally recommended

If a metal M is immersed in a solution of its ions M^{n+}, then its dissolution and deposition tendency creates a potential.

$$M \rightleftharpoons M^{n+} + n\,e^-$$

A measurable potential difference occurs only after two different of such half-cells are combined to form a galvanic cell (voltage, electromotive force EMF).

There are noble and base metals. This property depends on the potential of the half-cell of a metal. In experiment C4.4.3.1, voltage measurements on combinations of different metals are used to create an electromotive series of the metals. In so doing, the noblest or basest half-cell can serve as reference point.

The experiment can be carried out in two variants: With the demonstration unit for electrochemistry or using CASSY and a salt bridge.

C4.4.3

ELECTROCHEMICAL POTENTIALS

C4.4.3.2_p
Standard potentials of metals

C4.4.3.2_s
Standard potentials of metals
using stand material

Standard potentials of metals (C4.4.3.2_p)

Cat. No.	Description	C4.4.3.2_p	C4.4.3.2_s
664 4071	Electrochemistry demonstration unit, CPS	1	
664 401	Electrochemistry accessories set	1	
666 425	Panel frame C50, two-level, for CPS	1	
666 472	Table for electrochemistry, CPS	1	
602 043	Beaker, DURAN, 150 ml, squat	3	
667 7977	Electronic Balance 440-3N, 200 g : 0.01 g	1	1
665 754	Measuring cylinder 100 ml, with plastic base	1	1
672 9600	Copper(II) sulfate-5-hydrate, 100 g	1	1
675 5410	Zinc sulfate-7-hydrate, 250 g	1	1
674 6910	Hydrochloric acid, 1 mol/l, 1 l	1	
672 1901	Hexacloroplatinic acid, 5 g	1	
675 3400	Water, pure, 1 l	1	1
664 412	Standard hydrogen electrode HydroFlex		1
524 005W	Mobile-CASSY 2 WiFi		1
300 41	Stand rod, 25 cm, 12 mm Ø		1
300 11	Saddle base		1
301 09	Bosshead S		1
666 555	Universal clamp 0...80 mm		1
664 111	Beaker, DURAN, 100 ml, tall		4
667 455	Salt bridge, 90 mm x 90 mm, 20 mm diam.		1
667 255	Rubber stopper, solid, 16...21 mm diam.		1
591 53	Plate electrodes copper 76 x 40 mm, set of 10		1
591 54	Plate electrodes, zinc, 76 x 40 mm, set of 10		1
571 26	Adapter leads 2/4 mm, 30 cm, blue, set of 5		1
500 411	Connecting lead, 19 A, 25 cm, red		1

Cat. No.	Description	C4.4.3.2_p	C4.4.3.2_s
501 861	Crocodile-clips, polished, set of 6		1
672 6800	Potassium nitrate, 100 g		1
674 7920	Sulfuric acid, diluted, approx. 2 N, 500 ml		1

To determine the potential of a half-cell, a reference parameter is necessary. By international agreement, the half-cell H_2/H_3O^+ has been established as reference cell. That standard hydrogen electrode has been arbitrarily assigned the potential $E^0 = 0.00$ V.

In experiment C4.4.3.2, a standard hydrogen electrode is used to measure the standard potentials of various metals. This can be done either with the demonstration unit for electrochemistry or with CASSY and the prefabricated standard hydrogen electrode HydroFlex.

C4.4.3

ELECTROCHEMICAL POTENTIALS

C4.4.3.3
Standard potentials of non-metals

Standard potentials of non-metals (C4.4.3.3)

Cat. No.	Description	C4.4.3.3
664 4071	Electrochemistry demonstration unit, CPS	1
664 401	Electrochemistry accessories set	1
666 425	Panel frame C50, two-level, for CPS	1
666 472	Table for electrochemistry, CPS	1
602 032	Beaker, DURAN, 150 ml, tall	4
667 7977	Electronic Balance 440-3N, 200 g : 0.01 g	1
665 754	Measuring cylinder 100 ml, with plastic base	1
673 5700	Sodium chloride 250 g	1
674 6910	Hydrochloric acid, 1 mol/l, 1 l	1
672 4920	Potassium bromide, 250 g	1
672 6620	Potassium iodide, 50 g	1
672 1901	Hexacloroplatinic acid, 5 g	1
675 3400	Water, pure, 1 l	1

In experiment C4.4.3.3, the standard potentials of different non-metals are measured. For this purpose, the halogens are first produced from the salts by electrolysis using the electrochemistry demonstration unit. In the solution, the potential of the elementary halogens can then be measured against the standard hydrogen electrode for a short time.

Concentration potentials (Nernst equation) (C4.4.3.4)

C4.4.3
ELECTROCHEMICAL POTENTIALS

C4.4.3.4
Concentration potentials (Nernst equation)

Cat. No.	Description	C4.4.3.4
664 4071	Electrochemistry demonstration unit, CPS	1
664 401	Electrochemistry accessories set	1
666 425	Panel frame C50, two-level, for CPS	1
666 472	Table for electrochemistry, CPS	1
665 754	Measuring cylinder 100 ml, with plastic base	1
602 023	Beaker, Boro 3.3, 150 ml, squat	3
664 115	Beaker, DURAN, 600 ml, tall	1
665 212	Glass stirring rod 200 x 8 mm Ø	1
665 997	Graduated pipette 10 ml	3
666 003	Pipetting ball (Peleus ball)	1
675 3400	Water, pure, 1 l	1
672 9660	Copper(II) sulfate solution, 1 mol/l (15 %), 500 ml	1
673 8411	Sodium hydroxide solution, 0.1 mol/l, 1 l	1

If two similar half-cells which differ only in the concentration *c* of their electrolyte solutions are combined, then a potential difference also forms between those half-cells. The general relationship is described in the Nernst equation:

$$E = E^0 + \frac{R \cdot T}{n \cdot F} \ln c(M^{n+})$$

The potential *E* therefore depends on the temperature in Kelvin *T* and on the proportionality factor *R*, the universal gas constant. Other parameters which play a role include the ion valence *n* and the Faraday constant *F*. The dependence on concentration and temperature are investigated in experiment C4.4.3.4.

Temperature dependency of the potential (Nernst equation) (C4.4.3.5)

C4.4.3

ELECTROCHEMICAL POTENTIALS

C4.4.3.5
Temperature dependency of the potential (Nernst equation)

Cat. No.	Description	C4.4.3.5
664 4071	Electrochemistry demonstration unit, CPS	1
666 425	Panel frame C50, two-level, for CPS	1
666 472	Table for electrochemistry, CPS	1
664 401	Electrochemistry accessories set	1
665 754	Measuring cylinder 100 ml, with plastic base	1
602 023	Beaker, Boro 3.3, 150 ml, squat	1
602 011	Beaker, Boro 3.3, 400 ml, tall	1
664 115	Beaker, DURAN, 600 ml, tall	1
665 212	Glass stirring rod 200 x 8 mm Ø	1
665 997	Graduated pipette 10 ml	1
666 003	Pipetting ball (Peleus ball)	1
675 3400	Water, pure, 1 l	1
672 9660	Copper(II) sulfate solution, 1 mol/l (15 %), 500 ml	1
673 8411	Sodium hydroxide solution, 0.1 mol/l, 1 l	1
667 614	Heat protective gloves	1
666 839	Magnetic stirrer with hot plate	1

In a galvanic element that consists of identical half cells with different temperatures, a potential difference can be measured. The system aims to even the temperature differences which leads to solution and precipitation of copper in the half cells.

In experiment C4.4.3.5, a galvanic element is set-up that consists of identical half cells with different temperatures. The potential difference is measured over time.

The Daniell cell (C4.4.4.1_a)

C4.4.4

GALVANIC CELLS

C4.4.4.1_a
The Daniell cell

C4.4.4.1_b
The large Daniell cell

Cat. No.	Description	C4.4.4.1_a	C4.4.4.1_b
664 4071	Electrochemistry demonstration unit, CPS	1	1
666 472	Table for electrochemistry, CPS	1	
666 425	Panel frame C50, two-level, for CPS	1	
664 401	Electrochemistry accessories set	1	
665 754	Measuring cylinder 100 ml, with plastic base	1	
602 023	Beaker, Boro 3.3, 150 ml, squat	2	
664 132	Beaker, Boro3.3, 600 ml, squat	1	
665 212	Glass stirring rod 200 x 8 mm Ø	1	
665 997	Graduated pipette 10 ml	2	2
666 003	Pipetting ball (Peleus ball)	1	1
675 3400	Water, pure, 1 l	1	1
672 9660	Copper(II) sulfate solution, 1 mol/l (15 %), 500 ml	1	
675 5510	Zinc sulfate solution, approx. 1 M, 500 ml	1	
673 8411	Sodium hydroxide solution, 0.1 mol/l, 1 l	1	
664 397	Daniell cell		1
301 339	Stand bases, pair		1
501 45	Connecting lead 19 A, 50 cm, red/blue, pair		1
501 44	Connecting leads, 19 A, 25 cm, red/blue, pair		1
665 793	Volumetric flask, Boro 3.3, 100 ml		4
672 9610	Copper(II) sulfate-5-hydrate, 250 g		2
675 5410	Zinc sulfate-7-hydrate, 250 g		1

A galvanic cell comprises two half-cells which are connected to each other via an electrically conductive element. Each half-cell contains one electrode which is immersed in an electrolyte. The electrode material can contain metals or non-metals.

In the galvanic cell, the process is the reverse of electrolysis. Chemical energy is converted into electrical energy.

Experiment C4.4.4.1 studies the characteristics of a Cu/Zn cell (Daniell cell). In a Daniell cell, a copper plate is immersed in a copper(II)-sulfate solution and a zinc plate is immersed in a zinc sulfate solution. The solutions are separated from each other by a diaphragm (porous partition wall). The redox reaction does not begin until the copper plate and the zinc plate are connected by an electrically conductive cable.

C4.4.4

GALVANIC CELLS

C4.4.4.2_a
The Leclanché cell with Electrochemistry demonstration unit

C4.4.4.2_b
The large Leclanché cell

The Leclanché cell with Electrochemistry demonstration unit (C4.4.4.2_a)

Cat. No.	Description	C4.4.4.2_a	C4.4.4.2_b
664 4071	Electrochemistry demonstration unit, CPS	1	1
666 425	Panel frame C50, two-level, for CPS	1	
666 472	Table for electrochemistry, CPS	1	
664 401	Electrochemistry accessories set	1	
664 132	Beaker, Boro3.3, 600 ml, squat	1	
602 023	Beaker, Boro 3.3, 150 ml, squat	1	
665 217	Glass stirring rod, 500 mm x 8 mm diam., set of 10	1	
ADA CB501	Compact scale 500 g : 0.1 g	1	
665 754	Measuring cylinder 100 ml, with plastic base	1	
665 751	Measuring cylinder 10 ml, with plastic base	1	
666 584	Filtration stand for two funnels	1	
665 005	Funnel, Boro 3.3, 100 mm diam.	1	
609 082	Folded filter 125mmØ Typ: 595	1	
675 5100	Zinc chloride, dry, 50 g	1	
670 4000	Ammonium chloride, 100 g	1	
673 2200	Manganese(IV) oxide, 100 g	1	
672 1500	Graphite, 50 g	1	1
673 8400	Sodium hydroxide solution, diluted, aprox. 2 M, 500 ml	1	
675 3400	Water, pure, 1 l	1	
661 242	Wash bottle, PE, 250 ml	1	
671 3820	Carboxymethylcellulose, 100g	1	
664 398	Leclanché cell		1
301 339	Stand bases, pair		1
501 45	Connecting lead 19 A, 50 cm, red/blue, pair		1

Cat. No.	Description	C4.4.4.2_a	C4.4.4.2_b
501 44	Connecting leads, 19 A, 25 cm, red/blue, pair		1
602 010	Beaker, Boro 3.3, 150 ml, tall		1
664 131	Beaker Boro 3.3, 400 ml, squat		1
666 8471	Magnetic stirrer with hotplate		1
673 2210	Manganese(IV) oxide, 500 g		1
670 4010	Ammonium chloride, 250 g		1
674 9210	Starch, soluble, 250 g		1

The Leclanché cell is a zinc/coal battery. Here the negative pole is the steel-jacketed battery cup made of zinc. The positive pole is formed by a graphite bar which is surrounded by a mixture of graphite powder and manganese dioxide. An ammonium chloride solution (20 %) thickened by starch serves as the electrolyte. This prevents the cell from spilling out.

Experiment C4.4.4.2 demonstrates the principle of this dry cell. The voltage of the cell is first measured with the electrochemistry demonstration unit in the no-load condition. The Leclanché cell is then connected to the motor, and the voltage and current are measured simultaneously.

The Magensium Air Element (C4.4.4.3)

C4.4.4

GALVANIC CELLS

C4.4.4.3
The Magensium Air Element

Cat. No.	Description	C4.4.4.3
664 4081	Magnesium air element	1
664 4071	Electrochemistry demonstration unit, CPS	1
301 339	Stand bases, pair	1
571 262	Adapter lead 2/4 mm, 30 cm, red	2
571 26	Adapter leads 2/4 mm, 30 cm, blue, set of 5	1
571 231	Connecting leads 2-mm plugs, 15 cm, red	1
602 010	Beaker, Boro 3.3, 150 ml, tall	1
665 752	Measuring cylinder 25 ml, with plastic base	1
666 967	Spoon-ended spatula, stainless steel, 150 mm	1
665 212	Glass stirring rod 200 x 8 mm Ø	1
MA9 0204	Universal indicator paper pH 1...14, roll	1
667 7977	Electronic Balance 440-3N, 200 g : 0.01 g	1
673 5700	Sodium chloride 250 g	1
675 3400	Water, pure, 1 l	1

The magnesium-air cell is a galvanic cell. It is composed of a half-cell with a magnesium electrode in a sodium-chloride-solution and a half-cell containing a membrane, which enables the use of atmospheric oxygen for the redox reaction. Since atmospheric oxygen can continuously be supplied, the magnesium-air cell is considered a fuel cell.

In this cell, magnesium is oxidized at the anode, the electrons migrate towards the cathode, drive an electrical load and finally react with oxygen. Overall magnesium hydroxide is formed under the release of electrical energy.

C4.4.4

GALVANIC CELLS

C4.4.4.4
Influence of electrolyte concentration on the Daniell element

C4.4.4.5
Influence of the electrode gap on the Daniell element

Influence of electrolyte concentration on the Daniell element (C4.4.4.4)

Cat. No.	**Description**	**C4.4.4.4**	**C4.4.4.5**
664 4071	Electrochemistry demonstration unit, CPS	1	1
666 425	Panel frame C50, two-level, for CPS	1	1
666 472	Table for electrochemistry, CPS	1	1
664 401	Electrochemistry accessories set	1	1
665 754	Measuring cylinder 100 ml, with plastic base	1	1
602 023	Beaker, Boro 3.3, 150 ml, squat	4	2
664 115	Beaker, DURAN, 600 ml, tall	1	
665 212	Glass stirring rod 200 x 8 mm Ø	1	1
665 997	Graduated pipette 10 ml	2	2
666 003	Pipetting ball (Peleus ball)	1	1
675 3400	Water, pure, 1 l	1	1
672 9660	Copper(II) sulfate solution, 1 mol/l (15 %), 500 ml	1	1
675 5510	Zinc sulfate solution, approx. 1 M, 500 ml	1	1
673 8411	Sodium hydroxide solution, 0.1 mol/l, 1 l	1	1
664 132	Beaker, Boro3.3, 600 ml, squat		1

In a Daniell element, electrical energy is generated with zinc and copper electrodes. The voltage supplied by such a galvanic element depends on the material of the electrodes and solutions. The current, on the other hand, depends on the concentration of the solutions. This will be investigated in experiment C4.4.4.4.

Not only the type of electrode material and the concentration of the electrolyte solutions can have an influence on the performance of the Daniell element and thus of every galvanic cell. In experiment C4.4.4.5, therefore, the influence of the distance between the two electrodes is investigated. The further apart they are, the greater the internal resistance of the galvanic element becomes and the performance decreases. The ions in solution then have to cover a greater distance.

C4.4.4
GALVANIC CELLS

C4.4.4.6
Serial and parallel connection of elements

Serial and parallel connection of elements (C4.4.4.6)

Cat. No.	Description	C4.4.4.6
664 4071	Electrochemistry demonstration unit, CPS	1
666 425	Panel frame C50, two-level, for CPS	1
666 472	Table for electrochemistry, CPS	1
664 401	Electrochemistry accessories set	1
665 754	Measuring cylinder 100 ml, with plastic base	1
602 023	Beaker, Boro 3.3, 150 ml, squat	4
664 132	Beaker, Boro3.3, 600 ml, squat	1
665 212	Glass stirring rod 200 x 8 mm Ø	1
665 997	Graduated pipette 10 ml	2
666 003	Pipetting ball (Peleus ball)	1
675 3400	Water, pure, 1 l	1
672 9660	Copper(II) sulfate solution, 1 mol/l (15 %), 500 ml	1
675 5510	Zinc sulfate solution, approx. 1 M, 500 ml	1
673 8411	Sodium hydroxide solution, 0.1 mol/l, 1 l	1

A simple galvanic element such as the Daniell element usually does not provide enough power to operate loads. For this reason, in batteries several elements are connected in parallel and in series. In experiment C4.4.4.6, the influence of parallel and series connection on the performance of the Daniell element will be investigated.

C4.4.4

GALVANIC CELLS

C4.4.4.7_a

Recording characteristics of a Daniell element with the electrochemistry demonstration unit

Recording characteristics of a Daniell element with the electrochemistry demonstration unit (C4.4.4.7_a)

Cat. No.	Description	C4.4.4.7_a
664 4071	Electrochemistry demonstration unit, CPS	1
666 425	Panel frame C50, two-level, for CPS	1
666 472	Table for electrochemistry, CPS	1
664 401	Electrochemistry accessories set	1
458 120	Resistance module on screen	1
665 754	Measuring cylinder 100 ml, with plastic base	1
664 132	Beaker, Boro3.3, 600 ml, squat	1
675 3400	Water, pure, 1 l	1
672 9660	Copper(II) sulfate solution, 1 mol/l (15 %), 500 ml	1
675 5510	Zinc sulfate solution, approx. 1 M, 500 ml	1
673 8411	Sodium hydroxide solution, 0.1 mol/l, 1 l	1

The performance of galvanic elements is represented by characteristic curves. In experiment C4.4.4.7 the load characteristic and the power curve of a Daniell element are recorded. The optimum working resistance can then be determined.

Edison accumulator (C4.4.4.8)

C4.4.4
GALVANIC CELLS

C4.4.4.8
Edison accumulator

Cat. No.	Description	C4.4.4.8
664 4071	Electrochemistry demonstration unit, CPS	1
666 425	Panel frame C50, two-level, for CPS	1
666 472	Table for electrochemistry, CPS	1
664 401	Electrochemistry accessories set	1
602 023	Beaker, Boro 3.3, 150 ml, squat	1
664 130	Beaker, Boro 3.3, 250 ml, squat	1
607 105	Magnetic stirrer mini	1
666 851	Stirring magnet 25 mm x 6 mm Ø, circular	1
ADA CB501	Compact scale 500 g : 0.1 g	1
665 754	Measuring cylinder 100 ml, with plastic base	1
666 963	Spoon-ended spatula, stainless steel, 120 mm	1
664 157	Watch glass dish 125 mm Ø	1
672 6400	Potassium hydroxide, 250 g	1
675 3400	Water, pure, 1 l	1

Thomas Edison patented his accumulator in 1908. This was the first steel secondary element patented. In a secondary element or accumulator, the back reaction of the electricity generating reaction is possible. Thus, the cell can be charged and discharged. The Edison accumulator was used frequently up to the 1970ies. Today, modern accumulators include the Li-ion- or the Ni metal-hydride battery.

In this experiment, the Edison accumulator is set-up, charged and discharged.

C4.4.5

ELECTROLYSIS

C4.4.5.1_p
Electrolytic polarisation

C4.4.5.1_s
Electrolytic polarisation using stand material

Electrolytic polarisation (C4.4.5.1_p)

Cat. No.	Description	C4.4.5.1_p	C4.4.5.1_s
664 4071	Electrochemistry demonstration unit, CPS	1	
666 425	Panel frame C50, two-level, for CPS	1	
666 472	Table for electrochemistry, CPS	1	
665 754	Measuring cylinder 100 ml, with plastic base	1	
664 401	Electrochemistry accessories set	1	
673 8410	Sodium hydroxide solution, 0.1 mol/l, 500ml	1	1
672 9660	Copper(II) sulfate solution, 1 mol/l (15 %), 500 ml	1	1
524 011USB	Power-CASSY USB		1
524 220	CASSY Lab 2		1
664 373	Electrode holder		1
591 53	Plate electrodes copper 76 x 40 mm, set of 10		1
591 61	Plate electrodes, carbon, 76x40 mm, set of 5		1
664 420	Mesh electrodes, platinum, 55 x 40 mm, set of 2		1
664 131	Beaker Boro 3.3, 400 ml, squat		1
501 45	Connecting lead 19 A, 50 cm, red/blue, pair		1
300 11	Saddle base		1
300 41	Stand rod, 25 cm, 12 mm Ø		1
301 09	Bosshead S		1
	additionally required: PC with Windows XP/Vista/7/8/10 (x86 or x64)		1

When a direct electric current flows through an electrolyte it provokes a chemical reaction. The resulting changes in the electrolyte and the electrodes are referred to as ‘electrolysis‘.

A chemical reaction can take place because the direct current provides electrons to the solution locally at the negative pole (cathode) and at the same time electrons are transferred from the solution into the electrode at the positive pole (anode). As a result, reduction takes place at the cathode and oxidation at the anode.

In experiment C4.4.5.1 the voltage during an electrolysis is raised starting from zero. Note that there is no significant flow of current until a certain voltage level is reached. That voltage is called the decomposition voltage or the deposition voltage. It is the combination of the polarisation voltage and the overvoltage. Both parameters depend on the electrode material. Different electrode materials are investigated in experiment C4.4.5.1.

Determination of the Faraday constant (C4.4.5.2_p)

C4.4.5

ELECTROLYSIS

C4.4.5.2_p
Determination of the Faraday constant

C4.4.5.2_s
Determination of the Faraday constant using stand material

Cat. No.	Description	C4.4.5.2_p	C4.4.5.2_s
666 446	Electrolysis apparatus, CPS	1	
666 425	Panel frame C50, two-level, for CPS	1	
382 35	Thermometer, -10...+50 °C/0.1 K	1	1
531 831	Joule and wattmeter	1	1
521 546	DC Power Supply 0...16 V/0...5 A	1	1
501 46	Connecting leads 19 A, 100 cm, red/blue, pair	1	1
501 45	Connecting lead 19 A, 50 cm, red/blue, pair	1	1
665 755	Measuring cylinder 250 ml, with plastic base	1	
674 7920	Sulfuric acid, diluted, approx. 2 N (= 10 %), 500 ml	1	1
664 350	Water electrolysis apparatus		1
602 953	Measuring cylinder, Boro 3.3, 100 ml, glass base		1

In electrolysis, the electrical conduction processes are linked to a material deposition. The quantity of material deposited is proportional to the transported charge Q which flowed through the electrolyte. In this respect, the process is an application of Faraday's law.

$$Q = n \cdot F \cdot z$$

z = valency number of ions of the substance

F = Faraday constant

Experiment C4.4.5.2 determines the Faraday constant F. For this purpose, a Hofmann voltameter is used to produce a certain quantity of hydrogen. The number of moles n of hydrogen atoms deposited can be calculated from the volume V using the ideal gas equation. At the same time, the amount of electrical charge Q required for this can be determined from the electrical work W.

The experiment can be conducted using CPS or standard stand material.

C4.4.5

ELECTROLYSIS

C4.4.5.3
The Faraday laws

The Faraday laws (C4.4.5.3)

Cat. No.	Description	C4.4.5.3
664 4071	Electrochemistry demonstration unit, CPS	1
666 425	Panel frame C50, two-level, for CPS	1
666 472	Table for electrochemistry, CPS	1
664 401	Electrochemistry accessories set	1
602 9750	Burette, clearglass, 10ml, straight cock	1
665 816	Burette filling funnel plastic, 35 mm Ø	1
666 559	Burette clamp for 1 burette, roller clamp	1
300 42	Stand rod, 47 cm, 12 mm diam.	1
300 02	Stand base, V-shaped, small	1
602 022	Beaker Boro 3.3, 100 ml, squat	1
664 132	Beaker, Boro3.3, 600 ml, squat	1
665 793	Volumetric flask, Boro 3.3, 100 ml	1
665 795	Volumetric flask, Boro 3.3, 500 ml	1
665 754	Measuring cylinder 100 ml, with plastic base	1
604 5662	Spatula, double ended, 210 mm	1
ADA HCB123	Compact Balance 120 g : 0.001 g	1
666 584	Filtration stand for two funnels	1
665 005	Funnel, Boro 3.3, 100 mm diam.	1
609 082	Folded filter 125mmØ Typ: 595	1
675 5220	Zinc iodide solution, 50 %, 50 g	1
673 8000	Sodium thiosulfate-5-hydrate, 100 g	1
674 7920	Sulfuric acid, diluted, approx. 2 N (= 10 %), 500 ml	1
674 9220	Starch, soluble, 50 g	1
675 3400	Water, pure, 1 l	1
661 242	Wash bottle, PE, 250 ml	1

In 1833 *Michael Faraday* described the laws of electrolysis. He showed that there is a quantitative relationship between the amount of charge and the conversion of a chemical reaction at the electrode during electrolysis.

In this experiment, the Faraday laws are to be checked by electrolysis of aqueous zinc iodide solution and the Faraday constant *F* is to be determined. Zinc iodide is used because the products zinc and iodine can be quantitatively detected by weighing or by titration.

C4.4.6

GALVANIC PROCESSES IN ENGINEERING

C4.4.6.1
Galvanisation of a metal

Galvanisation of a metal (C4.4.6.1)

Cat. No.	Description	C4.4.6.1
664 4071	Electrochemistry demonstration unit, CPS	1
301 339	Stand bases, pair	1
664 137	Beaker, Boro3.3, 100 ml, tall	1
664 138	Beaker, Boro3.3, 250 ml, tall	1
591 53	Plate electrodes copper 76 x 40 mm, set of 10	1
501 45	Connecting lead 19 A, 50 cm, red/blue, pair	1
501 861	Crocodile-clips, polished, set of 6	1
666 767	Hotplate, 1500 W, 185 mm Ø	1
667 0344	Tweezer, blunt, 145 mm	1
664 153	Watch glass dish 60 mm Ø	3
ADA CB501	Compact scale 500 g : 0.1 g	1
672 4460	Potassium lye, 1 N (1 mol/l), 1 l	1
672 9600	Copper(II) sulfate-5-hydrate, 100 g	1
672 6710	Potassium sodium tartrate, 250 g	1
673 6800	Sodium hydroxide, pellets, 100 g	1
675 3400	Water, pure, 1 l	1
	additionally required: object to be galvanised	1

Galvanisation is a process in which objects are coated with a thin layer of metal by electrolytic means. Objects can be copper-plated, chrome-plated or silver-plated in this way.

In experiment C4.4.6.1, a thin layer of copper is applied to a metal object (e.g. a key or a nail) by means of galvanisation. In so doing, the object is wired as a cathode and immersed in a copper sulfate solution. A copper plate serves as the anode, which is also immersed in the copper sulfate solution. The process is started by applying a direct current source (3V).

The Eloxal process (C4.4.6.2)

C4.4.6

GALVANIC PROCESSES IN ENGINEERING

C4.4.6.2
The Eloxal process

Cat. No.	Description	C4.4.6.2
664 4071	Electrochemistry demonstration unit, CPS	1
666 425	Panel frame C50, two-level, for CPS	1
666 472	Table for electrochemistry, CPS	1
664 401	Electrochemistry accessories set	1
667 035	Crucible tongs 200 mm	1
665 9531	Dropping pipette 150 mm x 7 mm Ø	1
665 9541	Rubber bulb	1
664 130	Beaker, Boro 3.3, 250 ml, squat	1
602 740	Petri dish, 120 mm	1
666 839	Magnetic stirrer with hotplate	1
666 851	Stirring magnet 25 mm x 6 mm Ø, circular	1
670 0400	Acetone, 250 ml	1
674 7920	Sulfuric acid, diluted, approx. 2 N (= 10 %), 500 ml	1
673 8400	Sodium hydroxide solution, diluted, aprox. 2 M, 500 ml	1
675 3400	Water, pure, 1 l	1
	additionally required: dye, e.g. eosin or fluorescein	1

Anodic oxidation of aluminium treats the surface of aluminium in a way that it is a robust and attractive material. Using electolysis, the surface of aluminium is oxidised. The resulting oxide layer is very hard and can even be dyed.

In this experiment, aluminium is oxidised. The different properties of the non-oxidised and oxidised aluminium are compared.

C4.4.7

FUEL CELLS

C4.4.7.1
Investigation of a PEM fuel cell stack

C4.4.7.2
Recording the characteristic curves of a PEM fuel cell stack

Investigation of a PEM fuel cell stack (C4.4.7.1)

Cat. No.	**Description**	**C4.4.7.1-2**
666 4812	PEM fuel cell stack, CPS	1
666 4795	HydroStik PRO, CPS	1
666 4796	HydroStik PRO	1*
666 4794	Bubble counter, CPS	1
666 4831	Electric load, CPS	1
666 4798	HydroFill PRO	1
524 013	Sensor-CASSY 2	1
524 220	CASSY Lab 2	1
524 020USB	CASSY-Display USB	1*
501 44	Connecting leads, 19 A, 25 cm, red/blue, pair	1
501 45	Connecting lead 19 A, 50 cm, red/blue, pair	1
666 425	Panel frame C50, two-level, for CPS	1
667 198	Silicone tubing, 2 mm diam., 1 m	1
666 464	Blank panel, 100 mm, CPS	2
675 3400	Water, pure, 1 l	1
	additionally required: PC with Windows XP/Vista/7/8/10 (x86 or x64)	1

* additionally recommended

Fuel cells produce extremely efficient electric current in a „silent combustion“. Fuels are easily oxidised compounds such as hydrogen, hydrazine or methanol. The oxidation reaction takes place on a catalyst, usually platinum, over which the current generated is also carried. Because the fuels can be supplied continuously, it is possible - unlike with batteries - to generate electric power continuously.

Fuel cells are considered to be a technology of the future, because they are an extremely efficient means of converting the energy stored in a chemical compound into electric power. Unfortunately, however, it is not always easy to implement fuel cells in practical applications or to handle the fuels, which are usually gases.

PEM fuel cells contain a proton-conducting membrane which separates two half-cells. They require no other electrolytes, and that means that they can function with almost no liquid. Due to the low voltage that an individual fuel cell supplies, many fuel cells are wired together to form a „stack“. In experiment C4.4.7.1, the function of such a fuel cell stack is studied and various circuits are compared with one another.

The performance of fuel cells is analyzed by recording so-called characteristic curves. In experiment C4.4.7.2, the characteristic curves of voltage and output are recorded for the PEM fuel cell stack. The individual cells are wired in series in part a of the experiment and they are wired in parallel in part b of the experiment.

C4.4.7

FUEL CELLS

C4.4.7.3
The alkaline fuel cell/The detonating gas cell

The alkaline fuel cell/The detonating gas cell (C4.4.7.3)

Cat. No.	Description	C4.4.7.3
664 4071	Electrochemistry demonstration unit, CPS	1
666 425	Panel frame C50, two-level, for CPS	1
666 472	Table for electrochemistry, CPS	1
664 401	Electrochemistry accessories set	1
602 740	Petri dish, 120 mm	1
665 9531	Dropping pipette 150 mm x 7 mm Ø	2
665 9541	Rubber bulb	2
665 751	Measuring cylinder 10 ml, with plastic base	1
665 754	Measuring cylinder 100 ml, with plastic base	1
602 346	Laboratory bottle, 250 ml, GL 45 thread	1
607 105	Magnetic stirrer mini	1
ADA CB501	Compact scale 500 g : 0.1 g	1
664 157	Watch glass dish 125 mm Ø	1
661 242	Wash bottle, PE, 250 ml	1
670 0400	Acetone, 250 ml	1
675 3400	Water, pure, 1 l	1
672 6400	Potassium hydroxide, 250 g	1
674 6750	Hydrochloric acid, conc., 25 %, 250 ml	1
674 0430	Palladium chloride solution, 1 %, 50ml	1

A very simple fuel cell is the alkaline fuel cell. In this fuel cell, potassium hydroxide solution is used as the electrolyte. Hydrogen is used as fuel. It is oxidised on palladinised Nickel electrodes.

In this experiment, such a fuel cell is set up. Hydrogen and Oxygen are generated by electrolysis. Subsequently, the fuel cell is connected to a consumer and electric energy can be withdrawn.

C4.4.8

OSMOSIS

C4.6.2.1
Determination of the osmotic pressure of a sugar solution

Determination of the osmotic pressure of a sugar solution (C4.6.2.1)

Cat. No.	Description	C4.6.2.1
662 403	Osmosis apparatus, large	1
667 501	Scale for large osmosis apparatus	1
664 103	Beaker, DURAN, 250 ml, squat	1
665 754	Measuring cylinder 100 ml, with plastic base	1
665 794	Volumetric flask, Boro 3.3, 250 ml	2
667 7977	Electronic Balance 440-3N, 200 g : 0.01 g	1
665 953	Dropping pipette, 7 x 150 mm, 10 pcs.	1
665 954	Rubber bulbs, 10 pcs	1
666 6221	Experimental tray	1
674 6060	D(+)-Sucrose, 250 g	1

Osmosis is a diffusion process in one direction only which occurs when two similar solutions of different concentration are separated by a semi-permeable membrane. Only molecules of the solvent can diffuse through that membrane. Molecules or ions of a dissolved substance, which are too large, are held back. In so doing, more solvent molecules diffuse into the area of higher concentration than vice versa to create equalised concentrations on both chambers.

Experiment C4.6.2.1 uses the osmometer to demonstrate the principle of osmosis. This process plays a key role in regulating the volume and water of cells. The two chambers contain different concentrations of a solution and are separated by a semi-permeable membrane. The solvent flows osmotically into the solution of higher concentration. This raises the liquid level of that solution in the open system. The higher the concentration of the solution, the greater the water ingress. It slows to a stop when the hydrostatic pressure of the water column in the capillary tube is exactly equal to the osmotic pressure.

C5 CHEMICAL ENGINEERING

Production of sulfuric acid by the contact method (C5.1.1.1)

C5.1.1

PRODUCTION OF BASE CHEMICALS

C5.1.1.1
Production of sulfuric acid by the contact method

Cat. No.	Description	C5.1.1.1
666 360	Catalytic converter	1
666 428	Panel frame C100, two-level, for CPS	1
666 4660	Adhesive magnetic board 300 mm	6
666 4662	Holder, magnetic, size 2, 11...14 mm	6
666 4664	Holder, magnetic, size 4, 27...29 mm	3
665 001	Funnel for gas collection	1
664 442	Evaporating dish, 80 mm diam.	1
664 800	Gas scrubber bottle, lower section, 200 ml	3
664 805	Glass tube insert, ST 29/32	3
665 392	Joint clip plastic, ST 29/32	3
667 313	Glass connector, 1 GL 18, with glass olive	2
667 312	Glass connector, 2 x GL 18	2
665 9351	Woulff's bottle with manometer	1
667 261	Rubber stopper, one 7-mm hole, 25...31 mm Ø	1
524 005W	Mobile-CASSY 2 WiFi	1
529 676	Temperature probe, NiCr-Ni, 1.5 mm, type K	1
300 76	Laboratory stand II	2
300 02	Stand base, V-shaped, small	1
300 43	Stand rod, 75 cm, 12 mm diam.	1
301 72	Universal clamp, 0...120 mm	1
666 714	Cartridge burner, DIN type	2
375 56	Water jet pump	1
667 186	Vacuum rubber tubing, 8 mm diam.	1
307 64	Rubber tubing, 1 m x 6 mm diam.	1
665 226	Connector, straight, 6/8 mm Ø	1
608 020	Four-legged stand, rectangular, 155 x 155 x 220 mm	1
666 686	Heat protection cover plate, Ceran®, 155 mm x 155 mm	1
666 961	Double-ended microspatula, stainless steel, 185 mm	1
665 754	Measuring cylinder 100 ml, with plastic base	1
661 243	Wash bottle PE 500 ml	1
602 023	Beaker, Boro 3.3, 150 ml, squat	1
665 953	Dropping pipette, 7 x 150 mm, 10 pcs.	1
665 954	Rubber bulbs, 10 pcs	1
ADA CB501	Compact scale 500 g : 0.1 g	1
674 7510	Sulfur, cryst., 250 g	1
674 7860	Sulfuric acid, 95-98 %, 500 ml	1
672 0820	Fuchsine solution, 50 ml	1
670 7200	Barium chloride, 100 g	1
661 0821	Stopcock grease (grease stick)	1

Experiment C5.1.1.1 demonstrates the technical production of sulfuric acid by the contact method. The sulfur dioxide produced from the combustion of sulfur is oxidised by a catalyst to sulfur trioxide in the reaction tube. That is then led to water or sulfuric acid.

C5.1.1

PRODUCTION OF BASE CHEMICALS

C5.1.1.2

Synthesis of ammonia by the Haber-Bosch process

Synthesis of ammonia by the Haber-Bosch process (C5.1.1.2)

Cat. No.	Description	C5.1.1.2
664 0772	Reaction tube, quartz, 160 x 20 mm Ø	1
666 428	Panel frame C100, two-level, for CPS	1
666 4660	Adhesive magnetic board 300 mm	2
666 4659	Adhesive magnetic board 500 mm	2
667 286	Silicone stopper, one 7-mm hole, 16...21 mm Ø	2
666 4795	HydroStik PRO, CPS	1
666 4665	Holder, magnetic, size 5, 30...32 mm	2
666 4661	Holder, magnetic, size 1, 9...11 mm	3
666 9882	Combustion boat, glazed	1
667 194	Silicone tubing 7 mm Ø, 1 m	1
667 197	Silicone tubing, 4 mm diam., 1 m	1
667 198	Silicone tubing, 2 mm diam., 1 m	1
604 510	Tubing connector, 4...15 mm	1
665 914	Gas syringe, 100 ml with 3-way stopcock	2
666 714	Cartridge burner, DIN type	1
666 731	Gas igniter, mechanical	1
602 711	Three-way valve, ST, capillary tap, T-shape	1
667 312	Glass connector, 2 x GL 18	1
300 76	Laboratory stand II	1
666 4798	HydroFill PRO	1
660 980	Fine regulating valve for minican gas canisters	1
661 000	Minican pressurised gas canister, nitrogen	1
667 034	Tweezers, blunt, 200 mm	1
604 5662	Spatula, double ended, 210 mm	1
667 7933	Pocket Balance JE500	1

Cat. No.	Description	C5.1.1.2
MA9 0201	Universal indicator paper, roll	1
602 002	Test tube DURAN, 16 x 160 mm, set of 100	1
667 032	Test tube holder, wooden, 40 mm diam.	1
608 351	Mortar, 75 ml	1
608 361	Pestle, 115 mm long	1
664 154	Watch glass dish 80 mm Ø	1
602 032	Beaker, DURAN, 150 ml, tall	1
661 243	Wash bottle PE 500 ml	1
661 251	Flip-flap glass, 20 ml	1
671 8300	Iron powder, reduced, 50 g	1
670 2900	Aluminium oxide, 250 g	1
671 3200	Calcium oxide, powder, 100 g	1
672 6800	Potassium nitrate, 100 g	1

Experiment C5.1.1.2 uses the catalyst developed by Mittasch (iron powder, aluminium oxide, calcium oxide and potassium nitrate) in order to produce small quantities of ammonia even at normal pressure. The ammonia can be assayed using the base reaction on indicator paper.

C5.1.1

PRODUCTION OF BASE CHEMICALS

C5.1.1.3
Chlorine-alkali electrolysis

Chlorine-alkali electrolysis (C5.1.1.3)

Cat. No.	Description	C5.1.1.3
664 4071	Electrochemistry demonstration unit, CPS	1
666 425	Panel frame C50, two-level, for CPS	1
666 472	Table for electrochemistry, CPS	1
664 401	Electrochemistry accessories set	1
ADA CB501	Compact scale 500 g : 0.1 g	1
664 130	Beaker, Boro 3.3, 250 ml, squat	1
665 754	Measuring cylinder 100 ml, with plastic base	1
673 5710	Sodium chloride, 500 g	1
675 2550	Universal Indicator, 50 ml	1

Base chemicals serve as starting materials for many industrial products. In most cases they are produced in large quantities (more than 1 million tonnes per year) in optimised industrial plants.

The chlorine-alkali electrolysis is used to produce chlorine gas, hydrogen, and sodium hydroxide from a salt solution. Today, it is still the best way to produce these chemicals from a sodium chloride solution.

In the experiment, the chlorine-alkali electrolysis is conducted. Therefore, a sodium chloride solution is electrolysed. The formed chlorine gas and sodium hydroxide solution can be detected easily.

Extraction of iron by the blast furnace process (C5.1.2.1)

C5.1.2

EXTRACTION OF METALS FROM ORE

C5.1.2.1

Extraction of iron by the blast furnace process

Cat. No.	Description	C5.1.2.1
661 541	Blast furnace model	1
664 752	Mini-compressor, electric	1
521 551	AC/DC power supply 0...24 V/0...10 A	1
300 02	Stand base, V-shaped, small	1
301 26	Stand rod 25 cm, 10 mm Ø	1
301 09	Bosshead S	1
301 72	Universal clamp, 0...120 mm	1
667 104	Cover plate, 50 cm x 50 cm	1
665 223ET10	Connector, T-shaped, 8 mm Ø, 10 pieces	1
667 180	Rubber tubing 7 mm Ø, 1 m	1
656 016	Bunsen burner, universal	1
667 035	Crucible tongs 200 mm	1
667 176	Hofmann tubing clamp, 30 mm	1
510 15	Magnet with bore	1
667 7931	Pocket Balance JE120	1
661 083	Wooden turnings, 10 pieces	1
671 8810	Peroxide of iron (haematite), 250 g	1
670 2020	Activated charcoal, granulated, 500 g	1
672 2490	Charcoal, small pieces, 500 g	1
665 213	Glass stirring rod, 300 mm x 8 mm diam.	1*

* additionally recommended

Metal is certainly the most commonly used material in the manufacture of tools, weapons and jewellery. Hardly any other material has so profoundly marked human development.

Iron does not exist on the Earth as an element, but rather in the form of its oxides and sulphides in iron ore. They are the starting materials for the technical extraction of pig iron in the blast furnace.

The blast furnace operates at 1900 °C in order to smelt iron from iron ore. To attain that temperature, coke (and not coal) is used as fuel, and the fire inside the furnace is fanned with hot air at 1200 °C to 1300 °C degrees. Lime is added as an additional component; it binds contaminants. The blast furnace is fed from the top, so that alternating layers of coke and iron ore are formed.

The highest temperature occurs in the lower part of the furnace. The liquid iron, on which the slag floats, collects at the base. About once every two or three hours, the furnace is „tapped“. First the slag is allowed to flow out, and then the glowing yellow pig iron at about 1450 °C. The toxic waste gases (blast furnace gases) rise, are fed into a gas purification system, and heat the supply air for the furnace.

Experiment C5.1.2.1 uses the blast furnace model to demonstrate the reduction of iron ore in a way that is similar to the industrial scale process. Depending on the ore used and the reaction conditions (temperature, air supply, additives), the resulting reaction product is a mixture of different proportions of slag, partially reduced iron ore (Fe_3O_4) and metallic iron.

The thermite process (C5.1.2.2)

C5.1.2

EXTRACTION OF METALS FROM ORE

C5.1.2.2

The thermite process

Cat. No.	Description	C5.1.2.2
661 540	Thermite experiment	1
675 0440	Thermite igniting sticks	1
666 714	Cartridge burner, DIN type	1
666 731	Gas igniter, mechanical	1
667 035	Crucible tongs 200 mm	1
604 222	Measuring scoop, PP, 50 ml	1
510 15	Magnet with bore	1
667 104	Cover plate, 50 cm x 50 cm	1*
667 614	Heat protective gloves	1*
	additionally required: hammer, aluminium foil	1

* additionally recommended

Experiment C5.1.2.2 demonstrates the principle of the thermite process. In engineering, the thermite process is used to weld railway tracks together. A mixture of aluminium grit and iron(II, III) oxide is added to the apparatus and lit with an ignition rod. Liquid iron and aluminium oxide form in a very exothermic reaction. The iron has a higher density than aluminium oxide and so it sinks down in the melt.

$$Fe_2O_3 + 2\,Al \rightarrow 2\,Fe + Al_2O_3$$

Because aluminium releases immense quantities of energy in the reaction with oxygen, the reaction needs only to be started with an igniter. The energy released drives the rest of the process, and along with that it also liquefies the resulting iron.

Copper refining (C5.1.2.3)

C5.1.2

EXTRACTION OF METALS FROM ORE

C5.1.2.3
Copper refining

Cat. No.	Description	C5.1.2.3
664 4071	Electrochemistry demonstration unit, CPS	1
666 425	Panel frame C50, two-level, for CPS	1
666 472	Table for electrochemistry, CPS	1
664 401	Electrochemistry accessories set	1
664 130	Beaker, Boro 3.3, 250 ml, squat	1
664 131	Beaker Boro 3.3, 400 ml, squat	1
665 754	Measuring cylinder 100 ml, with plastic base	1
ADA HCB123	Compact Balance 120 g : 0.001 g	1
666 714	Cartridge burner, DIN type	1
602 783	Glass rod, 200 mm, diam. 6 mm	1
665 9531	Dropping pipette 150 mm x 7 mm Ø	1
665 9541	Rubber bulb	1
666 584	Filtration stand for two funnels	1
665 005	Funnel, Boro 3.3, 100 mm diam.	1
609 082	Folded filter 125mmØ Typ: 595	1
672 9600	Copper(II) sulfate-5-hydrate, 100 g	1
674 7850	Sulfuric acid, 95-98 %, 250 ml	1
673 8400	Sodium hydroxide solution, diluted, aprox. 2 M, 500 ml	1
675 3400	Water, pure, 1 l	1

Raw copper contains traces of other elements. These can be removed via electrolysis. To do so, raw copper is electrolysed in a copper sulfate solution. The raw copper is used as the anode. Here, the ignoble elements and copper will dissolve. At the cathode (also made from copper), pure copper is deposited.

In this experiment, the copper refinement is conducted using a brass electrode (copper, „contaminated“ by sinc).

C5.2.4

PIGMENTS AND DYESTUFFS

C5.2.4.1
Production and use of indigo

Production and use of indigo (C5.2.4.1)

Cat. No.	Description	C5.2.4.1
664 246	Erlenmeyer flask, DURAN, 100 ml, wide neck	1
665 162	Büchner funnel, 70 mm diam.	1
661 031	Round filter, Type 595, 70 mm diam., 100 pcs.	1
665 060	Rubber collars, set of 7	1
664 866	Suction flask, 500 ml, glass	1
382 21	Stirring thermometer -10...+110 °C	1
666 967	Spoon-ended spatula, stainless steel, 150 mm	1
665 751	Measuring cylinder 10 ml, with plastic base	1
665 754	Measuring cylinder 100 ml, with plastic base	1
665 996	Graduated pipette, 5 ml	1
666 003	Pipetting ball (Peleus ball)	1
664 101	Beaker, DURAN, 100 ml, squat	1
602 043	Beaker, DURAN, 150 ml, squat	1
664 103	Beaker, DURAN, 250 ml, squat	1
664 154	Watch glass dish 80 mm Ø	1
665 212	Glass stirring rod 200 x 8 mm Ø	1
667 7977	Electronic Balance 440-3N, 200 g : 0.01 g	1
375 56	Water jet pump	1
667 186	Vacuum rubber tubing, 8 mm diam.	1
666 839	Magnetic stirrer with hotplate	1
673 9390	2-Nitrobenzaldehyde, 5 g	1
670 0410	Acetone, 1 l	1
673 8420	Sodium hydroxide solution, 1 mol/l, 500 ml	1
671 9711	Ethanol, absolute, 500 ml	1
673 6310	Sodium dithionite, 250 g	1
673 6810	Sodium hydroxide, pellets, 250 g	1
	additionally required: white cotton cloth	1

Synthetic dyes have been known since the middle of the 19th century. Many major chemical companies started out as dye producers. The first dyes were extracted from tar. Today most dyes are based on crude oil.

Chemical compounds are coloured when they absorb wavelengths from the visible range of the spectrum. The compound then appears in the complementary colour of the absorbed wavelength.

Along with their colour, the ability to colour materials more or less colourfast is a decisive feature of dyes. That colouring is done by binding the dyes to the carrier materials or having the dyes penetrate into them. This, too, can be influenced by chemical means.

Experiment C5.2.4.1 synthesizes indigo, the dye used to colour jeans. Developed by Adolf von Baeyer in 1870, this synthesis was one of the first dye syntheses to be applied on an industrial scale. The educt used is nitrobenzaldehyde, which condenses with acetone under base conditions. The reduced, soluble leuco form of the dye is insolubly anchored in the tissue through oxidation by air.

C5.3.1

WASTE GAS PURIFICATION

C5.3.1.1
Analysis of waste gases

C5.3.1.2
Catalytic purification of automobile exhaust gases

Catalytic purification of automobile exhaust gases (C5.3.1.2)

Cat. No.	Description	C5.3.1.1	C5.3.1.2
665 914	Gas syringe, 100 ml with 3-way stopcock	3	2
667 312	Glass connector, 2 x GL 18	3	3
667 305	Screw cap, GL 18, with hole	3	
667 296	Silicone gaskets, GL 18/10, set of 10	3	
666 313	Testing tube for NO_x, 0.5...50 ppm, set of 10	1	1
666 319	Testing tube for CO, 0.5...7.0 %, set of 10	1	1
666 314	Testing tube for SO_2, 1...25 ppm, set of 10	1	1
667 015	Glass file, triganular	1	1
313 27	Hand-held stop-watch, 60s/0.2s	1	1
662 302	Spare air bag, set of 30	1	1
665 009	Funnel PP 75 mm Ø	1	1
666 360	Catalytic converter		1
524 005W	Mobile-CASSY 2 WiFi		1
529 676	Temperature probe, NiCr-Ni, 1.5 mm, type K		1
666 425	Panel frame C50, two-level, for CPS		1
666 4659	Adhesive magnetic board 500 mm		2
666 4661	Holder, magnetic, size 1, 9...11 mm		2
666 4662	Holder, magnetic, size 2, 11...14 mm		1
666 4665	Holder, magnetic, size 5, 30...32 mm		2
656 016	Bunsen burner, universal		1
607 020	Safety gas hose with clamp 0.5 m		1
300 76	Laboratory stand II		1
	additionally required: exhaust sample, such as car exhausts or cigarette smoke	1	
	additonally required: exhaust sample or a self produced exhaust mixture made of nitrogen dioxide and methane or carbonmonoxide		2

The fossil energy carriers coal, oil and natural gas are primarily used as fuels. The combustion processes generate waste gases which enter the atmosphere and are harmful to the environment and to human health. Carbon dioxide (CO_2) intensifies the greenhouse effect, for example, and sulfur dioxide (SO_2) and nitrogen oxides (NO_x) cause acid rain. Today pollution emissions are strictly controlled. Plant operators must reduce their emissions. Catalytic converters are a mandatory feature of automotive exhaust systems.

Under ideal conditions, the combustion of hydrocarbons would generate only water and carbon dioxide. When it involves a mixture of different fuels, e.g. petrol, then combustion can also produce nitrogen oxides or sulphur oxides. Experiment C5.3.1.1 uses detection tubes to test for the presence of such byproducts in different waste gases.

The so-called ‚three-way catalyst‘ removes the three most important toxic substances from automotive exhaust simultaneously: unburned hydrocarbons, carbon monoxide and nitrogen oxides. It consists of a ceramic carrier to which noble metals such as platinum and palladium are applied. The reactions which take place include the following:

$$CH_4 + 2\,NO_2 \rightleftharpoons CO_2 + 2\,H_2O + N_2$$
$$4\,CO + 2\,NO_2 \rightleftharpoons CO_2 + N_2$$
$$2\,CO + 2\,NO \rightleftharpoons 2\,CO_2 + N_2$$

In experiment V5.3.1.2, waste gases are purified with a three-way catalyst. The waste gas used in the investigation can be either automotive exhaust or a self-made mixture of waste gases.

C5.3.2

GLOBAL ENVIRONMENTAL PROBLEMS

C5.3.2.1
Greenhouse effect

Greenhouse effect (C5.3.2.1)

Cat. No.	Description	C5.3.2.1
666 2652	IR gas experiment kit	1
524 005W	Mobile-CASSY 2 WiFi	1
524 220	CASSY Lab 2	1
524 0401	µV sensor S	1
521 536	DC Power Supply 2 x 0...16 V/2 x 0...5 A	1
501 45	Connecting lead 19 A, 50 cm, red/blue, pair	2
501 861	Crocodile-clips, polished, set of 6	1
557 36	Moll's thermopile	1
375 58	Hand vacuum pump	1
604 500	PVC tubing 6 mm Ø, 1 m	1
604 431	Silicone tubing, 5 mm diam., 1 m	1
667 197	Silicone tubing, 4 mm diam., 1 m	1
604 520	Connector with nipple	1
661 0010	Minican pressurised gas canister, argon	1
660 988	Minican pressurised gas canister, ethane	1
661 0011	Minican pressurised gas canister, isobutane	1
660 999	Minican pressurised gas canister, carbon dioxide	1
660 998	Minican pressurised gas canister, oxygen	1
660 980	Fine regulating valve for minican gas canisters	1
	additionally required: PC with Windows 7 or higher with WIFI or USB connection	1

The Earth's climate is determined by a complex interaction of numerous factors. Many of those factors mutually affect and strengthen one another. As a result, the climate is subject to constant fluctuations on all time scales, from decades to millions of years. Today humans are intervening in this self-regulating system to a massive extent.

In experiment C5.3.2.1, the IR-CO_2 experimentation kit is used to demonstrate the absorption of infrared (IR) radiation by CO_2 in the wavelength range from 4100 to 4300 nm. The short-wave radiation of the Sun penetrates water vapour, carbon dioxide, ozone, nitrous oxide and methane in the Earth's atmosphere and reaches the surface of the Earth unimpeded. The long-wave heat radiation is absorbed. Acting like the glass of a greenhouse, the greenhouse gases impede the release of energy from the Earth and cause heat to build up. Only a small part of the heat radiation is emitted directly into space - the far greater share is reflected back toward the surface of the Earth. This is referred to as the natural greenhouse effect. The proportion of greenhouse gases is changing as a result of human activity. The associated temperature increase is referred to as the anthropogenic greenhouse effect.

C5.3.2

GLOBAL ENVIRONMENTAL PROBLEMS

C5.3.2.2
Ozone hole problem

Ozone hole problem (C5.3.2.2)

Cat. No.	Description	C5.3.2.2
666 265	UV-IR-VIS experiment kit	1
524 005W	Mobile-CASSY 2 WiFi	1
524 220	CASSY Lab 2	1
524 0511	Lux adapter S	1
666 246	UV-C sensor	1
667 818	Spark gap supply unit	1
500 621	Safety connecting lead 50 cm, red	1
500 622	Safety connecting lead 50 cm, blue	1
667 489	Crocodile clips, insulated, set of 2	1
667 241	Rubber bellows, single bulb	1
665 957	Disposable syringe, 1 ml, with Luer fitting	1
603 030	Cannulae, 0.6 mm diam., set of 10	1
671 6600	Dichloromethane, 250 ml	1
	additionally required: PC with Windows 7 or higher with WIFI or USB connection	1

In experiment C5.3.2.2, the UV-IR-VIS experimentation kit is used to demonstrate the absorption of UV-C radiation by ozone and the formation and decomposition of ozone. The ozone layer in the stratosphere (at a height of 15 to 50 km) is vitally important to life on Earth. Without its protective effect, strong shortwave UV radiation would make life outside of water impossible. The ozone layer acts as a filter for radiation from 220 to 310 nm. As a result it completely absorbs UV-C radiation (220 nm to 280 nm) and absorbs most of the UV-B radiation (280 nm to 320 nm).

For that reason, a reduction in the ozone concentration (ozone depletion, „ozone hole“) is increasing the intensity of biologically effective UV-B radiation. This can damage plants, thereby reducing harvest yields. Phytoplankton (types of algae at shallow ocean depths) are also affected - an important link in the food chain of the sea. Because it also absorbs a considerable quantity of carbon dioxide, it represents an integral part of the carbon cycle and plays a role in the greenhouse effect. Ozone forms in the stratosphere by the effect of hard UV radiation on oxygen.

Recording a breakthrough curve of activated carbon filters (C5.3.3.1)

C5.3.3

WATER CYCLE

C5.3.3.1
Recording a breakthrough curve of activated carbon filters

Cat. No.	Description	C5.3.3.1
524 005W	Mobile-CASSY 2 WiFi	1
524 220	CASSY Lab 2	1
300 11	Saddle base	1
300 41	Stand rod, 25 cm, 12 mm Ø	1
301 09	Bosshead S	1
666 555	Universal clamp 0...80 mm	1
524 069	Immersion photometer S	1
665 592	Chromatography column, 235 x 20 mm diam.	1
665 796	Volumetric flask, Boro 3.3, 1000 ml	1
664 131	Beaker Boro 3.3, 400 ml, squat	1
666 968	Spoon-ended spatula, stainless steel, 180 mm	1
667 7977	Electronic Balance 440-3N, 200 g : 0.01 g	1
604 009	Laboratory beaker PMP 25 ml, tall shape	1
672 1000	Glass wool, 10 g	1
661 0821	Stopcock grease (grease stick)	1
670 2000	Activated charcoal, granulated, 100 g	1
672 3400	Indigo carmine, 10 g	1
671 9720	Ethanol, denaturated, 1 l	1

Water can be purified with the help of activated carbon. Impurities, e.g. organic substances, adsorb on activated carbon and are thus filtered out of the water. A filter loses its filtering properties when it can no longer adsorb a substance. Then a so-called breakthrough occurs and the filter no longer has any filtering properties for this impurity.

In this experiment the breakthrough curve of the dye indigocarmine on activated carbon is determined. For this purpose, the dye is placed on activated carbon and the colour of the filtrate is measured until it returns to the initial value of the unfiltered solution.

Production of fuel from rapeseed oil (C5.4.1.1)

C5.4.1

FUELS

C5.4.1.1
Production of fuel from rapeseed oil

C5.4.1.2
Analysis of fuel from rapeseed oil

Cat. No.	Description	C5.4.1.1	C5.4.1.2
666 8471	Magnetic stirrer with hotplate	1	
666 851	Stirring magnet 25 mm x 6 mm Ø, circular	1	
666 850	Stirring magnet, 15 mm x 5 mm diam.	1	
602 004	Test tubes, DURAN, 20 x 180 mm, set of 100	1	
667 053	Test tube rack, for 10 tubes, 22 mm diam.	1	
664 103	Beaker, DURAN, 250 ml, squat	1	
602 022	Beaker Boro 3.3, 100 ml, squat	1	
300 02	Stand base, V-shaped, small	1	
301 27	Stand rod 50 cm, 10 mm Ø	1	
301 09	Bosshead S	2	1
666 555	Universal clamp 0...80 mm	2	1
382 21	Stirring thermometer -10...+110 °C	1	
665 953	Dropping pipette, 7 x 150 mm, 10 pcs.	1	
665 954	Rubber bulbs, 10 pcs	1	
665 995	Graduated pipette 2 ml	1	
665 996	Graduated pipette, 5 ml	1	
666 003	Pipetting ball (Peleus ball)	1	3
667 257	Rubber stopper solid, 19...24 mm Ø	1	
667 258	Rubber stopper, one 7-mm hole, 19...24 mm Ø	1	
665 204	Glass tube, 300 mm x 8 mm diam.	1	
673 2700	Methanol, 250 ml	1	
673 6800	Sodium hydroxide, pellets, 100 g	1	
524 005W	Mobile-CASSY 2 WiFi		1
524 044	Temperature sensor S, NTC		1
607 5025	Magnetic stirrer with hotplate		1

Cat. No.	Description	C5.4.1.1	C5.4.1.2
300 41	Stand rod, 25 cm, 12 mm Ø		1
608 310	Evaporating dish 24 ml, 60 mm dia.		3
672 2520	Wooden turnings		1
665 994	Graduated pipette 1 ml		1
LDS 00001	Stopwatch, digital		1
672 1740	Heating oil, 250 ml		1
	additionally required: rapeseed oil, cardboard	1	
	additionally required: biodiesel from rapeseed oil produced in experiment C5.4.1.1 rapeseed oil lighter		1

Rising energy demand ushered in by the industrial age in combination with the continuously increasing world population have caused worldwide consumption of fossil fuels such as oil, natural gas and coal to increase by more than twenty-fold over the past 100 years. The resulting shortage of fossil fuels demands, along with more frugal use of energy, the search for equivalent renewable sources of energy, including the suitable eco-friendly fuels.

In experiment C5.4.1.1, sodium methoxide is used to produce biodiesel from rapeseed oil. In this reaction, the rapeseed oil is first split into glycerine and fatty acids, and then esterified with methanol (transesterification) in a second step. The rapeseed acid-methylesters produced in this way represent the actual biodiesel.

In experiment C5.4.1.2 rapeseed oil is analysed. For this purpose, the viscosity and inflammability of rapeseed oil, diesel fuel, and rapeseed oil are compared.

C6.2.2.3

Production of yoghurt

For more information on this experience, see page 168.

C6 BIOCHEMISTRY

C6.1.1

CARBOHYDRATES

C6.1.1.1
Test for reducing sugar - Fehling's reaction

Test for reducing sugar - Fehling's reaction (C6.1.1.1)

Cat. No.	Description	C6.1.1.1
666 8471	Magnetic stirrer with hotplate	1
382 33	Thermometer, -10...+150 °C/1 K	1
665 793	Volumetric flask, Boro 3.3, 100 ml	2
665 212	Glass stirring rod 200 x 8 mm Ø	1
602 010	Beaker, Boro 3.3, 150 ml, tall	1
664 132	Beaker, Boro3.3, 600 ml, squat	1
665 754	Measuring cylinder 100 ml, with plastic base	1
667 7977	Electronic Balance 440-3N, 200 g : 0.01 g	1
665 997	Graduated pipette 10 ml	1
666 003	Pipetting ball (Peleus ball)	1
664 045	Test tubes, Fiolax, 30 x 200 mm, set of 10	1
667 054	Test tube rack, for 12 tubes, 32 mm diam.	1
665 953	Dropping pipette, 7 x 150 mm, 10 pcs.	1
665 954	Rubber bulbs, 10 pcs	1
666 961	Double-ended microspatula, stainless steel, 185 mm	1
661 243	Wash bottle PE 500 ml	1
672 1100	D(+)-Glucose, 100 g	1
672 0700	D(-)-Fructose, 50 g	1
674 6050	D(+)-Sucrose, 100 g	1
672 6710	Potassium sodium tartrate, 250 g	1
673 6800	Sodium hydroxide, pellets, 100 g	1
672 9600	Copper(II) sulfate-5-hydrate, 100 g	1
674 6750	Hydrochloric acid, conc., 25 %, 250 ml	1
661 091	Boiling stones 100 g	1

Carbohydrate is the collective name for a broad-ranging group of natural substances to which all types of sugar, starch and cellulose belong. They have the general molecular formula $C_n(H_2O)_m$ (n and m either equal or only slightly different), which is why they were previously erroneously regarded as „hydrates of carbon". Carbohydrates are polyalcohols, in which a primary or a secondary hydroxyl group is oxidised to the aldehyde group or the ketone group (carbonyl group).

Fehling's solution was developed by Herrmann Fehling in 1848. It is a reaction for the detection of reducing groups, such as aldehyde functions, for example. It makes it possible to differentiate between reducing and non-reducing sugars. Originally it was also used to determine blood sugar content in diabetics by means of titration. Experiment C6.1.1.1 uses the Fehling reagent to analyse glucose, fructose and sucrose.

C6.1.2

AMINO ACIDS AND PROTEINS

C6.1.2.1
Enzymatics: Splitting urea with urease

C6.1.2.2
Michealis-Menten kinetics using the enzyme urease

Enzymatics: Splitting urea with urease (C6.1.2.1)

Cat. No.	Description	C6.1.2.1	C6.1.2.2
524 005W	Mobile-CASSY 2 WiFi	1	1
524 220	CASSY Lab 2	1	1
524 0671	Conductivity adapter S	1	1
529 670	Conductivity sensor	1	1
607 105	Magnetic stirrer mini	1	1
300 11	Saddle base	1	1
301 26	Stand rod 25 cm, 10 mm Ø	1	1
301 09	Bosshead S	1	
666 555	Universal clamp 0...80 mm	1	1
602 010	Beaker, Boro 3.3, 150 ml, tall	2	5
665 997	Graduated pipette 10 ml	1	1
666 003	Pipetting ball (Peleus ball)	1	1
665 793	Volumetric flask, Boro 3.3, 100 ml	1	1
664 153	Watch glass dish 60 mm Ø	2	2
604 170	Powder funnel d=65mm	2	2
664 043	Test tubes, Fiolax, 16 x 160 mm, set of 10	1	1
667 253	Rubber stopper solid, 14...18 mm Ø	2	6
667 050	Test tube rack, plastic, for 9 tubes, 18 mm Ø	1	1
666 961	Double-ended microspatula, stainless steel, 185 mm	1	1
667 7977	Electronic Balance 440-3N, 200 g : 0.01 g	1	1
670 3900	Ammonium carbonate, 100 g	1	
672 1700	Urea, 100 g	1	1
675 2810	Urease (1 U/mg), 5 g	1	1
672 9600	Copper(II) sulfate-5-hydrate, 100 g	1	
675 3400	Water, pure, 1 l	1	1

Cat. No.	Description	C6.1.2.1	C6.1.2.2
666 543	Double, crossed boss head, 0...16 mm		1
666 851	Stirring magnet 25 mm x 6 mm Ø, circular		5
661 243	Wash bottle PE 500 ml		1
	additionally required: PC with Windows 7 or higher with WIFI or USB connection	1	1

Proteins are the building blocks of the cell. A distinction is drawn between scaffold proteins, which provide stability, and globular, soluble proteins. The subgroup of globular proteins includes enzymes, which catalyse reactions. They play an important role in the digestion of food, for example.

Experiment C6.1.2.1 takes a closer look at the enzyme urease. Urease splits urea into ammonia and carbonate ions. Since the urea solution does not conduct electricity, but a solution with ammonia and carbonate does, the course of the reaction can be recorded with conductivity measurements. The maximum rate of reaction and the reaction order are determined. Also an inhibitor is tested.

In experiment C6.1.2.2 the kinetics of the enzyme urease are examined. The rate of the reaction with different starting concentration is measured. Applying Michaelis-Menten kinetics, the maximal reaction rate v_{max} and the michaelis constant K_m can be determined.

C6.1.4

FATS AND OILS

C6.1.4.1
Determination of the calorific value of olive oil with a demonstration calorimeter

Determination of the calorific value of olive oil with a demonstration calorimeter (C6.1.4.1)

Cat. No.	Description	C6.1.4.1
524 013	Sensor-CASSY 2	1
524 220	CASSY Lab 2	1
529 676	Temperature probe, NiCr-Ni, 1.5 mm, type K	1
524 0673	NiCr-Ni adapter S, type K	1
667 325	Calorimeter for solids and liquids	1
666 603	Base rail, 95 cm	1
666 615	Universal bosshead	4
301 27	Stand rod 50 cm, 10 mm Ø	4
666 555	Universal clamp 0...80 mm	5
301 72	Universal clamp, 0...120 mm	2
301 09	Bosshead S	8
664 800	Gas scrubber bottle, lower section, 200 ml	4
664 805	Glass tube insert, ST 29/32	4
665 392	Joint clip plastic, ST 29/32	4
521 536	DC Power Supply 2 x 0...16 V/2 x 0...5 A	1
521 231	Low-voltage power supply 3/6/9/12 V	1
666 819	Stirring top, with GL 32 screw thread	1
501 45	Connecting lead 19 A, 50 cm, red/blue, pair	3
667 183	Rubber tubing, 1 m x 8 mm diam., DIN 12865	1
667 197	Silicone tubing, 4 mm diam., 1 m	1
604 510	Tubing connector, 4...15 mm	1
609 072	Round filter,90mm Ø, 100 pcs Typ 589	1
ADA HCB3001	Precision Balance, 3000 g / 0,1 g	1
667 7977	Electronic Balance 440-3N, 200 g : 0.01 g	1
660 998	Minican pressurised gas canister, oxygen	1

Cat. No.	Description	C6.1.4.1
660 980	Fine regulating valve for minican gas canisters	1
673 8420	Sodium hydroxide solution, 1 mol/l, 500 ml	1
674 7850	Sulfuric acid, 95-98 %, 250 ml	1
661 0821	Stopcock grease (grease stick)	1
	additionally required: PC with Windows XP/Vista/7/8/10 (x86 or x64)	1

In experiment C6.1.4.1, the calorific value of olive oil is determined. For this purpose, olive oil is burned in an O_2 atmosphere and the temperature rise is measured in the calorimeter. A filament is used to ignite the oil. The energy released is calculated using either a previously determined heat capacity of the filled calorimeter or the individual theoretical values of the heat capacities of the glass jacket and calorimeter liquid. The quantity of heat Q is calculated according to the following formula:

$$Q = \Delta T \times (m_k \times C_k + m(H_2O) \times C(H_2O))$$

Here ΔT represents the temperature difference, m_k and $m(H_2O)$ are the mass of the calorimeter and of the water, and C_k and $C(H_2O)$ are the heat capacities of the glass apparatus and the water. In order to calculate the heat of combustion ΔH, the ignition energy, which also contributed to the heating of the apparatus, must be subtracted. The quantity of heat is then expressed relative to one mol of substance.

Yeast fermentation - Test of oxygen consumption (C6.2.1.1)

C6.2.1

ALCOHOLIC FERMENTATION

C6.2.1.1
Yeast fermentation - Test of oxygen consumption

Cat. No.	Description	C6.2.1.1
524 005W	Mobile-CASSY 2 WiFi	1
524 220	CASSY Lab 2	1
524 0521	Oxygen adapter S	1
667 458	Oxygen electrode	1
386 40	Glass calorimeter	1
607 105	Magnetic stirrer mini	1
666 851	Stirring magnet 25 mm x 6 mm Ø, circular	1
300 11	Saddle base	2
300 41	Stand rod, 25 cm, 12 mm Ø	2
666 555	Universal clamp 0...80 mm	2
301 09	Bosshead S	2
660 998	Minican pressurised gas canister, oxygen	1
660 980	Fine regulating valve for minican gas canisters	1
604 481	Rubber tubing, 1 m x 4 mm diam., DIN 12865	1
604 510	Tubing connector, 4...15 mm	1
307 64	Rubber tubing, 1 m x 6 mm diam.	1
665 953	Dropping pipette, 7 x 150 mm, 10 pcs.	1
667 7977	Electronic Balance 440-3N, 200 g : 0.01 g	1
604 5661	Spatula, double ended, 185 mm	2
665 752	Measuring cylinder 25 ml, with plastic base	1
665 754	Measuring cylinder 100 ml, with plastic base	1
602 346	Laboratory bottle, 250 ml, GL 45 thread	1
602 725	Laboratory dish, 140 mm diam., 900 ml	1
664 103	Beaker, DURAN, 250 ml, squat	1
661 242	Wash bottle, PE, 250 ml	1

Cat. No.	Description	C6.2.1.1
672 1100	D(+)-Glucose, 100 g	1
	additionally required: fresh yeast	1

In biotechnology, products are produced with the aid of microorganisms. This occurs in large vessels known as bioreactors. Bioreactors can be operated in batches (batch processing) or continuously. In any case, successful culture relies on understanding the growth conditions of microorganisms.

Experiment C6.2.1.1 verifies the respiration in a yeast fermentation by measuring the oxygen consumption. For this purpose, a yeast suspension is saturated with oxygen. Then the oxygen supply is shut off and the oxygen saturation is tracked.

C6.2.2

BIOTECHNOLOGICAL PRODUCTS

C6.2.2.3
Production of yoghurt

Production of yoghurt (C6.2.2.3)

Cat. No.	Description	C6.2.2.3
665 563	Miniature separation tank	5
382 33	Thermometer, -10...+150 °C/1 K	1
666 767	Hotplate, 1500 W, 185 mm Ø	1
607 0721	Bath vessel, stainless steel	1
666 8061	Drying Oven/Hot Air Sterilizer E 28	1
666 966	Spoon-ended spatula, PP, 180 mm	1
665 753	Measuring cylinder 50 ml, with plastic base	1
MA9 0201	Universal indicator paper, roll	1
	additionally required: PC with Windows 7 or higher with WIFI or USB connection	1
	additionally required: fresh yeast	1

For thousands of years now, humans have been using biotechnology to produce food, textiles and other commodities. A whole series of perfectly ordinary, everyday things – including leavened bread, yoghurt, cheese, wine, beer and vinegar – are produced with the help of cultivated microorganisms.

Biotechnology is a technology which uses the living organism or parts of it to manufacture or modify products.

In experiment C6.2.2.3, yoghurt is produced from milk. If some yoghurt or isolated cultures of *Lactobacillus bulgaricus* (lactic acid bacteria) and possibly *Streptococcus themophilus* are added to milk, then the milk will become yoghurt. Yoghurt is the end product of an anaerobic bacteria metabolism. Lactic acid bacteria ferment in the lactose contained in the milk. The latter is first split into glucose and galactose by the enzyme lactase. Those cleavage products are then transformed into lactic acid by glycolysis and lactic acid fermentation.

APPENDIX

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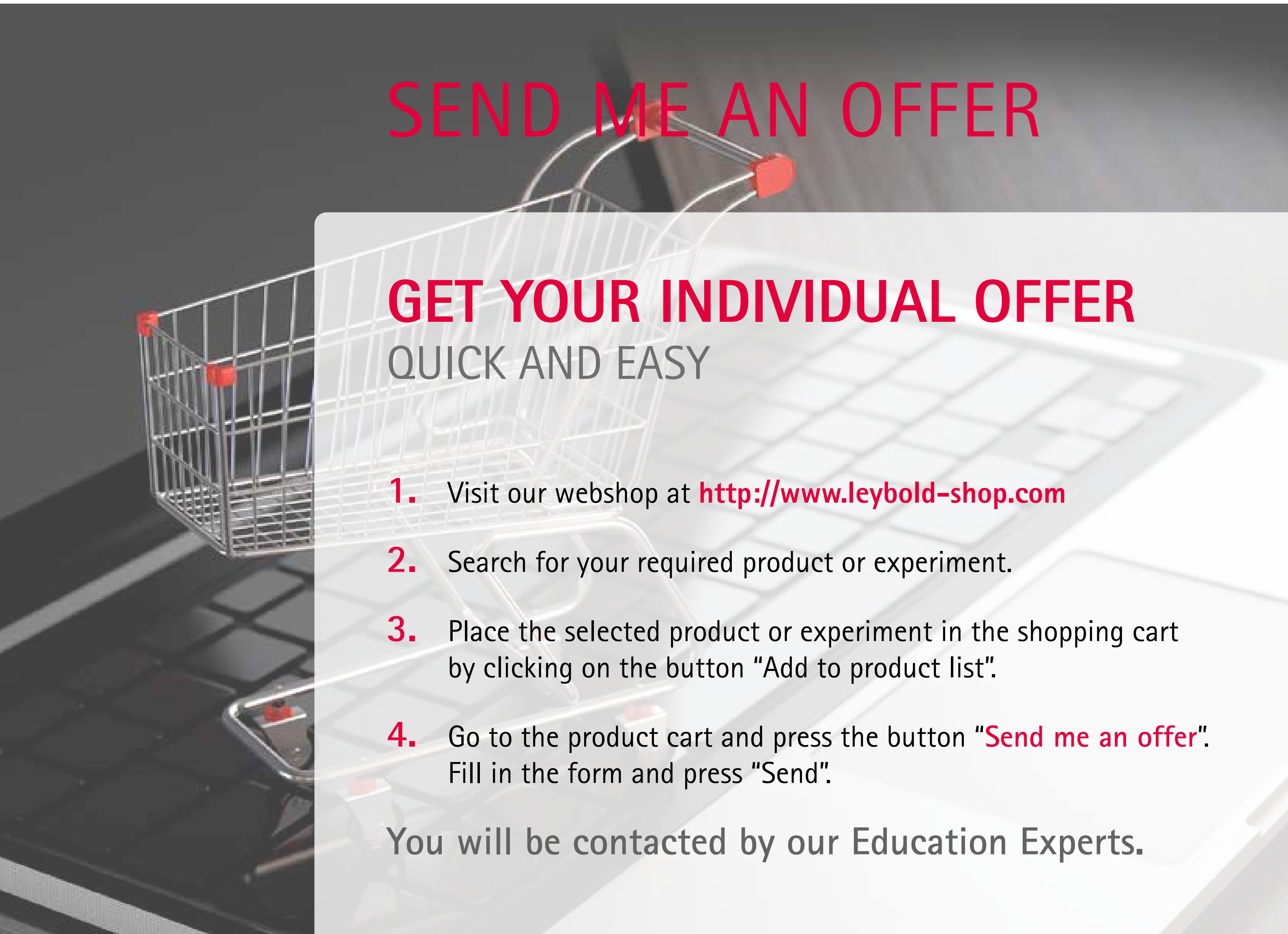

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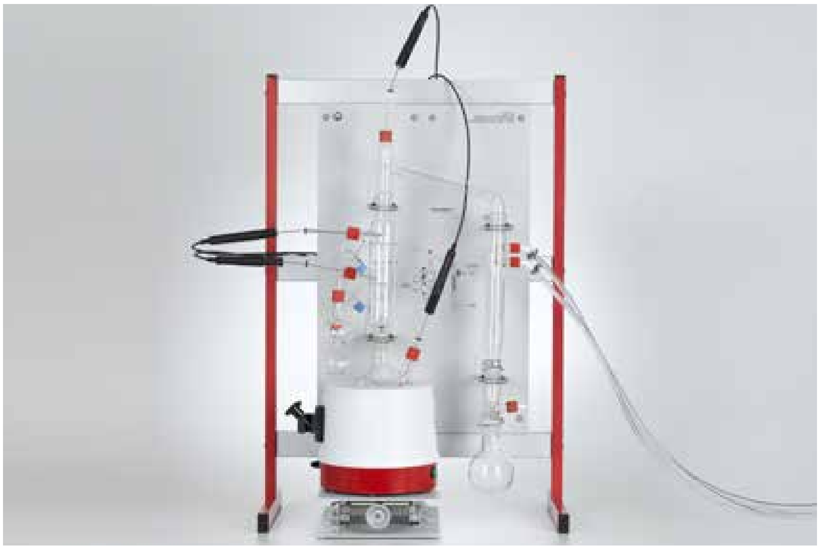
CONTACT

GERMANY:

LD DIDACTIC GmbH
Leyboldstr. 1
50354 Huerth
Germany
Tel.: +49 2233 604 0
Fax: +49 2233 604 222
E-Mail: info@ld-didactic.de
www.ld-didactic.com



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