Founded in Göttingen, Germany in 1913 by Dr. Gotthelf Leimbach, Phywe Systeme GmbH & Co. KG quickly advanced to one of the leading manufacturers of scientific equipment.

Over this period of more than 90 years Phywe has been putting quality and innovation into its products as a fundamental requirement.

As a well known international supplier in the fields of science and engineering we have made a significant impact on the market through high quality equipment.

Phywe products are made in Germany and in use throughout the world in the fields of education and research, from primary schools right through to university level.

Up-to-date educational systems, planning and commissioning of scientific and engineering laboratories to meet specific requirements are our daily business.

As a supplier of complete, fully developed and established systems, Phywe provides teaching and learning systems for students as well as teacher demonstration experiments. The system ranges from simple, easy to operate equipment intended for student use up to coverage of highly sophisticated and specialised university equipment demands.

Phywe Systeme GmbH & Co. KG has achieved a very high standard based on research and technology and through exchange of experiences with universities and high schools as well as with professors and teachers.

As experienced and competent manufacturer, we would gladly assist you in the selection of the "right" experiments for your particular curricula.
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Natural sciences have a longstanding tradition in Göttingen. More than 40 Nobel prizewinners coming from all sorts of scientific disciplines and numerous university institutes successfully conduct research in practically all areas of science.

The following research institutions and university institutes are located in Göttingen: Academy of Science, several Max-Planck institutes, the German Primate Centre, the Centre of Molecular Physiology of the Brain, the Centre of Molecular Life Science – to name just a few.

We are in contact with these institutions and exchange our views with them to ensure that the latest trends and scientific innovations are always reflected in the product range of Phywe Systeme GmbH & Co. KG.
GÖTTINGEN is a city of teaching and research. Scientific equipment, teaching equipment and laboratory installations developed and produced in this city are famous throughout the world.

Göttingen would not be what it is without its university.

“Georgia Augusta” was founded in 1734 and by 1777 it was Germany’s largest university, with 700 students. It still is one of the leading universities in Germany, with 14 faculties, significant scientific facilities and more than 30,000 students.

The gracious Goose Girl ("Gänseliesel") on the market place well is the most kissed girl in Germany. Why? Because every newly graduated doctor must kiss the cold beauty on her bronze mouth. That is Göttingen tradition.
The experiments in the PHYWE Publication Series “Laboratory Experiments Chemistry” are intended for the heads of chemistry laboratory courses at universities, colleges and similar institutions and also for advanced courses in high schools.

All experiments are uniformly built-up and contain references such as Related topics and Principle and task to introduce the subject.

Theory and evaluation states full theory involved and shows graphical and numerical experimental results including error calculations.

Example for measurement parameters for easy and safe experimentation.

Picture and Equipment List guarantee time-saving and easy conducting of the experiment.

Experimental literature
Laboratory Experiments Chemistry
Long Version No. 16504.12
The present volume which has been developed by PHYWE, complements the previously existing collection of about 80 experiments in seven chapters as the comprehensive Table of Contents shows. In this brochure we present the experiments in short form. The experiments can be ordered or offered completely or partially, if desired, in accordance with the Comprehensive Equipment Lists. On request, we will gladly send you detailed experimental descriptions.

You can order the experiments as follows:

**What you need:**

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**Chromatographic separation procedures: gas chromatography**

**Didactically adapted descriptions of experiments - easy, direct preparation by the students is possible**

**Comprehensive experiments - cover the entire range of classical and modern chemistry**

**Complete equipment offering modular experimental set-up - multiple use of individual devices, cost effective and flexible**

**Developed and proven by practicioners - unproblematical and reliable performance**

**Excellent measurement accuracy - results agree with theory**

**Computer-assisted experiments - simple, rapid assessment of the results**
Laboratory Experiments

The experiments in the Phywe publication series “Laboratory Experiments” are intended for the heads of laboratories, colleges of advanced technology, technical colleges and similar institutions and also for advanced courses in high schools. Laboratory Experiments Physics, Chemistry and Biology is also available on CD-ROM. Available in German, English and Spanish.

Special brochures

Additionally there are special brochures for our particularly successful teaching systems TESS (available in German, English, French and Spanish), Cobra3 (available in German, English) and Natural Sciences on the board (available in German, English).
Kinetic Theory

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LEC 01.01 Velocity of molecules and the MAXWELL BOLTZMANN distribution function
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LEC 01.03 Diffusion in gases: the diffusion coefficient of bromine in air
LEC 01.04 Determination of molar mass using the ideal gas law
LEC 01.05 Determination of the molar mass of a liquid
LEC 01.06 Determination of the molecular weight of a polymer from intrinsic viscosity measurement
LEC 01.07 Thermal conductivity of gases
LEC 01.08 Viscosity measurements with the falling ball viscometer
LEC 01.09 Viscosity of Newtonian and non-Newtonian liquids (rotary viscometer)
LEC 01.11 Gay-Lussac’s law
LEC 01.12 AMONTONS’ law
LEC 01.13 Boyle and Mariotte’s law
01.01 Velocity of molecules and the MAXWELL BOLTZMANN distribution function

What you need:

- Kinetic gas theory apparatus 09060.00 1
- Receiver with recording chamber 09061.00 1
- Power supply, variable, 15 VAC/12 VDC/5 A 13530.93 1
- Precision balance CPA 6235 (620 g/0.001 g), set with software 49224.88 1
- Digital stroboscope 21809.93 1
- Stopwatch, digital, 1/100 sec. 03071.01 1
- Tripod base -PASS- 02002.55 2
- Connecting cord, l = 750 mm, red 07362.01 1
- Connecting cord, l = 750 mm, blue 07362.04 1
- Glass beaker, 50 ml, tall 36001.00 5
- Spoon 40874.00 1

Velocity of molecules and the MAXWELL BOLTZMANN distribution function

What you can learn about

- Kinetic theory of gases
- Temperature
- Model kinetic energy
- Average velocity
- Velocity distribution

Principle and tasks

By means of the model apparatus for kinetic theory of gases, the motion of gas molecules is simulated and the velocity is determined by registration of the throw distance of the glass balls. This velocity distribution is compared to the theoretical MAXWELL-BOLTZMANN equation.

Distribution of molecule velocities of oxygen at 273 K.

Experimental and theoretical velocity distribution in the model experiment.
Principle and tasks
The viscosity of a gas relates to its resistance to flow. It is determined by the rate of transfer of the flow momentum from the faster moving layers to the slower ones.

The so-called transpiration methods provide a convenient way of measuring gas viscosities. In the approach used here, the rate of flow of the gas is recorded by monitoring the evacuation of a vessel through a capillary tube under a constant pressure differential. Using simple gas kinetic theory, the molecular diameter for the gas can be estimated.
01.03. Diffusion in gases: the diffusion coefficient of bromine in air

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**Diffusion in gases: the diffusion coefficient of bromine in air**

**What you can learn about**

- Kinetic theory of gases
- Transport properties
- Fick’s laws of diffusion
- Self and mutual diffusion coefficients

**Principle and tasks**

Diffusion arises from the flow of matter down a concentration gradient. In the evaporation method, a stationary concentration gradient is achieved in which the concentration falls linearly with distance. Under these conditions the diffusion coefficient of the diffusing substance may be calculated by a direct application of Fick’s first law of diffusion.
Principle and tasks
All gases may be considered, to a first approximation, to obey the ideal gas equation which relates the pressure $p$, volume $V$, temperature $T$ and amount of substance $n$ of a gas. If the volume occupied by a known mass of gas is measured at a given temperature and pressure, the equation can be used to estimate the molar mass of the gas.

In this experiment the molar masses of gases helium, nitrogen, carbon dioxide and methane are determined.

What you need:

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Determination of molar mass using the ideal gas law

P3010401
01.05. Determination of the molar mass of a liquid

Principle and tasks
The molar mass of a liquid is determined by evaporation of the liquid at constant temperature and pressure and measuring the volume of the formed vapour by means of a calibrated gas syringe. In this experiment the molar masses of diethyl ether and methanol are determined.

What you need:

- Set gas laws with glass jacket
- Laboratory thermometer, -10...+150°C
- Weather monitor, LCD
- Syringe, 1 ml
- Cannula 0.6×60 mm
- Precision balance CPA 623 S (620 g/0.001 g), set with software
- Beads, 200 g
- Power regulator
- Methanol, 500 ml
- Diethyl ether, 250 ml
- Water, distilled, 5 l
- Paper towels

Determination of the molar mass of a liquid P3010501
Determination of the molecular weight of a polymer from intrinsic viscosity measurement

**What you can learn about**
- Viscosity of liquids
- Ostwald capillary viscometer
- Poiseuille's equation
- Macromolecules

**Principle and tasks**

The viscosity of a liquid is effectively determined by the strength of the intermolecular attractive forces. In solutions, the viscosity of the solvent can alter significantly depending on the type and concentration of solute present. Due to their size, macromolecules have a very considerable impact on the viscosity of the solvent. Viscosity measurements can be used to estimate the mean molecular mass of a macromolecule if something is known about its conformation.

Using a thermostatic capillary viscometer, the viscosities of solutions of polystyrene in toluene are measured over a range of five polymer concentrations and the molecular weight is estimated.

**Plot used to determine the intrinsic viscosity $\eta$**. Data for polystyrene in toluene at 25.0°C.

**What you need:**

- Immersion thermostat, 100°C 08492.93 1
- Bath for thermostat, 6 l, Makrolon 08487.02 1
- Accessory set for immersion thermostat 08492.01 1
- Retort stand, $h = 750$ mm 37694.00 1
- Right angle clamp 37697.00 1
- Universal clamp 37715.00 1
- Capillary viscometer, 0.4 mm 03102.03 1
- Stop watch, digital, 1/100 s 03071.01 1
- Analytical balance CPA 224S (220 g/0.1 mg), set with software 49221.88 1
- Weighing dishes, $80 \times 50 \times 14$ mm 45019.25 1
- Volumetric flask, 250 ml 36550.00 1
- Volumetric flask, 100 ml 36548.00 1
- Volumetric pipette, 5 ml 36577.00 6
- Volumetric pipette, 20 ml 36579.00 1
- Volumetric pipette, 50 ml 36581.00 1
- Pipettor 36592.00 1
- Pipette dish 36589.00 1
- Funnel, glass, $d_0 = 80$ mm 34459.00 1
- Water jet pump 02728.00 1
- Rubber tubing, vacuum, $d = 6$ mm 39282.00 4
- Rubber tubing, $d = 6$ mm 39282.00 4
- Hose clips, $d = 8...12$ mm 40996.01 4
- Beaker, 250 ml, tall 36004.00 4
- Graduated cylinder, 100 ml 36629.00 1
- Glass rods, $d = 5$ mm, $l = 200$ mm 40485.03 1
- Spoon 33398.00 1
- Pasteur pipettes 36590.00 1
- Rubber bulbs 39275.00 1
- Wash bottle, 500 ml 33931.00 1

**Determination of the molecular weight of a polymer from intrinsic viscosity measurement**

P3010601
01.07 Thermal conductivity of gases

Principle and tasks
The thermal conductivity of a gas is expressed by the coefficient of thermal conductivity which is a function of the average particle velocity and the free path distance. In the experimental set-up there is a functional correlation between the thermal conductivities of the gases at the measuring probe and the voltage signal at the control unit. If the logarithm of the respective coefficient of thermal conductivity is plotted against the measured voltages, a straight line is obtained which can be used as a calibration curve for the determination of the coefficients of additional gases.

What you need:

- Measuring probe for gas chromatograph 36670.10 1
- Control unit for gas chromatograph 36670.99 1
- Digital multimeter 07042.00 1
- Connection cord, l = 250 mm, blue 07360.04 1
- Connection cord, l = 250 mm, red 07360.01 1
- Retort stand, h = 500 mm 37692.00 1
- Right angle clamp 37697.00 1
- Universal clamp 37715.00 1
- Pasteur pipettes 36590.00 1
- Graduated cylinder, 25 ml 36627.00 1
- Gas syringe, 100 ml 02614.00 1
- Rubber tubing, d = 6 mm 39282.00 1
- Steel cylinder helium, 2 l, filled 41776.00 1
- Reducing valve for helium 33481.00 1
- Table stand for 2 l steel cylinders 41774.00 1
- Wrench for steel cylinders 40322.00 1
- Fine control valve 33499.00 1
- Compressed gas, methane, 12 l 41772.08 1
- Compressed gas, carbon dioxide, 21 g 41772.06 1
- Silicone fluid for heating bath 31849.50 1

Calibration curve for the determination of coefficients of thermal conductivity.

Thermal conductivity of gases

P3010701
Principle and tasks
Due to internal friction among their particles, liquids and gases have different viscosities. The viscosity is a function of the substance’s structure and its temperature.

In a first experiment the viscosities of methanol-water mixtures of various composition are measured at constant temperature. Subsequently the viscosities of water and methanol are determined at different temperatures.

What you can learn about
→ Newtonian liquid
→ Stokes law
→ Fluidity
→ Dynamic and kinematic viscosity
→ Viscosity measurements

What you need:

- Falling ball viscometer
- Thermometer, +24...+51°C
- Immersion thermostat, 100°C
- Accessory set for immersion thermostat
- Bath for thermostat, 6 l, Makrolon
- Retort stand, h = 750 mm
- Right angle clamp
- Universal clamp with joint
- Pycnometer, calibrated, 25 ml
- Volumetric flask, 100 ml
- Glass beaker, 150 ml, tall
- Glass beaker, 250 ml, short
- Pasteur pipettes
- Rubber bulbs
- Hose clips, d = 8...12 mm
- Rubber tubing, d1 = 6 mm
- Stopwatch, digital, 1/100 s
- Precision balance CPA 623 S (620 g/0.001 g), set with software
- Wash bottle, 500 ml
- Methanol, 500 ml
- Water, distilled, 5 l

Viscosity measurements with the falling ball viscometer

<table>
<thead>
<tr>
<th>Item Description</th>
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</tr>
</thead>
<tbody>
<tr>
<td>Falling ball viscometer</td>
<td>18220.00</td>
<td>1</td>
</tr>
<tr>
<td>Thermometer, +24...+51°C</td>
<td>18220.02</td>
<td>1</td>
</tr>
<tr>
<td>Immersion thermostat, 100°C</td>
<td>08492.93</td>
<td>1</td>
</tr>
<tr>
<td>Accessory set for immersion thermostat</td>
<td>08492.01</td>
<td>1</td>
</tr>
<tr>
<td>Bath for thermostat, 6 l, Makrolon</td>
<td>08487.02</td>
<td>1</td>
</tr>
<tr>
<td>Retort stand, h = 750 mm</td>
<td>37694.00</td>
<td>1</td>
</tr>
<tr>
<td>Right angle clamp</td>
<td>37697.00</td>
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</tr>
<tr>
<td>Universal clamp with joint</td>
<td>37716.00</td>
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</tr>
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<td>Pycnometer, calibrated, 25 ml</td>
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<tr>
<td>Volumetric flask, 100 ml</td>
<td>36013.00</td>
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</tr>
<tr>
<td>Glass beaker, 150 ml, tall</td>
<td>36090.00</td>
<td>1</td>
</tr>
<tr>
<td>Glass beaker, 250 ml, short</td>
<td>39275.03</td>
<td>1</td>
</tr>
<tr>
<td>Hose clips, d = 8...12 mm</td>
<td>40996.01</td>
<td>6</td>
</tr>
<tr>
<td>Rubber tubing, d1 = 6 mm</td>
<td>39282.00</td>
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</tr>
<tr>
<td>Stopwatch, digital, 1/100 s</td>
<td>03071.01</td>
<td>1</td>
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<tr>
<td>Precision balance CPA 623 S (620 g/0.001 g), set with software</td>
<td>49224.88</td>
<td>1</td>
</tr>
<tr>
<td>Wash bottle, 500 ml</td>
<td>33931.00</td>
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</tr>
<tr>
<td>Methanol, 500 ml</td>
<td>30142.50</td>
<td>2</td>
</tr>
<tr>
<td>Water, distilled, 5 l</td>
<td>31246.81</td>
<td>1</td>
</tr>
</tbody>
</table>

Temperature dependence of the dynamic viscosity $\eta$ of water (o) and methanol (+) respectively.
01.09. Viscosity of Newtonian and non-Newtonian liquids (rotary viscometer)

What you need:

<table>
<thead>
<tr>
<th>Item</th>
<th>Code</th>
<th>Quantity</th>
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<tbody>
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<td>Rotary viscometer</td>
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<tr>
<td>Right angle clamp</td>
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<td>Spring balance holder</td>
<td>03065.20</td>
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<tr>
<td>Support rod with hole, l = 100 mm</td>
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<td>Magnetic heating stirrer</td>
<td>35750.93</td>
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<td>Electronic temperature control</td>
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<tr>
<td>Magnetic stirrer bar, l = 30mm</td>
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<tr>
<td>Separator for magnetic bars</td>
<td>35680.03</td>
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<tr>
<td>Glass beaker, 250 ml, tall</td>
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<tr>
<td>Glass rod, l = 200 mm, d = 5 mm</td>
<td>40485.03</td>
<td>2</td>
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<td>Glycerol, 250 ml</td>
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</tr>
<tr>
<td>Liquid paraffin, 250 ml</td>
<td>30180.25</td>
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<tr>
<td>Castor oil, 250 ml</td>
<td>31799.27</td>
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</tr>
<tr>
<td>Acetone, chem. pure, 250 ml</td>
<td>30004.25</td>
<td>3</td>
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</table>

Viscosity of Newtonian and non-Newtonian liquids (rotary viscometer)  P3010901

Principle and tasks

The viscosity of liquids can be determined with a rotation viscometer. It consists of a motor with variable rotation speed driving a cylinder immersed in the liquid to be investigated with a spiral spring. The viscosity of the liquid generates a moment of rotation at the cylinder which can be measured with the aid of the torsion of the spiral spring and read on a scale.

What you can learn about

- Shear stress
- Internal friction
- Viscosity
- Newtonian liquid
- non-Newtonian liquid

![Moment of rotation as a function of frequency for a Newtonian liquid (+ Glycerine, o Liquid paraffin).](image1)

![Moment of rotation as a function of frequency for a non-Newtonian liquid (chocolate at 302 K).](image2)
Principle and tasks
The state of a gas is determined by temperature, pressure and amount of substance. For the limiting case of ideal gases, these state variables are linked via the general equation of state. For a change of state under isobaric conditions this equation becomes the 1st law of Gay-Lussac. The validity of Gay-Lussac’s law is experimentally investigated for a constant amount of gas (air).

What you can learn about

- Coefficient of thermal expansion
- General equation of state for ideal gases
- Universal gas constant
- Gay-Lussac’s law

What you need:

- Set gas laws with glass jacket 43003.88 1
- Set data acquisition for gas laws with glass jacket 43003.30 1
- Temperature measuring module NiCr-Ni 12104.00 1
- Thermocouple, NiCr-Ni, sheated 13615.01 1
- Water, distilled, 5 l 31246.81 1
- PC, Windows® XP or higher

Gay-Lussac’s law

Dependence of the volume on the temperature under isobaric conditions.
01.12 Amontons’ law

Principle and tasks
The state of a gas is determined by temperature, pressure and amount of substance. For the limiting case of ideal gases, these state variables are linked via the general equation of state. For a change of state under isochoric conditions this equation becomes Amontons’ law.

In this experiment it is investigated whether Amontons’ law is valid for a constant amount of gas (air).

What you can learn about
- Thermal tension coefficient
- General equation of state for ideal gases
- Universal gas constant
- Amontons’ law

What you need:
- Set gas laws with glass jacket 43003.88 1
- Set data acquisition for gas laws with glass jacket 43003.30 1
- Water, distilled, 5 l 31246.81 1
- Motor oil
- PC, Windows® XP or higher

Amontons’ law

Dependence of the pressure on the temperature under isochoric conditions.
Principle and tasks
The state of a gas is determined by temperature, pressure and amount of substance. For the limiting case of ideal gases, these state variables are linked via the general equation of state. In case of isothermal process control this equation becomes Boyle and Mariotte's law.

The validity of Boyle and Mariotte's law is experimentally investigated for a constant amount of gas (air). From the resulting relationship the universal gas constant is calculated.

What you need:
- Set gas laws with glass jacket 43003.88 1
- Set data acquisition for gas laws with glass jacket 43003.30 1
- Water, distilled, 5 l 31246.81 1
- Motor oil
- PC, Windows® XP or higher

What you can learn about
- Cubic compressibility coefficient
- General equation of state for ideal gases
- Universal gas constant
- Boyle and Mariotte’s law
Thermochemistry/Calorimetry

Contents
LEC 02.01 Thermal equation of state and critical point
LEC 02.02 Adiabatic coefficient of gases – Flammersfeld oscillator
LEC 02.03 Heat capacity of gases
LEC 02.04 Determination of the enthalpy of vaporization of liquids
LEC 02.05 Partial molar volumes
LEC 02.06 Determination of the mixing enthalpy of binary fluid mixtures
LEC 02.07 Determination of the hydration enthalpy of an electrolyte
LEC 02.08 Determination of the enthalpy of neutralisation
LEC 02.09 Determination of the melting enthalpy of a pure substance
LEC 02.10 Boiling point elevation
LEC 02.11 Freezing point depression
LEC 02.12 Determination of the enthalpy of combustion with a calorimetric bomb
LEC 02.15 Determination of the heat of formation for water
LEC 02.16 Determination of the heat of formation for CO\textsubscript{2} and CO (Hess law)
LEC 02.17 Determination of the calorific value for heating oil and the gross calorific value for olive oil
LEC 02.18 Dilatometry
# 02.01 Thermal equation of state and critical point

## Principle and tasks

A substance which is gaseous under normal conditions is enclosed in a variable volume and the dependence of pressure on volume is recorded at different temperatures. The critical point is determined graphically from a plot of the isotherms.

## What you can learn about
- Equation of state
- Van der WAALS equation
- Boyle temperature
- Critical point
- Interaction potential
- Molecule radius

## What you need:

<table>
<thead>
<tr>
<th>Item</th>
<th>Item No</th>
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<td>Critical point apparatus</td>
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</tr>
<tr>
<td>Bath for thermostat, 6 l, Makrolon</td>
<td>08487.02</td>
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<td>Gasket for GL 18, 8 mm hole</td>
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<td>Laboratory thermometer, -10...+100°C</td>
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<td>Safety bottle with manometer</td>
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<td>Tripod base -PASS-</td>
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<td>Support rod, l = 500 mm</td>
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<td>1</td>
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<tr>
<td>Universal clamp</td>
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<tr>
<td>Rubber tubing, d₁ = 8 mm</td>
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<td>Rubber tubing, vacuum, d₁ = 8 mm</td>
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<td>Rubber tubing, vacuum, d₁ = 6 mm</td>
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<td>Pinchcock, w = 15 mm</td>
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<tr>
<td>Hose clip, d = 8...12 mm</td>
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<tr>
<td>Hose clip, d = 12...20 mm</td>
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<td>Mercury tray</td>
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</tr>
<tr>
<td>Compressed gas, ethane, 14 g</td>
<td>41772.09</td>
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</table>

**Interaction potential dependend on the molecular distance.**

---

**Thermal equation of state and critical point**

<table>
<thead>
<tr>
<th>Code</th>
<th>Item</th>
<th>P3020101</th>
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</thead>
<tbody>
<tr>
<td>E/8</td>
<td>repulsion</td>
<td>attraction</td>
</tr>
</tbody>
</table>

---

**Thermochemistry/Calorimetry**

**LEC 02**
Adiabatic coefficient of gases - Flammersfeld oscillator

Principle and tasks
A mass oscillates on a volume of gas in a precision glass tube. The oscillation is maintained by leading escaping gas back into the system. The adiabatic coefficient of various gases is determined from the periodic time of the oscillation.

What you need:

<table>
<thead>
<tr>
<th>Item</th>
<th>Code</th>
<th>Quantity</th>
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</thead>
<tbody>
<tr>
<td>Gas oscillator, Flammersfeld</td>
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<td>Graduated cylinder, 1000 ml</td>
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</tr>
<tr>
<td>Aspirator bottle, 1000 ml</td>
<td>34175.00</td>
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</tr>
<tr>
<td>Air control valve</td>
<td>37003.00</td>
<td>1</td>
</tr>
<tr>
<td>Light barrier with counter</td>
<td>11207.30</td>
<td>1</td>
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<tr>
<td>Power supply 5 VDC / 2.4 A</td>
<td>11076.99</td>
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<tr>
<td>Micrometer</td>
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<tr>
<td>Glass tubes, right-angled</td>
<td>36701.52</td>
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</tr>
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<td>Rubber stopper, d = 17 / 22 mm, 1 hole</td>
<td>39255.01</td>
<td>1</td>
</tr>
<tr>
<td>Rubber stopper, d = 26 / 32 mm, 1 hole</td>
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</tr>
<tr>
<td>Rubber tubing, d = 6 mm</td>
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<tr>
<td>Sliding weight balance, 101 g</td>
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</tr>
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<td>Aquarium pump, 230 VAC</td>
<td>64565.93</td>
<td>1</td>
</tr>
<tr>
<td>Aneroid barometer</td>
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<td>Stop watch, digital, 1/100 s</td>
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<td>1</td>
</tr>
<tr>
<td>Tripod base - PASS-</td>
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<td>1</td>
</tr>
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<tr>
<td>Universal clamp</td>
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<td>Reducing valve for nitrogen</td>
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<td>1</td>
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<tr>
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<tr>
<td>Steel cylinder, nitrogen, 10 l, filled</td>
<td>41763.00</td>
<td>1</td>
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</tbody>
</table>

Adiabatic coefficient of gases - Flammersfeld oscillator

What you can learn about

→ Equation of adiabatic change of state
→ Polytropic equation
→ Rüchardt's experiment
→ Thermal capacity of gases
02.03 Heat capacity of gases

What you can learn about

- 1st law of thermodynamics
- Universal gas constant
- Isobars
- Isotherms
- Isochors and adiabatic changes of state

Principle and tasks

Heat is added to a gas in a glass vessel by an electric heater which is switched on briefly. The temperature increase results in a pressure increase which is measured with a manometer. Under isobaric conditions a temperature increase results in a volume dilatation that can be read from a gas syringe. The molar heat capacities $C_v$ and $C_p$ are calculated from pressure and volume change.

What you need:

- Experiment P3020311 with Cobra3 Basic-Unit
- Experiment P3020301 with digital counter

Pressure change $\Delta P$ as a function of the heat-up time $\Delta t$. $U' = 4.59 \text{ V}$, $I = 0.43 \text{ A}$.

Universal clamp
Right angle clamp
PC, Windows® XP or higher

Heat capacity of gases
Principle and tasks
The vaporization of a liquid occurs with heat absorption. To determine the enthalpy of vaporization, a known mass of the liquid which is to be investigated is vaporized in a special vaporization vessel in a current of air. The quantity of heat absorbed which corresponds to the enthalpy of vaporization can be calorimetrically determined.

Temperature-time curve of the vaporisation of diethyl ether and determining the heat capacity of the system.

What you need:
- Set calorimetry 43030.88 1
- Set data acquisition for set calorimetry 43030.30 1
- Evaporation vessel for calorimeter 04405.00 1
- Separator for magnetic bars 35680.03 1
- Right angle clamp 37697.00 2
- Universal clamp 37715.00 2
- Retort stand, h = 500 mm 37692.00 1
- Precision balance CPA 623S (620 g/0.001 g), set with software 49224.88 1
- Precision balance CPA 6202S (6200 g/0.01 g), set with software 49226.88 1
- Safety bottle with manometer 34170.88 1
- Water jet pump 02728.00 1
- Erlenmeyer flask, 250 ml, wide 36134.00 1
- Rubber tubing, vacuum, d = 6 mm 39286.00 1
- Rubber tubing, d = 6 mm 39282.00 1
- Rubber bulbs 39282.03 1
- Hose clip, d = 12…20 mm 40995.00 5
- Air control valve 37003.00 1
- Syringe, 20 ml 02591.03 1
- Cannula, 0.9 × 70 mm 02597.04 1
- Wash bottle, 500 ml 33931.00 1
- Diethyl ether, 250 ml 30007.25 1
- Methanol, 500 ml 30142.50 1
- Water, distilled, 5 l 31246.81 1
- PC, Windows® XP or higher

Determination of the enthalpy of vaporization of liquids P3020411
02.05 Partial molar volumes

Principle and tasks
Due to intermolecular interactions, the measured total volume resulting from the mixture of two real liquids deviates from the calculated volume of the individual components. To describe this non-ideal behaviour in the mixing phase, one defines partial molar quantities which are dependent on the system composition. These values can be experimentally determined, in this case by measuring the densities of different ethanol-water mixtures with pycnometers.

What you need:
- Precision balance CPA 623S (620 g/0.001 g), set with software
- Immersion thermostat, 100°C
- Bath for thermostat, 6 l, Makrolon
- Accessory set for immersion thermostat
- H-base - PASS-
- Support rod, l = 500 mm
- Right angle clamp
- Universal clamp
- Pycnometer, calibrated, 25 ml
- Bottle, narrow neck, 100 ml
- Funnel, glass, d₀ = 55 mm
- Glass beaker, 50 ml, tall
- Pasteur pipettes
- Rubber bulbs
- Rubber tubing, d₁ = 6 mm
- Hose clip, d₂ = 8...12 mm
- Wash bottle, 500 ml
- Ethyl alcohol, absolute, 500 ml
- Water, distilled 5 l

Partial molar volumes

What you can learn about
- Principles of thermodynamics
- Ideal and non-ideal behaviour of gases and liquids
- Volume contraction
- Molar and partial molar quantities

Dependence of the mean mixing volumes $\Delta_m V$ on the composition of different ethanol/water mixtures.
Determining the mixing enthalpy of binary fluid mixtures 02.06

**Principle and tasks**
When two miscible liquids are mixed, a positive or negative heat effect occurs, which is caused by the interactions between the molecules. This heat effect is dependent on the mixing ratio. The integral mixing enthalpy and the differential molar mixing enthalpy can be determined by calorimetric measurements of the heat of reaction.

**Temperature-time curve of the mixing of two miscible fluids and determining the heat capacity of the system.**

<table>
<thead>
<tr>
<th>What you need:</th>
<th></th>
</tr>
</thead>
<tbody>
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<td>Set data acquisition for set calorimetry</td>
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<td>08492.93</td>
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<tr>
<td>Accessory set for immersion thermostat</td>
<td>08492.01</td>
</tr>
<tr>
<td>Bath for thermostat, 6 l, Makrolon</td>
<td>08487.02</td>
</tr>
<tr>
<td>Rubber tubing, d = 6 mm</td>
<td>39282.00</td>
</tr>
<tr>
<td>Hose clips, d = 8…12 mm</td>
<td>40996.01</td>
</tr>
<tr>
<td>Separator for magnetic bars</td>
<td>35680.03</td>
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<tr>
<td>Right angle clamp</td>
<td>37697.00</td>
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<tr>
<td>Universal clamp</td>
<td>37715.00</td>
</tr>
<tr>
<td>Retort stand, h = 500 mm</td>
<td>37692.00</td>
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<td>Erlenmeyer flask, 100 ml, narrow neck, PN 19</td>
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<tr>
<td>Pasteur pipettes</td>
<td>36590.00</td>
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<tr>
<td>Rubber bulbs</td>
<td>39275.03</td>
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<tr>
<td>Wash bottle, 500 ml</td>
<td>33931.00</td>
</tr>
<tr>
<td>Acetone, chem. pure, 250 ml</td>
<td>30004.25</td>
</tr>
<tr>
<td>Water, distilled, 5 l</td>
<td>31246.81</td>
</tr>
<tr>
<td>PC, Windows® XP or higher</td>
<td></td>
</tr>
</tbody>
</table>

**Determination of the mixing enthalpy of binary fluid mixtures** P3020611
Determination of the hydration enthalpy of an electrolyte

Principle and tasks
When a solid electrolyte dissolves in water, a positive or negative heat effect occurs as a result of the destruction of the crystal lattice and the formation of hydrated ions. The enthalpy of hydration of copper sulphate can be calculated from the different heats of reaction measured when anhydrous and hydrated copper sulphate are separately dissolved in water.

What you can learn about
- Integral enthalpy of solution
- Hess’ law
- Ion solvation
- Calorimetry
- Heat capacity

Temperature-time curves of solution of anhydrous and hydrated copper sulphate and determining the heat capacity of the system.

What you need:
- Set calorimetry
- Set data acquisition for set calorimetry
- Separator for magnetic bars
- Precision balance CPA 6202 S (6200 g/0.01 g), set with software
- Mortar with pestle, 190 ml
- Porcelain dish, 115 ml, d = 100 mm
- Crucible tongs, 200 mm
- Tripod, d = 140 mm, h = 240 mm
- Wire gauze, 160 x 160 mm
- Butane burner
- Butane cartridge
- Glass beaker, 50 ml, tall
- Spoon
- Powder funnel, d = 100 mm
- Wash bottle, 500 ml
- Desiccator
- Porcelain plate for desiccators
- Silicone grease, 100 g, 1 tube
- Silica gel, orange, granulated, 500 g
- Copper(II) sulphate, anhydride, 250 g
- Copper(II) sulphate, 250 g
- Water, distilled, 5 l
- PC, Windows® XP or higher
Determination of the enthalpy of neutralisation

Principle and tasks
When a strong acid is neutralised with a strong base in dilute solution, the same amount of heat is always released. If the reaction takes place under isobaric conditions, this heat is known as the enthalpy of neutralisation. The chemical reaction which generates this heat is the reaction of protons and hydroxyl ions to form undissociated water. The temperature change during the neutralisation of a potassium hydroxide solution with a hydrochloric acid solution is measured and the enthalpy of neutralisation is calculated.

Temperature-time curve of neutralisation and determining the heat capacity of the system.

What you need:
- Set calorimetry
- Set data acquisition for set calorimetry
- Delivery pipette, 50 ml
- Pipettor
- Rubber bulb, double
- Pinchcock, w = 15 mm
- Separator for magnetic bars
- Right angle clamp
- Universal clamp
- Precision balance CPA 6202S (6200 g/0.01 g), set with software
- Volumetric flask, 500 ml
- Glass beaker, 100 ml, tall
- Glass beaker, 600 ml, tall
- Pasteur pipettes
- Rubber bulbs
- Wash bottle, 500 ml
- Potassium hydroxide for 1 l of 1 M solution, ampoule
- Hydrochloric acid for 1 l of 1 M solution, ampoule
- Water, distilled, 5 l
- PC, Windows® XP or higher

What you can learn about
- Enthalpy of neutralisation
- Calorimetry
- Heat capacity
02.09 Determination of the melting enthalpy of a pure substance

**Principle and tasks**

When a solid melts, energy is required for the destruction of the crystal lattice. A substance whose melting point lies slightly below room temperature is first cooled until it solidifies and then melted in a calorimeter. The melting enthalpy is calculated from the decrease in temperature due to the melting process which is measured in the calorimeter.

**What you can learn about**
- Melting point and melting enthalpy
- Latent heat
- Gibbs' phase rule
- Calorimetry
- Heat capacity

**What you need:**

- Set calorimetry 43030.88 1
- Set data acquisition for set calorimetry 43030.30 1
- Separator for magnetic bars 35680.03 1
- Right angle clamp 37697.00 1
- Universal clamp 37715.00 1
- Precision balance CPA 6202S (6200 g/0.01 g), set with software 49226.88 1
- Test tube, 30/200 mm, Duran, PN 29 36294.00 2
- Rubber stopper 32/30 39258.00 2
- Dewar vessel, 500 ml 33006.00 1
- Pasteur pipettes 36590.00 1
- Rubber bulbs 39275.03 1
- Wash bottle, 500 ml 33931.00 1
- 1,4-Dioxan, 1000 ml 31266.70 1
- Water, distilled, 5 l 31246.81 1
- PC, Windows® XP or higher

**Temperature-time curve for the melting process of dioxan and determining the heat capacity of the system.**
Principle and tasks
The boiling point of a solution is always higher than that of the pure solvent. The dependence of the temperature difference (elevated boiling point) on the concentration of the solute can be determined using a suitable apparatus.
Measuring the increase in boiling point of water as a function of the concentration of table salt, urea and hydroquinone the molar mass of the solute can be determined.

What you need:
- Apparatus for elevation of boiling point 36820.00 1
- Temperature meter, digital, 4-2 13617.93 1
- Temperature probe, immersion type Pt100, Teflon 11759.04 1
- Heating hood, 250 ml 49542.93 1
- Clamp for heating hood 49557.01 1
- Power regulator 32288.93 1
- Flask, round, 250 ml, GL 25/12 35812.15 1
- Glass beaker, 250 ml, tall 36004.00 1
- Jointing, GL 25/8 41242.03 1
- Silicone tubing, d = 7 mm 39296.00 1
- Retort stand, h = 750 mm 37694.00 1
- Right angle clamp 37697.00 3
- Universal clamp 37715.00 3
- Mortar with pestle, 190 ml 32604.00 3
- Pinchcock, w = 15 mm 43631.15 1
- Microspoon 33393.00 1
- Pellet press for calorimeter 04403.04 1
- Precision balance CPA 623S (620 g/0.001 g), set with software 49224.88 1
- Weighing dishes, 80 × 110 × 14 mm 45019.05 1
- Funnel, glass, d = 80 mm 34459.00 1
- Pasteur pipettes 36590.00 1
- Rubber bulbs 39275.03 1
- Wash bottle, 500 ml 33931.00 1
- Beads, 200 g 36937.20 1

What you can learn about
- Raoult’s law
- Henry’s law
- Ebullioscopy
- Gibbs-Helmholtz equation

Boiling point elevation

Boiling point increase as a function of concentration of table salt in an aqueous solution.

Sodium chloride, 500 g 30155.50 1
Urea, pure, 250 g 30086.25 1
Hydroquinone, 250 g 30089.25 1
Glycerine, 250 ml 30084.25 1
Water, distilled, 5 l 31246.81 1
Parallel vice
02.11 Freezing point depression

Principle and tasks
The freezing point of a solution is lower than that of the pure solvent. The depression of the freezing point can be determined experimentally using a suitable apparatus (cryoscopy). If the cryoscopy constants of the solvent are known, the molecular mass of the dissolved substances can be determined.

What you need:

<table>
<thead>
<tr>
<th>Item</th>
<th>Code</th>
<th>Quantity</th>
</tr>
</thead>
<tbody>
<tr>
<td>Apparatus for freezing point depression</td>
<td>36821.00</td>
<td>1</td>
</tr>
<tr>
<td>Gasket for GL 25, 12 mm hole</td>
<td>41243.03</td>
<td>1</td>
</tr>
<tr>
<td>Temperature meter digital, 4-2</td>
<td>13617.93</td>
<td>1</td>
</tr>
<tr>
<td>Temperature probe, Pt100</td>
<td>11759.01</td>
<td>2</td>
</tr>
<tr>
<td>Protective sleeves for temperature probe</td>
<td>11762.05</td>
<td>1</td>
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<tr>
<td>Magnetic heating stirrer</td>
<td>35750.93</td>
<td>1</td>
</tr>
<tr>
<td>Magnetic stirrer bar, l = 30 mm</td>
<td>46299.02</td>
<td>1</td>
</tr>
<tr>
<td>Support rod, stainless steel, l = 500 mm, M10 thread</td>
<td>02022.20</td>
<td>2</td>
</tr>
<tr>
<td>Right angle clamp</td>
<td>37715.00</td>
<td>2</td>
</tr>
<tr>
<td>Universal clamp</td>
<td>36017.00</td>
<td>1</td>
</tr>
<tr>
<td>Volumetric pipette, 50 ml</td>
<td>36581.00</td>
<td>1</td>
</tr>
<tr>
<td>Pipettor</td>
<td>36592.00</td>
<td>1</td>
</tr>
<tr>
<td>Precision balance CPA 623 S (620 g/0.001 g), set with software</td>
<td>49224.88</td>
<td>1</td>
</tr>
<tr>
<td>Weighing dishes, 80 × 50 × 14 mm</td>
<td>45019.25</td>
<td>1</td>
</tr>
<tr>
<td>Stopwatch, digital, 1/100 s</td>
<td>03071.01</td>
<td>1</td>
</tr>
<tr>
<td>Pellet press for calorimeter</td>
<td>04403.04</td>
<td>1</td>
</tr>
<tr>
<td>Mortar with pestle, 70 ml, porcelain</td>
<td>32603.00</td>
<td>2</td>
</tr>
<tr>
<td>Microspoon</td>
<td>33393.00</td>
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<tr>
<td>Spoon</td>
<td>33398.00</td>
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<tr>
<td>Funnel, plastic, d = 50 mm</td>
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</tr>
<tr>
<td>Pasteur pipettes</td>
<td>36590.00</td>
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</tr>
<tr>
<td>Rubber bulbs</td>
<td>39275.03</td>
<td>1</td>
</tr>
<tr>
<td>Glass rod, l = 300 mm, d = 8 mm</td>
<td>40485.06</td>
<td>1</td>
</tr>
<tr>
<td>Wash bottle, 500 ml</td>
<td>33931.00</td>
<td>1</td>
</tr>
<tr>
<td>Sodium chloride, 500 g</td>
<td>30155.50</td>
<td>1</td>
</tr>
<tr>
<td>Hydroquinone, 250 g</td>
<td>30089.25</td>
<td>1</td>
</tr>
<tr>
<td>Raw alcohol for burning, 1000 ml</td>
<td>31150.70</td>
<td>1</td>
</tr>
<tr>
<td>Water, distilled, 5 l</td>
<td>31246.81</td>
<td>1</td>
</tr>
</tbody>
</table>

What you can learn about
- Raoult’s law
- Cryoscopy
- Chemical potential
- Gibbs-Helmholtz equation
- Van’t Hoff factor

Cooling curve of a water/table salt mixture.
Principle and tasks
The calorimetric bomb is used to completely burn substances in excess oxygen. The heat of combustion released is absorbed by the calorimetric vessel in which the bomb is immersed, and results in a temperature increase $\Delta T$. The heat capacity of the system is first determined by adding a defined amount of heat from the combustion of benzoic acid. Subsequently, under the same conditions the combustion enthalpy of naphthalene is determined.

Determining the corrected temperature difference.

What you need:
- Calorimetric bomb 04403.00 1
- Test vessel for calorimeter bomb 04403.03 1
- Pressure tube with fittings 39299.00 1
- Calorimeter, transparent 04402.00 1
- Magnetic heating stirrer 35750.93 1
- Magnetic stirrer bar, l = 30 mm, oval 35680.04 1
- Support rod, stainless steel, l = 500 mm, M10 thread 02022.20 1
- Right angle clamp 37697.00 1
- Universal clamp 37715.00 1
- Temperature meter digital, 4-2 13617.93 1
- Temperature probe, Pt100 11759.01 1
- Power supply, universal 13500.93 1
- Connecting cord, l = 750 mm, black 07362.05 2
- Steel cylinder oxygen, 2 l, filled 41778.00 1
- Reducing valve for oxygen 33482.00 1
- Table stand for 2 l steel cylinders 41774.00 1
- Wrench for steel cylinders 40322.00 1
- Precision balance CPA 623S (620 g/0.001 g), set with software 49224.88 1
- Precision balance CPA 6202S (6200 g/0.01 g), set with software 49226.88 1
- Weighing dishes, 80/11003 50/11003 14 mm 45019.25 1
- Mortar with pestle, 70 ml, porcelain 32603.00 1
- Pellet press for calorimeter 04403.04 1
- Graduated vessel, 1 l, with handle 36640.00 1
- Stopwatch, digital, 1/100 s 03071.01 1
- Microspoon 33393.00 1
- Wash bottle, 500 ml 33931.00 1
- Funnel, plastic, $d = 50$ mm 36890.00 1
- Scissors, straight, blunt, l = 140 mm 64625.00 1
- Iron wire, $d = 0.2$ mm, l = 100 m 06104.00 1

Benzoic acid, 100 g 30251.10 1
Naphthalene white, 250g 48299.25 1
Water, distilled, 5 l 31246.81 1

Determination of the enthalpy of combustion with a calorimetric bomb P3021401
02.15 Determination of the heat of formation for water

What you can learn about

→ 1st law of thermodynamics
→ Calorimetry
→ Enthalpy of reaction
→ Enthalpy of formation

Principle and tasks

The standard molar enthalpy of formation is defined as the heat of reaction occurring in the direct formation of one mole of the pertinent pure substance from the stable pure elements at constant pressure. For the conversion of hydrogen and oxygen to water, standard enthalpies of formation can be measured directly using calorimetry.

What you need:

- High voltage supply unit, 0-10 kV: 13670.93
- Connecting cord, 30 KV, l = 1000 mm: 07367.00
- Glass jacket: 02615.00
- Calorimeter insert for glass jacket: 02615.01
- Lid for calorimeter insert: 02615.02
- Gas syringe, 100 ml, with 3-way cock: 02617.00
- Gas syringe holder with stop: 02058.00
- Silicone tubing, d = 7 mm: 39296.00
- H-base - PASS-: 02009.55
- Support rod, l = 250 mm: 02031.00
- Support rod, l = 500 mm: 02032.00
- Support rod, l = 750 mm: 02033.00
- Right angle clamp: 37697.00
- Universal clamp: 37715.00
- Weather monitor, LCD: 87997.10
- Laboratory thermometer -10...+50 C: 38034.00
- Magnifying glass, 10 x, d = 23 mm: 64598.00
- Magnetic stirrer bar, l = 30 mm: 46299.00
- Magnet, d = 10 mm, l = 200 mm: 06311.00
- Funnel, glass, d = 55 mm: 34457.00
- Graduated vessel, 1 l, with handle: 36640.00
- Precision balance CPA 623 S (620 g/0.001 g), set with software: 49224.88
- Steel cylinder hydrogen, 2 l, filled: 41775.00
- Steel cylinder oxygen, 2 l, filled: 41778.00
- Reducing valve for hydrogen: 33484.00
- Reducing valve for oxygen: 33482.00
- Table stand for 2 l steel cylinders: 41774.00
- Wrench for steel cylinders: 40322.00
- Rubber tubing, d = 6 mm: 39282.00
- Water, distilled, 5 l: 31246.81

Determination of the heat of formation for water: P3021501
**Principle and tasks**

The standard molar enthalpy of formation is defined as the heat of reaction occurring in the direct formation of one mole of the pertinent pure substance from the stable pure elements at constant pressure. For the conversion of carbon and oxygen to CO₂, the standard enthalpies of formation can be determined using calorimetry. The enthalpies of reaction for the combustion of carbon and carbon monoxide are measured and the enthalpy of formation of CO₂ is calculated using Hess’ law.

**What you need:**

- Glass jacket
- Calorimeter insert for glass jacket
- Combustion lance for gases
- Gasometer, 1000 ml
- Retort stand, h = 750 mm
- H-base - PASS-
- Support rod, l = 250 mm
- Barrel base - PASS-
- Right angle clamp
- Universal clamp
- Magnetic stirring bar, l = 30 mm
- Magnet, d = 10 mm, l = 200 mm
- Weather monitor, LCD
- Laboratory thermometer -10... +50°C
- Magnifying glass, 10 \(\times\) , d = 23 mm
- Funnel, glass, d = 55 mm
- Graduated vessel, l = 1, with handle
- Paper, ceramic fibre 1.0 × 500 × 2000 mm
- Commercial weight, 500 g
- Stopcock, 3-way, T-shaped, glass
- Test tube GL25/8, with olive
- Glass tubes, right-angled
- Pinchcock, w = 15 mm
- Funnel for gas generator, 50 ml, GL18
- Flask, round, 1-neck, 100 ml, GL25/12
- U-tube, 2 side tubes, GL25/8
- Test tube 180 × 20 mm, PN19
- Rubber stopper, d = 22/17 mm
- Rubber stopper, d = 38/31 mm, 1 hole 15 mm
- Test tube holder, d = 22 mm
- Teclu burner, natural gas
- Safety gas tubing
- Hose clip, d = 12... 20 mm
- Lighter for natural / liquified gases

**Steel cylinder oxygen, 2 l, filled**

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<th>Item Description</th>
<th>Quantity</th>
</tr>
</thead>
<tbody>
<tr>
<td>41778.00</td>
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**Reducing valve for oxygen**

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<th>Quantity</th>
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<tbody>
<tr>
<td>33482.00</td>
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**Wrench for steel cylinders**

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</thead>
<tbody>
<tr>
<td>40322.00</td>
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**Table stand for 2 l steel cylinders**

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<tbody>
<tr>
<td>41774.00</td>
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**Hose clip, d = 8...12 mm**

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<td>40996.01</td>
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**Precision balance CPA 6235 (620 g/0.001 g), set with software**

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<th>Item Description</th>
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</thead>
<tbody>
<tr>
<td>49224.88</td>
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**Mortar with pestle, 150 ml, porcelain**

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<tbody>
<tr>
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**Scissors, straight, blunt, l = 140 mm**

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**Tweezers, straight, blunt, l = 200 mm**

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**Water jet pump**

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<td>02728.00</td>
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**Rubber tubing, d = 6 mm**

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<td>39262.00</td>
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**Protective glasses, green glass**

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**Quartz glass wool, 10 g**

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<tbody>
<tr>
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**Charcoal, small pieces, 300 g**

<table>
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<th>Quantity</th>
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<tbody>
<tr>
<td>30088.30</td>
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**Formic acid 98-100 %, 250 ml**

<table>
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</thead>
<tbody>
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<td>30021.25</td>
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**Sulphuric acid, 95-98 %, 500 ml**

<table>
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</thead>
<tbody>
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<td>30219.50</td>
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**Sodium hydroxide, flakes, 500 g**

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<td>30157.50</td>
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**Glycerol, 250 ml**

<table>
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<td>30084.25</td>
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</table>

**Water, distilled, 5 l**

<table>
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</tr>
</thead>
<tbody>
<tr>
<td>31246.81</td>
<td>1</td>
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</tbody>
</table>

**What you can learn about**

- 1st law of thermodynamics
- Hess’ law
- Calorimetry
- Enthalpy of reaction
- Enthalpy of formation

**Determination of the heat of formation for CO₂ and CO (Hess’ law)**

<table>
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<th>Quantity</th>
</tr>
</thead>
<tbody>
<tr>
<td>P3021601</td>
<td></td>
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</tbody>
</table>
Principle and tasks
The heat of reaction generated during the complete combustion of 1 kg of solid or liquid fuel is known as the calorific value $H$. In the experiment calorific value of olive oil is determined. In order to ensure complete combustion, the combustion takes place in oxygen. The heat generated during the combustion is absorbed by a glass jacket calorimeter of known heat capacity. From the temperature increase in the calorimeter the calorific value of the olive oil can be calculated.

What you can learn about
- 1st law of thermodynamics
- Enthalpy of reaction
- Enthalpy of combustion
- Calorimetry
- Heat capacity

What you need:

<table>
<thead>
<tr>
<th>Item</th>
<th>Code</th>
<th>Quantity</th>
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<tbody>
<tr>
<td>Glass jacket</td>
<td>02615.00</td>
<td>1</td>
</tr>
<tr>
<td>Calorimeter insert for glass jacket</td>
<td>02615.01</td>
<td>1</td>
</tr>
<tr>
<td>Combustion lance for gases</td>
<td>02613.00</td>
<td>1</td>
</tr>
<tr>
<td>H-base - PASS-</td>
<td>02009.55</td>
<td>1</td>
</tr>
<tr>
<td>Support Support rod, $l = 500$ mm</td>
<td>02032.00</td>
<td>1</td>
</tr>
<tr>
<td>Rubber stopper, $d = 38/31$ mm, 1 hole 15 mm</td>
<td>39260.19</td>
<td>1</td>
</tr>
<tr>
<td>Laboratory thermometer, -10...+50°C</td>
<td>38034.00</td>
<td>1</td>
</tr>
<tr>
<td>Magnet, $d = 10$ mm, $l = 200$ mm</td>
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<td>1</td>
</tr>
<tr>
<td>Magnetic stirrer bar, $l = 30$ mm</td>
<td>46299.02</td>
<td>1</td>
</tr>
<tr>
<td>Funnel, glass, $d = 55$ mm</td>
<td>34457.00</td>
<td>1</td>
</tr>
<tr>
<td>Graduated vessel, 1 l, with handle</td>
<td>36640.00</td>
<td>1</td>
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<tr>
<td>Glass tube, $d = 10/8$ mm, $l = 300$ mm</td>
<td>45125.01</td>
<td>1</td>
</tr>
<tr>
<td>Glass beaker, 50 ml, tall</td>
<td>36001.00</td>
<td>1</td>
</tr>
<tr>
<td>Precision balance CPA 6235 (620 g/0.001 g), set with software</td>
<td>49224.88</td>
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</tr>
<tr>
<td>Steel cylinder oxygen, 2 l, filled</td>
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<tr>
<td>Reducing valve for oxygen</td>
<td>33482.00</td>
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</tr>
<tr>
<td>Table stand for 2 l steel cylinders</td>
<td>41774.00</td>
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</tr>
<tr>
<td>Wrench for steel cylinders</td>
<td>40322.00</td>
<td>1</td>
</tr>
<tr>
<td>Rubber tubing, $d = 6$ mm</td>
<td>39282.00</td>
<td>2</td>
</tr>
<tr>
<td>Hose clip, $d = 8...12$ mm</td>
<td>40996.01</td>
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<td>Teclu burner, natural gas</td>
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<td>Safety gas tubing</td>
<td>39281.10</td>
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<td>Lighter for natural / liquified gases</td>
<td>38874.00</td>
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<td>Tweezers, straight, blunt, 200 mm</td>
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<tr>
<td>Scissors, straight, blunt, $l = 140$ mm</td>
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<tr>
<td>Wood splints, $l = 35$ cm, $d = 3$ mm</td>
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<td>1</td>
</tr>
<tr>
<td>Protective glasses, green glass</td>
<td>39317.00</td>
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</tr>
<tr>
<td>Glycerol, 250 ml</td>
<td>30084.25</td>
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<tr>
<td>Olive oil, pure, 100 ml</td>
<td>30177.10</td>
<td>1</td>
</tr>
<tr>
<td>Water, distilled, 5 l</td>
<td>31246.81</td>
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Determination of the calorific value for heating oil and the gross calorific value for olive oil

P3021701
Principle and tasks
The volume expansion of liquids and the linear expansion of various materials is determined as a function of temperature. In order to investigate expansion, pipes made of brass, steel, copper, aluminium and glass are clamped tight at one end, and water from a temperature controlled bath is circulated through them. The change in length at various temperatures is measured using a dilatometer. The measurement of the volume change of water is achieved using a flat-bottomed flask with a graduated upright pipe which is located in a temperature controlled bath (pycnometer).

What you can learn about
- Linear thermal expansion
- Volume expansion
- Heat capacity
- Lattice potential

What you need:
Dilatometer with clock gauge 04233.00 1
Copper tube 04231.05 1
Brass tube 04231.02 1
Iron tube 04231.03 1
Glass tube 04231.04 1
Aluminium tube 04231.06 1
Retort stand, h = 750 mm 37694.00 1
Right angle clamp 37697.00 1
Universal clamp 37715.00 1
Precision balance CPA 623 S (620 g/0.001 g), set with software 49224.88 1
Syringe, 1 ml 02593.03 1
Cannula, 0.6 x 60 mm 02599.04 1
Glass beaker, 100 ml, tall 36002.00 1
Flask, flat bottom, 100 ml, IGJ 19/26 35811.01 1
Measuring tube, l = 300 mm, IGJ 19/26 03024.00 1
Immersion thermostat, 100°C 08492.93 1
Accessory set for immersion thermostat 08492.01 1
Bath for thermostat, 6 l, Makrolon 08487.01 1
Rubber tubing, d = 6 mm 39282.00 4
Hose clip, d = 8…12 mm 40996.01 6
Wash bottle, 500 ml 33931.00 1
Water, distilled, 5 l 31246.81 1

Dilatometry 02.18

Length change Δl of the copper pipe as a function of temperature.

Volume of water as a function of temperature.
Contents
LEC 03.01 Evaporative equilibrium
LEC 03.02 Vapour pressure of mixtures of ideal fluids
LEC 03.04 Boiling point diagram of a binary mixture
LEC 03.05 Solubility diagram of two partially miscible liquids
LEC 03.06 Miscibility gap in a ternary system
LEC 03.07 Distribution equilibrium
LEC 03.08 Solubility product
LEC 03.09 Dissociation equilibrium
LEC 03.10 Complex formation equilibrium
LEC 03.11 Dissociation constants
LEC 03.13 The melting point of a binary system
LEC 03.14 Law of integral ratio of volumes
LEC 03.15 Determination of the number of theoretical trays in a distillation column
LEC 03.16 Fractional distillation with the bubble tray column
LEC 03.17 Chromatographic separation procedures: gas chromatography
03.01 Evaporative equilibrium

Principle and tasks
For each temperature a specific vapour pressure establishes above a liquid. If the external pressure is lowered by drawing off the gas phase, the equilibrium re-establishes itself through evaporation of a part of the liquid phase.

The enthalpy of vaporisation of acetone is determined by measuring the vapour pressure at different temperatures.

What you need:

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<tr>
<th>Item</th>
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<tr>
<td>Pressure sensor</td>
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</tr>
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<td>Tubing adapter, 3-5 / 6-10 mm</td>
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<tr>
<td>Silicone tubing, ( d = 7 ) mm</td>
<td>39296.00</td>
<td>1</td>
</tr>
<tr>
<td>Silicone tubing, ( d = 2 ) mm</td>
<td>39298.00</td>
<td>1</td>
</tr>
<tr>
<td>Retort stand, ( h = 750 ) mm</td>
<td>37694.00</td>
<td>2</td>
</tr>
<tr>
<td>Right angle clamp</td>
<td>37697.00</td>
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</tr>
<tr>
<td>Universal clamp</td>
<td>37715.00</td>
<td>3</td>
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<tr>
<td>Round flask, 100 ml, 1 × GL 25/8, 2 × GL 25/12</td>
<td>35677.15</td>
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<td>Jointing for connecting caps, GL 25/8</td>
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<td>One-way stopcock, straight</td>
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<tr>
<td>Water jet pump</td>
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<tr>
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<td>Graduated cylinder, 50 ml</td>
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<td>Funnel, glass, ( d = 55 ) mm</td>
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<td>Glass rod, ( d = 8 ) mm, ( l = 8 ) mm</td>
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<td>Graduated vessel with handle, 1 l</td>
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<tr>
<td>Pasteur pipettes</td>
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</tr>
<tr>
<td>Rubber bulbs</td>
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<td>1</td>
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<tr>
<td>Acetone, 250 ml</td>
<td>30004.25</td>
<td>1</td>
</tr>
<tr>
<td>Glycerine, 250 ml</td>
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<td>Sodium chloride, chem. pure, 500 g</td>
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<td>1</td>
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<tr>
<td>Ice</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Water</td>
<td></td>
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</tbody>
</table>

Evaporative equilibrium P3030101

Plot of the logarithm of the vapour pressure against the reciprocal temperature.

What you can learn about
→ Vapour pressure
→ Enthalpy of vaporization
→ Clausius-Clapeyron equation
→ Trouton-Pictet rule
**Vapour pressure of mixtures of ideal fluids 03.02**

**Principle and tasks**
According to Raoult’s law, the vapour pressures of ideal solutions is the sum of the partial pressures of the individual components. Mixtures of benzene and toluene show an almost ideal behaviour. The vapour pressures of benzene, toluene and different compositions of them are measured with a digital manometer under isothermal conditions.

**What you can learn about**
- Vapour pressure
- Raoult’s law
- Partial pressure

**What you need:**

<table>
<thead>
<tr>
<th>Item Description</th>
<th>Part Number</th>
<th>Quantity</th>
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</thead>
<tbody>
<tr>
<td>Barometer / Manometer, hand-held</td>
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<tr>
<td>Pressure sensor</td>
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<tr>
<td>Tubing adapter, 3-5 / 6-10 mm</td>
<td>47517.01</td>
<td>1</td>
</tr>
<tr>
<td>Silicone tubing, $d = 7$ mm</td>
<td>39296.00</td>
<td>1</td>
</tr>
<tr>
<td>Silicone tubing, $d = 2$ mm</td>
<td>39298.00</td>
<td>1</td>
</tr>
<tr>
<td>Immersion thermostat, 100°C</td>
<td>08492.93</td>
<td>1</td>
</tr>
<tr>
<td>Accessory set for immersion thermostat</td>
<td>08492.01</td>
<td>1</td>
</tr>
<tr>
<td>Bath for thermostat, 6 l, Makrolon</td>
<td>08487.02</td>
<td>1</td>
</tr>
<tr>
<td>H-base - PASS-</td>
<td>02009.55</td>
<td>1</td>
</tr>
<tr>
<td>Support rod, l = 750 mm</td>
<td>02033.00</td>
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<tr>
<td>Retort stand, h = 750 mm</td>
<td>37694.00</td>
<td>1</td>
</tr>
<tr>
<td>Right angle clamp</td>
<td>37697.00</td>
<td>4</td>
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<tr>
<td>Universal clamp</td>
<td>37715.00</td>
<td>4</td>
</tr>
<tr>
<td>Round bottom flask, 100 ml, 2-neck, IGJ 19/26</td>
<td>35842.05</td>
<td>3</td>
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<tr>
<td>Stopper, IGJ 19/26, glass, clear</td>
<td>41252.10</td>
<td>1</td>
</tr>
<tr>
<td>Connecting tube, IGJ 19/26 - GL 18/8</td>
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<tr>
<td>Glass tube, right-angled, 85+60 mm</td>
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<tr>
<td>Glass tube, right-angled, 230+55 mm</td>
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<td>Stopcock, 3-way, T-shaped, capillary</td>
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<tr>
<td>Security bottle with manometer</td>
<td>34170.88</td>
<td>1</td>
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<tr>
<td>Water jet pump</td>
<td>02728.00</td>
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<td>Volumetric pipette, 50 ml</td>
<td>36581.00</td>
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<td>Volumetric pipette, 25 ml</td>
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<td>Pipettor</td>
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<td>Pipette dish</td>
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<tr>
<td>Rubber tubing, $d = 6$ mm</td>
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<tr>
<td>Hose clip, $d = 8...12$ mm</td>
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<td>Benzene, pure, 500 ml</td>
<td>30038.50</td>
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<td>Toluene, pure, 250 ml</td>
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</tr>
<tr>
<td>Silicone grease, 100 g, 1 tube</td>
<td>31863.10</td>
<td>1</td>
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</tbody>
</table>

**Vapour pressure curve of the benzene/toluene system.**

**Vapour pressure of mixtures of ideal fluids**

---

**What you can learn about**

- Vapour pressure
- Raoult’s law
- Partial pressure
03.04 Boiling point diagram of a binary mixture

What you need:

- Abbe refractometer 35912.00 1
- Temperature meter, digital, 4-2 13617.93 1
- Temperature probe, immersion type, Pt100 11759.01 1
- Protective sleeve for immersion probe 11762.05 1
- Heating hood, 100 ml 49541.93 1
- Clamp for heating mantle 49557.01 1
- Power regulator 32288.93 1
- Immersion thermostat, 100°C 08492.93 1
- Accessory set for immersion thermostat 08492.01 1
- Bath for thermostat, 6 l, Makrolon 08487.02 1
- Retort stand, h = 750 mm 37694.00 2
- Right angle clamp 37697.00 2
- Universal clamp 37715.00 2
- Burette clamp, roller mounting 37720.00 1
- Round bottom flask, 100 ml, 2-neck, IGJ 19/26 35842.05 2
- Dimroth cooler, IGJ 19/26 35816.05 1
- Column head, IGJ 19 35919.01 1
- Stopper, IGJ 19/26, glass, clear 41252.10 1
- Clamp for ground joint, plastic, IGJ 19 43614.00 3
- Teflon collar, IGJ 19 43616.00 1
- Rubber tubing, d = 6 mm 39282.00 5
- Hose clip, d = 8…12 mm 40996.01 10
- Burette, 50 ml, lateral stopcock, Schellbach lines 36513.01 2
- Erlenmeyer flask, 100 ml, narrow neck 36118.00 11
- Rubber stopper, 24/30 mm 39256.00 11
- Glass beaker, 100 ml, tall 36002.00 2
- Pasteur pipettes 36590.00 1
- Rubber bulbs 39275.03 1
- Funnel, glass, d = 55 mm 34457.00 3
- Beads, 200 g 36937.20 1
- Water jet pump 02728.00 1
- Laboratory pencil, waterproof 38711.00 1
- Methanol, 500 ml 30142.50 1
- Chloroform, pure, 250 ml 48045.25 1
- Glycerine, 250 ml 30084.25 1

Boiling point diagram of a binary mixture P3030401

What you can learn about
- Fundamentals of distillation
- Equilibrium diagram
- Chemical potential
- Raoult’s law

Principle and tasks

A boiling point diagram shows the boiling points of a binary mixture as a function of the vapour/liquid equilibrium of the mixture at constant pressure.

The boiling points of various mixtures of methanol and chloroform are measured and the composition of the liquid phases are determined using refractometry and a calibration curve.
Principle and tasks
A number of different phenol/water mixtures are prepared and heated until complete miscibility is achieved. Subsequently the mixtures are cooled down and the temperatures are recorded at which turbidity, as a result of separation, becomes visible. Plots of the separation temperature versus the composition of the mixtures show a separation curve.

What you need:
- Immersion thermostat, 100°C 08492.93 1
- Accessory set for immersion thermostat 08492.01 1
- Bath for thermostat, 6 l, Makrolon 08487.02 1
- Rubber tubing, d = 6 mm 39282.00 3
- Hose clip, d = 8…12 mm 40996.01 4
- Rack for 20 test tubes 08487.03 1
- Test tubes, 16/160 mm 37656.10 1
- Rubber stopper, 14/18 mm 39254.00 7
- Retort stand, h = 750 mm 37694.00 1
- Burette clamp, roller mounting 37720.00 1
- Burette, 10 ml, straight stopcock, Schellbach lines 47152.01 1
- Glass beaker, 150 ml, tall 36003.00 1
- Funnel, glass, d = 55 mm 34457.00 1
- Precision balance CPA 623S (620 g/0.001 g), set with software 49224.88 1
- Wash bottle, 500 ml 33931.00 1
- Spoon 33398.00 1
- Pasteur pipettes 36590.00 1
- Rubber bulbs 39275.03 1
- Laboratory pencil, waterproof 38711.00 1
- Phenol, loose crystals, pure, 100 g 30185.1 0 1
- Distilled water, 5 l 31246.81 1

Solubility diagram of two partially miscible liquids

Solubility diagram of the phenol/water system.
03.06 Miscibility gap in a ternary system

What you need:

<table>
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<tr>
<th>Item</th>
<th>Code</th>
<th>Quantity</th>
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<tr>
<td>Accessory set for immersion thermostat</td>
<td>08492.01</td>
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<tr>
<td>Bath for thermostat, 6 l, Makrolon</td>
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<tr>
<td>Rubber tubing, d = 6 mm</td>
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</tr>
<tr>
<td>Hose clip, d = 8...12 mm</td>
<td>40996.01</td>
<td>4</td>
</tr>
<tr>
<td>Rack for 20 test tubes</td>
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<td>1</td>
</tr>
<tr>
<td>Test tubes, 16/160 mm</td>
<td>37656.10</td>
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<td>Rubber stopper, 18/20 mm</td>
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</tr>
<tr>
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<tr>
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</tr>
<tr>
<td>Pasteur pipettes</td>
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</tr>
<tr>
<td>Rubber bulbs</td>
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</tr>
<tr>
<td>Laboratory pencil, waterproof</td>
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<tr>
<td>Chloroform, pure, 250 ml</td>
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<tr>
<td>Distilled water, 5 l</td>
<td>31246.81</td>
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What you need:

<table>
<thead>
<tr>
<th>Item</th>
<th>Code</th>
<th>Quantity</th>
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</thead>
<tbody>
<tr>
<td>Acetic acid, 99...100%, 1000 ml</td>
<td>31301.70</td>
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</tr>
<tr>
<td>Chloroform, pure, 250 ml</td>
<td>48045.25</td>
<td>1</td>
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<tr>
<td>Distilled water, 5 l</td>
<td>31246.81</td>
<td>1</td>
</tr>
</tbody>
</table>

What you can learn about

- Three component system
- Miscibility gap
- Phase diagram
- Gibb’s phase law

Principle and tasks

A number of complete miscible two component mixtures are prepared to investigate the three component - acetic acid/chloroform/water system. These mixtures are titrated with the third component until a two phase system is formed causing turbidity. The phase diagram for the three component system is plotted in a triangular diagram.
**What you need:**

<table>
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<tr>
<th>Item</th>
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<td>Cells for spectrophotometer</td>
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<td>Precision balance CPA 623 S (620 g/0.001 g), set with software</td>
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<tr>
<td>Weighing dishes, 80 × 50 × 14 mm</td>
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<tr>
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</tr>
<tr>
<td>Support ring, d = 80 mm</td>
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</tr>
<tr>
<td>Right angle clamp</td>
<td>37697.00</td>
<td>2</td>
</tr>
<tr>
<td>Erlenmeyer flask, 1000 ml, narrow neck</td>
<td>36122.00</td>
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</tr>
<tr>
<td>Erlenmeyer flask, 500 ml, narrow neck</td>
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<td>Rubber stopper, 36/44 mm</td>
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<td>1</td>
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<tr>
<td>Rubber stopper, 29/35 mm</td>
<td>39259.00</td>
<td>2</td>
</tr>
<tr>
<td>Volumetric flask, 50 ml, IGJ 12/21</td>
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</tr>
<tr>
<td>Volumetric flask, 250 ml, IGJ 14/23</td>
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</tr>
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<td>Funnel, glass, d₁ = 55 mm</td>
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</tr>
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<tr>
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</tr>
<tr>
<td>Volumetric pipette, 20 ml</td>
<td>36579.00</td>
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<td>Pipette dish</td>
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</tr>
<tr>
<td>Pipettor</td>
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</tr>
<tr>
<td>Glass beaker, 100 ml, tall</td>
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</tr>
<tr>
<td>Pasteur pipettes</td>
<td>36590.00</td>
<td>1</td>
</tr>
<tr>
<td>Rubber bulbs</td>
<td>39275.03</td>
<td>1</td>
</tr>
<tr>
<td>Laboratory thermometer</td>
<td>38034.00</td>
<td>1</td>
</tr>
<tr>
<td>Wash bottle, 500 ml</td>
<td>33931.00</td>
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<tr>
<td>trans-Azobenzene, 100 g</td>
<td>31064.10</td>
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<tr>
<td>Acetonitrile, 1000 ml</td>
<td>30000.70</td>
<td>1</td>
</tr>
<tr>
<td>n-Heptane, 250 ml</td>
<td>31366.25</td>
<td>1</td>
</tr>
</tbody>
</table>

**What you can learn about**

- Phase equilibrium
- Distribution and extraction
- Nernst’s distribution law
- Lambert-Beer law
- Photometry

**Principle and tasks**

At constant temperature and pressure, a dissolved substance will distribute itself between two immiscible liquids at a constant ratio of concentration. The equilibrium concentrations in both phases can be determined for substances sensitive to UV light or dyed substances by photometric measurements in the near UV or visible light regions of the electromagnetic spectrum.

**Relationship between extinction E and concentration Cₐ for trans-azobenzene in acetonitrile at λ = 400 nm (▲), λ = 420 nm (●) and λ = 440 nm (■).**

**Section of the UV/VIS spectrum of trans-azobenzene in acetonitrile before (◇), after single (×) and after repeated extraction (▽) for total volume of n-heptane.**
03.08 Solubility product

**Principle and tasks**
The solubility of poorly soluble salts is expressed as the solubility product, i.e. the product of the concentrations of cations and anions in the solution, which are in equilibrium with the solid salt. These concentrations can be determined via conductivity measurements.

**What you can learn about**
- Solubility
- Dissociation
- Ionic conductivity
- Ion mobility

---

**What you need:**

<table>
<thead>
<tr>
<th>Item Description</th>
<th>Code</th>
<th>Quantity</th>
</tr>
</thead>
<tbody>
<tr>
<td>Digital conductivity meter, demo</td>
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<td>1</td>
</tr>
<tr>
<td>Conductivity / temperature probe</td>
<td>13701.01</td>
<td>1</td>
</tr>
<tr>
<td>Immersion thermostat, 100°C</td>
<td>08492.93</td>
<td>1</td>
</tr>
<tr>
<td>Accessory set for immersion thermostat</td>
<td>08492.01</td>
<td>1</td>
</tr>
<tr>
<td>Bath for thermostat, 6 l, Makrolon</td>
<td>08487.02</td>
<td>1</td>
</tr>
<tr>
<td>Rubber tubing, ( d = 6 ) mm</td>
<td>39282.00</td>
<td>3</td>
</tr>
<tr>
<td>Hose clip, ( d = 8 \ldots 12 ) mm</td>
<td>40996.01</td>
<td>4</td>
</tr>
<tr>
<td>Precision balance CPA 623 S (620 g/0.001 g), set with software</td>
<td>49224.88</td>
<td>1</td>
</tr>
<tr>
<td>Weighing dishes, 80 ( \times 50 \times ) 14 mm</td>
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<td>1</td>
</tr>
<tr>
<td>Magnetic stirrer, mini</td>
<td>47334.93</td>
<td>1</td>
</tr>
<tr>
<td>Magnetic stirrer bar, ( l = 30 ) mm</td>
<td>46299.02</td>
<td>2</td>
</tr>
<tr>
<td>Mortar with pestle</td>
<td>32603.00</td>
<td>2</td>
</tr>
<tr>
<td>Spoon</td>
<td>33398.00</td>
<td>1</td>
</tr>
<tr>
<td>Retort stand, ( h = 750 ) mm</td>
<td>37694.00</td>
<td>2</td>
</tr>
<tr>
<td>Right angle clamp</td>
<td>37697.00</td>
<td>3</td>
</tr>
<tr>
<td>Universal clamp</td>
<td>37715.00</td>
<td>3</td>
</tr>
<tr>
<td>Erlenmeyer flask, 100 ml, narrow neck</td>
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<td>Powder funnel, ( d = 65 ) mm</td>
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<tr>
<td>Wash bottle, 500 ml</td>
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<tr>
<td>Calcium carbonate, powder, 500 g</td>
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<td>Calcium fluoride, 100 g</td>
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<td>Conductivity standard solution</td>
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</tr>
<tr>
<td>Water, distilled, 5 l</td>
<td>31246.81</td>
<td>1</td>
</tr>
</tbody>
</table>

**Solubility product**

P3030801
Carboxylic acids are potential electrolytes, which exist in a weakly dissociated condition in aqueous solutions. The location of the dissociation equilibrium is quantitatively described by the $K_a$ or $pK_a$ value, which can be determined with potentiometric measurements.
03.10 Complex formation equilibrium

Principle and tasks

Many metals, in particular transition elements, can form complexes with charged or neutral ligands. The stability of these complexes is described by the complex formation constant. In the case of the silver amine complex, the complex formation constant can be determined with a precipitation titration from a silver salt solution.

What you need:

- Burette, 25 ml, lateral stopcock, Schellbach lines 36506.01 1
- Burette clamp, roller mounting 37720.00 1
- Retort stand, h = 750 mm 37694.00 1
- Graduated pipette, 25 ml 36602.00 1
- Volumetric pipette, 5 ml 36577.00 1
- Volumetric pipette, 10 ml 36578.00 1
- Volumetric pipette, 20 ml 36579.00 2
- Pipettor 36592.00 1
- Pipette dish 36589.00 1
- Erlenmeyer flask, 250 ml, wide neck 36134.00 5
- Volumetric flask, 100 ml, IGJ 12/21 36548.00 4
- Volumetric flask, 250 ml, IGJ 14/23 36550.00 3
- Funnel, glass, d0 = 55 mm 34457.00 3
- Precision balance CPA 623S (620 g/0.001 g), set with software 49224.88 1
- Weighing dishes, 80 x 50 x14 mm 45019.25 1
- Magnetic stirrer, mini 47334.93 1
- Magnetic stirrer bar, l = 30 mm 46299.02 1
- Spoon 33398.00 1
- Pasteur pipettes 36590.00 1
- Rubber bulbs 39275.03 1
- Wash bottle, 500 ml 33931.00 1
- Silver nitrate, cryst., 15 g 30222.00 1
- Potassium bromide, 100 g 30258.10 1
- Ammonia solution, 25%, 1000 ml 30933.70 1
- Water, distilled, 5 l 31246.81 1

What you can learn about:

- Complex formation
- Chemical equilibrium
- Equilibrium constant

Complex formation equilibrium graph:

- Determination of the number of ligands bound in the complex.
Principle and tasks

Thymol blue, a colour indicator, is partially dissociated as a weak acid in aqueous solution, whereby the ionised and non-ionised forms demonstrate absorption maxima at different wavelengths in the visible region of the electromagnetic spectrum. The $K_a$ or $pK_a$ value of the indicators, which characterise the position of the dissociation equilibrium, can thus be advantageously determined using photometric measurements in the visible spectral region.

What you need:

- Spectrophotometer 190 - 1100 nm
- Cells for spectrophotometer
- Precision balance CPA 623S (620 g/0.001 g), set with software
- Weighing dishes, 80 x 50 x 14 mm
- Microspoon
- Volumetric flask, 50 ml, IGJ 12/21
- Volumetric flask, 1000 ml, IGJ 24/29
- Funnel, glass, d = 55 mm
- Volumetric pipette, 1 ml
- Volumetric pipette, 5 ml
- Volumetric pipette, 10 ml
- Pipette dish
- Pipettor
- Graduated cylinder, 250 ml
- Glass beaker, 150 ml, tall
- Pasteur pipettes
- Rubber bulbs
- Laboratory thermometer
- Wash bottle, 500 ml
- Buffer solution pH 9.00, 1000 ml
- Thymol blue, indicator, powder, 5 g
- Hydrochloric acid, 0.1 M, 1000 ml
- Sodium hydroxide, 0.1 M, 1000 ml
- Ethanol, absolute, 500 ml
- Water, distilled, 5 l

Dissociation constants 03.11

- $K_a$ or $pK_a$ value
- Henderson-Hasselbalch equation
- Lambert-Beer law
- Photometry

What you can learn about

- Strong and weak acids
- Dissociation constants and $pK_a$ value
- Henderson-Hasselbalch equation
- Lambert-Beer law
- Photometry

Absorption spectra of thymol blue at pH = 4 (□), pH = 9 (△) and pH = 11 (○).
03.13 The melting point of a binary system

**What you need:**

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<tr>
<th>Experiment</th>
<th>Description</th>
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<th>Unit</th>
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<td>Cobra3 Basic-Unit</td>
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<tr>
<td>P3031340</td>
<td>Cobra3 Chem-Unit</td>
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<td></td>
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<td>3887.40</td>
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<td>48299.25</td>
<td>Naphthalene, white, 250 g</td>
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<tr>
<td>31113.10</td>
<td>Biphenyl, 100 g</td>
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<td>31311.70</td>
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<tr>
<td>49224.88</td>
<td>Teclu burner, natural gas</td>
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<tr>
<td>49224.88</td>
<td>PC, Windows® XP or higher</td>
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</table>

**What you can learn about**

- Melting point
- Binary system
- Eutectic mixture
- Gibbs’ phase law

**Principle and tasks**

In plotting the cooling curves of binary mixtures one determines the temperatures of melting and solidification of specimens with differing molar fractions of the two components. These results are entered in a temperature versus concentration diagram. The composition of the eutectic mixture and its melting point is determined from the melting point diagram.

**Cooling curve of a mixture of naphthalene and biphenyl.**

**The melting point of a binary system**

P3031311/40
Principle and tasks
According to Gay-Lussac’s law of chemical volumes, gases react in volume ratios which are whole numbers. The volume ratio for the conversion of hydrogen with oxygen to water is experimentally determined by burning gas mixtures of different compositions and measuring the resulting gas volume.

What you need:
- Law of constant proportions
- Avogadro’s law
- General equation of state for ideal gases
- Gay-Lussac’s law

<table>
<thead>
<tr>
<th>Item</th>
<th>Quantity</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>Slow eudiometer</td>
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<tr>
<td>Glass jacket</td>
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<tr>
<td>Heating apparatus</td>
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<td>Power regulator</td>
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<td>Immersion probe, NiCr-Ni</td>
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<td>H-base - PASS-</td>
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<tr>
<td>Universal clamp</td>
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</tr>
<tr>
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</tr>
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<td>Syringe, 50 ml</td>
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<td>Gas bar</td>
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<td>Graduated vessel, with handle</td>
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</tr>
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<td>Reduction valve for hydrogen</td>
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<tr>
<td>Reduction valve for oxygen</td>
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</tr>
<tr>
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<tr>
<td>Steel cylinder, oxygen, 2 l, filled</td>
<td>41778.00</td>
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<td>Table stand for 2 l steel cylinders</td>
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<td>Wrench for steel cylinder</td>
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<tr>
<td>Silicone fluid for heating bath, 500 ml</td>
<td>31849.50</td>
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</tr>
</tbody>
</table>

Law of integral ratio of volumes

dependence of the final volume \( V_f \) reduced to room temperature from the initial volume \( V_i \) of hydrogen-oxygen mixtures of different composition.
03.15 Determination of the number of theoretical trays in a distillation column

**What you need:**

<table>
<thead>
<tr>
<th>Item</th>
<th>Code</th>
<th>Qty</th>
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<td>Set rectification plant</td>
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<td>Set data acquisition for set rectification plant</td>
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<td>Immersion thermostat C10</td>
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</tr>
<tr>
<td>Accessory set for C10 thermostat</td>
<td>08492.01</td>
<td>1</td>
</tr>
<tr>
<td>Bath for thermostat, Makrolon</td>
<td>08487.02</td>
<td>1</td>
</tr>
<tr>
<td>Rubber tubing, i.d. = 6 mm</td>
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<td>4</td>
</tr>
<tr>
<td>Rubber caps, 10 pcs</td>
<td>39275.03</td>
<td>1</td>
</tr>
<tr>
<td>Pasteur pipettes, 250 pcs</td>
<td>36590.00</td>
<td>1</td>
</tr>
<tr>
<td>Set of Precision Balance Sartorius CPA 623S and measure software balances</td>
<td>49224.88</td>
<td>1</td>
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<td>Graduated cylinder 1000 ml</td>
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</tr>
<tr>
<td>Funnel, glass, top diameter 150 mm</td>
<td>34461.00</td>
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</tr>
<tr>
<td>Stop clock, demonstration, diameter 13 cm</td>
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</tr>
<tr>
<td>Boiling Stones, 200 g</td>
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<td>n-Heptane, 1000 ml</td>
<td>31366.70</td>
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</tr>
<tr>
<td>Methylcyclohexane, 1 l</td>
<td>31566.70</td>
<td>3</td>
</tr>
<tr>
<td>Water, distilled, 5 l</td>
<td>31246.81</td>
<td>2</td>
</tr>
</tbody>
</table>

**Determination of the number of theoretical trays in a distillation column**

**What you can learn about**

- Bubble tray column
- Number of theoretical trays
- Rectification
- Raoult’s law
- Boiling-point diagram

**Principle and tasks**

The separation power of a rectification column can be determined with an appropriate binary mixture, whose equilibrium composition is measured in the distillation flask and in the domed glass head of the distillation apparatus. The number of theoretical trays can be numerically or graphically obtained from the measured values.

Equilibrium diagram.
Fractional distillation with the bubble tray column

Principle and tasks

In countercurrent distillation (rectification) using a column, the rising vapour can enter into interactions with the condensate. In this manner, a fractional distillation, i.e. a distillation in several steps for the separation of substances with similar boiling points, can be performed in a single apparatus. If bubble tray columns are used condensate can be removed from the individual bubble trays. The sump product, the head products and the condensates of both trays are examined and compared gas chromatographically.

Table stand for 2 l gas cylinder
Reducing valve for helium
Wrench for steel cylinders
Immersion thermostat, 100°C
Accessory set for immersion thermostat
Bath for thermostat, 6 l, Makrolon
Rubber tubing, vacuum, d = 6 mm
Rubber tubing, d = 6 mm
Hose clip, d = 12…20 mm
Hose clip, d = 8…12 mm
Precision balance CPA 623 S (620 g/0.001 g), set with software
Round bottom flask, 500 ml, IGJ 29/32
Adapter, IGJ 29 to GL 18/8
Ground joint collar, IGJ 29
Glass stopper, IGJ 29/32
Trough, 150 × 150 × 65 mm
Water jet pump
Security bottle with manometer
Spoon with spatula end, I = 150 mm
Funnel, glass, d = 55 mm
Funnel, glass, d = 80 mm
Snap-cap vials
Pasteur pipettes
Rubber bulbs
Graduated cylinder, 100 ml
Glass beaker, 150 ml, tall
Glass beaker, 250 ml, tall
Stirring rod, glass
Laboratory pencil, waterproof
Beads, 200 g
Quartz glass wool, 10 g
Chromosorb, PAW, 80/100 mesh, 20 g
Dinonylphthalate, 100 ml
Acetone, 250 ml
n-Pentane, 250 ml
n-Hexane, 100 ml
n-Heptane, 250 ml
Water, distilled, 5 l
Soap solution + Drying oven + PC, Windows 95 or higher

What you need:

Cobra3 Chem-Unit 12153.00 1
Power supply 12V/2A 12151.99 1
Data cable, RS232 14520.61 1
Software Cobra3 Chem-Unit 13615.05 3
Temperature probe, Pt1000 12123.00 1
Protective sleeve for temperature probe, l = 160 mm 1
Heating hood, 250 ml 49542.93 1
Support clamp for heating hood 49557.01 1
Power regulator 32288.93 1
H-base -PASS- 02009.55 2
Support rod, l = 1000 mm 02034.00 2
Support rod, l = 750 mm 02033.00 2
Support rod, l = 250 mm 02031.00 1
Retort stand, h = 500 mm 37692.00 1
Right angle clamp 37697.00 1
Universal clamp 37691.00 1
Bubble tray column, GL25/12 35914.15 1
Round bottom flask, two-necked, 250 ml, GL 25/12, GL 18/8 35843.15 1
Adapter, IGJ 19 / GL tube d = 12 mm 35816.05 1
Column head with stopcock, IGJ 19 34880.01 1
Dropping funnel with stopcock, 50 ml, GL 18 35862.00 1
Connecting caps, GL18 35800.05 1
Gasket for GL 18, 8 mm hole 43617.00 1
Ground joint collar, PTFE, IGJ 19 43614.00 2
Ground joint clamp, IGJ 19 43616.00 1
Control unit for gas chromatography 36670.99 1
Measuring probe for gas chromatography 36671.00 1
Glass jacket 02615.00 1
Gas separation column 36670.00 1
Rubber caps 02615.03 1
Glass tube, straight, l = 80 mm 36701.65 1
Soap bubble flow meter 36665.00 1
Microfilter syringe, 10 ml 02607.00 1
Connecting cable, l = 250 mm, red 07360.01 1
Connecting cable, l = 250 mm, blue 07360.04 1
Laboratory thermometer, -10…+100°C 38056.00 1
Stop watch, digital, 1/100 s 03071.01 1
Steel cylinder, helium, 2 l, filled 41776.00 1

What you can learn about:

− Bubble tray column
− Rectification
− Continuous and discontinuous distillation
− Gas chromatography

Fractional distillation with the bubble tray column

P3031640
03.17 Chromatographic separation procedures: gas chromatography

What you need:

Cobra3 Chem-Unit 12153.00 1
Power supply 12 V/2 A 12151.99 1
Data cable, RSZ32 14602.00 1
Software Cobra3 Chem-Unit 14520.61 1
Connecting cable, l = 250 mm, red 07360.01 1
Connecting cable, l = 250 mm, blue 07360.04 1
Control unit for gas chromatography 36670.99 1
Measuring probe for gas chromatography 36670.10 1
Glass jacket 02615.00 1
Gas separation column 36670.00 1
Rubber caps 02615.03 1
Soap bubble flow meter 36675.00 1
H-base - PASS- 02009.55 1
Support rod, l = 750 mm 37692.00 2
Retort stand, h = 500 mm 37692.00 1
Right angle clamp 37715.00 6
Universal clamp 37715.00 6
Microliter syringe, 10 ml 02607.00 1
Syringe, 1 ml 02593.03 1
Cannula, 0.45 mm × 12 mm 02598.04 1
Glass tube, straight, l = 80 mm 36701.65 1
Laboratory thermometer, -10...+100°C 38056.00 1
Stop watch, digital, 1/100 s 03071.01 1
Steel cylinder, helium, 2 l, filled 41776.00 1
Table stand for 2 l gas cylinder 37692.00 1
Reducing valve for helium 41774.00 1
Wrench for steel cylinders 39282.00 6
Hose clip, d = 6 mm 40996.01 7
Hose clip, d = 12...20 mm 40995.00 2
Gas bar 40466.00 2
Precision balance CPA 623S (620 g/0.001 g), set with software 49224.88 1
Round bottom flask, 500 ml, IJG 29/32 35862.00 1
Adapter, IJG 29 to GL 18/8 35678.02 1
Ground joint collar, IJG 29 43617.00 1
Glass stopper, IJG 29/32 41256.10 1
Trough, 150 × 150 × 65 mm 33928.00 1
Water jet pump 02728.00 1
Security bottle with manometer 34170.88 1

What you can learn about:

- Chromatography
- Chromatogram
- Thermal conductivity detector
- Nernst’s law of distribution
- Number of theoretical trays

Chemical equilibrium

Principle and tasks

Chromatographic procedures allow a separation of substance mixtures with the aid of a stationary separation phase and a mobile phase. In gas chromatography the mobile phase is a gas which transports the substance through the separation column at a constant flow rate. The establishment of equilibria between the stationary phase and the different substances results in different migration rates of the individual components. At the end of the column a thermal conductivity cell detects the different substances on the basis of their differing thermal conductivities.

A mixture of butane gases and a two-component mixture consisting of ethanol and ethyl acetate are separated and identified chromatographically.

Spoon with spatula end, l = 150 mm 33398.00 1
Funnel, glass, d = 55 mm 34457.00 1
Snap-cap vials 33621.03 2
Pasteur pipettes 36590.00 1
Rubber bulbs 39275.03 1
Glass beaker, 150 ml, tall 36003.00 2
Laboratory pencil, waterproof 38711.00 1
Fine control valve 33499.00 1
Compressed gas, n-butane 41773.11 1
Compressed gas, iso-butane 41773.12 1
Quartz glass wool, 10 g 31773.03 1
Chromosorb, PAW, 80/100 mesh, 20 g 31246.81 1
Dinonylphthalate, 100 ml 31276.10 1
Acetone, 250 ml 30004.25 1
Ethyl alcohol, absolute, 500 ml 30008.50 1
Ethyl acetate, 250 ml 30075.25 1
Butane burner Labogaz 206 32178.00 1
Butane cartridge C 206 47535.00 1
Water, distilled, 5 l 31276.10 1
Soap solution • Drying oven • PC, Windows® XP or higher

Chromatographic separation procedures: gas chromatography

P3031740
4

Interfacial Chemistry

Contents
LEC 04.01 Determination of the surface tension of pure liquids with the bubble pressure method
LEC 04.02 Determining surface tension using the ring method (Du Nouy method)
LEC 04.03 Free films
LEC 04.04 Contact angle
LEC 04.06 Electrokinetic potential
LEC 04.07 Electrophoretic mobility
LEC 04.08 Adsorption isotherms
04.01 Determination of the surface tension of pure liquids with the bubble pressure method

**Principle and tasks**

The bubble pressure method is a procedure for the determination of surface tension which is easily performed experimentally. A capillary tube is vertically immersed in the liquid to be investigated. Then the pressure required to force a gas bubble out of the capillary is determined. The surface tension can be calculated from the pressure increase, the radius of the capillary tube and its immersion depth.

**What you need:**

<table>
<thead>
<tr>
<th>Item</th>
<th>Code</th>
<th>Quantity</th>
</tr>
</thead>
<tbody>
<tr>
<td>Lab jack, 160 × 130 mm</td>
<td>02074</td>
<td>2</td>
</tr>
<tr>
<td>U-tube pressure gauge</td>
<td>03931</td>
<td>1</td>
</tr>
<tr>
<td>Retort stand, h = 750 mm</td>
<td>37694</td>
<td>2</td>
</tr>
<tr>
<td>Right angle clamp</td>
<td>37697</td>
<td>2</td>
</tr>
<tr>
<td>Universal clamp</td>
<td>37715</td>
<td>2</td>
</tr>
<tr>
<td>Capillary tube, d = 1.5 mm, l = 450 mm</td>
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<td>Glass beaker, 250 ml, tall</td>
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<td>Pasteur pipettes</td>
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<td>Aspirator bottle, clear, 1000 ml</td>
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<td>Bottle, narrow mouth, 1000 ml, clear</td>
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<td>Stopcock, 1-way, straight, glass</td>
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<td>Glass tubes, right-angled, 230 × 55 mm</td>
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<td>Silicone tubing, d = 7 mm</td>
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<td>Rubber stopper, d = 32/26 mm, 2 holes</td>
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<td>Rubber stopper, d = 22/17 mm, 1 hole</td>
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<td>Graduated cylinder, 100 ml</td>
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<td>Vernier caliper</td>
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<td>Hydrochloric acid 37%, 1000 ml</td>
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<td>Nitric acid, 65%, 1000 ml</td>
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<td>1</td>
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<tr>
<td>Water, distilled, 5 l</td>
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<td>Ethylene glycol, 250 ml</td>
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<tr>
<td>Water, distilled, 5 l</td>
<td>31246</td>
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</tbody>
</table>

**What you can learn about**

- Interfacial surface tension
- Interfacial surface energy
- Hydrostatic pressure
- Intermolecular interactions
Determining surface tension using the ring method (Du Nouy method) 04.02

What you can learn about
- Surface energy
- Surface tension
- Adhesion
- Critical point

Principle and tasks
A molecule in a liquid is subject to forces exerted by all molecules surrounding. The resultant force acting on a molecule in a boundary layer of a liquid surface is directed towards the interior of the liquid. This force is measured on a ring shortly before a liquid film tears using a torsion meter. The surface tension is calculated from the diameter of the ring and the tear-off force. In this experiment the surface tension of olive oil and water/methanol mixtures are determined.

Temperature dependence of surface tension of olive oil.

Surface tension of water/ethanol mixtures as a function of ethanol concentration.

What you need:
- Torsion dynamometer, 0.01 N
- Surface tension measuring ring
- Retort stand, h = 500 mm
- Magnetic heating stirrer
- Electronic temperature control
- Spring balance holder
- Support rod with hole, l = 100 mm
- Support rod, l = 500 mm, M10 thread
- Magnetic stirrer bar, l = 30 mm
- Universal clamp
- Right angle clamp
- Right angle clamp -PASS-
- Crystallizing dish, 1000 ml
- Crystallizing dish, 560 ml
- Silk thread, l = 200 m
- Glass tubes, straight, l = 150 mm
- Stopcock, 1-way, straight, glass
- Silicone tubing, d_i = 6 mm
- Volumetric pipette, 10 ml
- Volumetric pipette, 20 ml
- Pipettor
- Pipette dish
- Graduated cylinder, 100 ml
- Water jet pump
- Ethyl alcohol, absolute, 500 ml
- Olive oil, pure, 100 ml
- Water, distilled, 5 l

Determining surface tension using the ring method (Du Nouy method) P3040201
04.03 Free films

**What you need:**

- Digital conductivity meter: 13701.93
- Conductivity/temperature electrode: 13701.01
- Adapter conductivity cells: 13701.02
- Platinum electrode in protective tube, l = 8mm: 45206.00
- Platinum wire, d = 0.3 mm, l = 100 mm: 31739.03
- Connecting cord, l = 500 mm, yellow: 07361.02
- H-base - PASS-: 02009.55
- Support rod, l = 500 mm: 02032.00
- Right angle clamp: 37697.00
- Universal clamp: 37715.00
- Support rod with hole, l = 100 mm: 02036.01
- Spring balance holder: 03065.20
- Slide mount: 08286.05
- Round flask, 100 ml, 3-neck, GL25 / 2 GL18: 35677.15
- Closure caps, GL25: 41221.03
- Rubber tubing, d1 = 4 mm: 39280.00
- Volumetric flask 500 ml, IGJ 19/26: 36551.00
- Funnel, glass, d0 = 55 mm: 34457.00
- Precision balance CPA 6235 (620 g/0.001 g), set with software: 49224.88
- Weighing dishes, 80 × 50 × 14 mm: 45019.25
- Glass beaker, 100 ml, tall: 36002.00
- Spoon: 33398.00
- Microspoon: 33393.00
- Wash bottle, 500 ml: 33931.00
- Pasteur pipettes: 36590.00
- Rubber bulbs: 39275.03
- Standard solution 1413 µS/ cm, 460ml: 47070.02
- Sodium chloride, 500 g: 30155.50
- Sodium dodec. hydrogen sulphate, 100 g: 31280.10
- Water, distilled, 5 l: 31246.81

**Free films**

P3040301

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**Principle and tasks**

If a platinum wire ring is drawn through an aqueous tenside solution a tubular film is formed of water, whose boundaries to the air are made up of tenside membranes. The film comprises an aqueous electrolyte solution sandwiched between two monomolecular membranes of lauryl sulphate ions. Its thickness can be estimated by measuring the conductivity, provided that the specific conductivity of the electrolyte and the geometry of the film are known.

**What you can learn about**

- Tensides
- Double membrane
- Surface tension
- Electrolyte conductivity
Principle and tasks
The edge of a drop of liquid forms a characteristic angle on a solid surface. The Wilhelmy method can be used to determine this boundary angle if the surface tension of the liquid is known. The method measures the increase in weight, which occurs when a right-angled plate with a smooth surface and known geometry is immersed into a solution.

What you can learn about
- Contact angle
- Wilhelmy equation
- Surface tension
- Wetting

What you need:
- Torsion dynamometer, 0.01 N 02416.00 1
- Dial gauge 10 / 0.01 mm 03013.00 1
- Retort stand, h = 500 mm 37692.00 2
- Lab jack, 160 × 130 mm 02074.00 1
- Right angle clamp - PASS- 02040.55 1
- Right angle clamp 37697.00 1
- Universal clamp 37715.00 1
- Microscopic slides 64691.00 1
- Glass beaker, 50 ml, tall 36001.00 1
- Scissors, straight, pointed, l = 110 mm 64623.00 1
- Wash bottle, 500 ml 33931.00 1
- Ethyl acetate, 250 ml 30075.25 1
- Water, distilled, 5 l 31246.81 1
- Scotch tape
- Thread
- Paper towels

Contact angle P3040401
04.06 Electrokinetic potential

What you need:

- Power supply, regulated, 0...600 VDC 13672.93 1
- Retort stand, h = 750 mm 37694.00 1
- Universal clamp 37715.00 2
- Right angle clamp 37697.00 2
- U tube, 2 side tubes, GL25/8 36959.15 1
- Connecting caps, GL25 41231.03 1
- Gasket for GL25, 8 mm hole 41242.03 1
- Platinum electrode in protection tube, I = 8 mm 45206.00 2
- Connecting cord, I = 750 mm, blue 07362.04 1
- Connecting cord, I = 750 mm, red 07362.01 1
- Precision manometer 03091.00 1
- Tripod base -PASS- 02002.55 1
- Glass beaker, 600 ml, tall 36006.00 1
- Glass beaker, 100 ml, tall 36002.00 1
- Stop watch, interruption type 03076.01 1
- Silicone tubing, d = 5 mm 39297.00 1
- Spoon 33398.00 1
- Precision balance CPA 623S (620 g/0.001 g), set with software 49224.88 1
- Silica gel 60, 0.2 - 0.5 mm, 1 kg 31507.70 1
- Wash bottle, 500 ml 33931.00 1
- Water, distilled, 5 l 31246.81 1

What you can learn about

- Electrochemical double layer
- Helmholtz (Smoluchowski) equation
- Electro-osmosis
- Phase boundary

Principle and tasks

At the solid-liquid interface an electrokinetic potential is formed, which results in electrokinetic phenomena. Electro-osmosis is demonstrated on a finely particulate solid suspension in water. On application of a high electrical field strength a liquid current which can be detected with the aid of a precision manometer is induced.

Dependence of the time required to produce a pressure alternation of 0.1 hPa on the applied cell voltage.
**What you can learn about**
- Molecular and colloid suspensions
- Amino acids and proteins
- Electrophoresis and electrochromatography
- Migration rate
- Electrophoretic mobility

**Principle and tasks**
Electrophoresis is a standard method of modern biochemistry. It enables the isolation and identification of ionisable molecules according to their differing migration rates in an electric field, which are due to their charges and masses. The proteins contained in egg white are separated using gel electrophoresis. By comparing the fractionated proteins with a reference mixture of proteins, their approximate molar masses are determined.

**What you need:**
- Electrophoresis chamber, vertical
- Electrophoresis power supply, 100/200 V
- Precision balance, with data output, 320 g
- Reaction vials, 1.5 ml
- Rack for reaction vials
- Microlitre pipette, 2-20 µl
- Microlitre pipette, 25-250 µl
- Disposable tips, yellow
- Graduated cylinder, 100 ml
- Graduated cylinder, 1000 ml
- Erlenmeyer flask, 1000 ml, wide neck
- Petri dish, d = 200 mm
- Glass beaker, 250 ml, short
- Pasteur pipettes
- Rubber bulbs
- Glass rod, l = 300 mm, d = 8 mm
- Ruler, l = 200 mm
- Stop clock
- Scalpel, metal handle
- Protective gloves, vinyl, medium
- Acrylamide gel, 10 %
- SDS-PAGE Standards BR, 0.2 ml
- Tris-glycine-buffer, 10×, 1000 ml
- Laemmli buffer, 30 ml
- Coomassie brilliant blue solution, 1000 ml
- Water, distilled, 5 l
- Chicken egg

**Electrophoretic mobility 04.07**

Identification and determination of the molar masses of egg white proteins.
04.08 Adsorption isotherms

**What you need:**
- Retort stand, \( h = 750 \) mm: 37694.00 2
- Burette clamp, roller mounting: 37720.00 1
- Filtration stand for 2 funnels: 33401.88 1
- Magnetic stirrer, mini: 47334.93 2
- Magnetic stirrer bar, \( l = 30 \) mm: 46299.02 2
- Separator for magnetic bars: 35680.03 1
- Precision balance CPA 6235 (620 g/0.001 g), set with software: 49224.88 1
- Burette 50 ml, lateral stopcock: 36513.01 1
- Volumetric flask 1000 ml, IGJ 24/29: 36552.00 1
- Volumetric flask 250 ml, IGJ 14/23: 36550.00 6
- Volumetric pipette, 10 ml: 36578.00 1
- Volumetric pipette, 25 ml: 36580.00 1
- Volumetric pipette, 50 ml: 36581.00 1
- Volumetric pipette, 100 ml: 36582.00 1
- Graduated pipette, 25 ml: 36602.00 1
- Pipetor: 36592.00 1
- Pipette dish: 36589.00 1
- Erlenmeyer IGJ 29/32, 250 ml: 46126.00 6
- Stopper, PP, for IGJ 29/32: 47508.00 6
- Erlenmeyer flask, wide neck, 250 ml: 36134.00 7
- Glass beaker, 100 ml, tall: 36002.00 7
- Funnel, glass, \( d_o = 55 \) mm: 34457.00 7
- Circular filters, \( d = 90 \) mm: 32977.03 1
- Pasteur pipettes: 36590.00 1
- Rubber bulbs: 39275.03 1
- Spoon: 33398.00 2
- Wash bottle, 500 ml: 33931.00 1
- Citric acid, 250 g: 30063.25 1
- Caustic soda solution, 1.0 M, 1000 ml: 48329.70 1
- Phenolphthalein, 1% solution, 100 ml: 31714.10 1
- Activated carbon, granular, 500 g: 30011.50 1
- Water, distilled, 5 l: 31246.81 1

**Adsorption isotherms**

**What you can learn about**
- Adsorption
- Adsorbing agent and adsorbate
- Adsorbing and adsorbed substances
- Adsorption isotherm after Henry

**Principle and tasks**
In general, the term adsorption is used to describe the attachment of gases or dissolved substances to the surface of a solid (or liquid interfaces). At a constant temperature, the quantity of absorbed substances is a function of the type of system investigated and the partial pressure and/or the concentration of the substance in question. The residual equilibrium concentrations of citric acid are determined after stirring solutions of differing initial concentrations with a constant mass of active carbon. Using the measured results, the adsorption isotherm is investigated which is valid for the given system.
Chemical Kinetics

Contents
LEC 05.01 Saponification rate of tert-butyl chloride
LEC 05.02 Reaction rate and activation energy of the acid hydrolysis of ethyl acetate
LEC 05.03 Kinetics of saccharose inversion
LEC 05.07 Halogen exchange rate
LEC 05.08 Conductometric measurements on the saponification of esters
LEC 05.09 Enzyme kinetics: Determination of the Michaelis constant
LEC 05.10 Enzyme kinetics: Inhibition and poisoning of enzymes
05.01 Saponification rate of tert-butyl chloride

Principle and tasks
Tertiary butylhalogenides are saponified in aqueous and aqueous basic solutions according to an SN1 mechanism to tertiary butanol. The kinetics of the reaction can be followed via the temporal consumption of hydroxide ions and evaluated accordingly.

The concentration-time diagram for the saponification of tert-butyl chloride with sodium hydroxide solution is determined. Based on the experimental data, the valid reaction order can be established.

What you need:
- Magnetic heating stirrer
- Magnetic stirrer bar, l = 30 mm
- Support rod, l = 500 mm, M10 thread
- Right angle clamp
- Universal clamp
- Burette clamp, roller mounting
- Digital thermometer
- Immersion probe, NiCr-Ni
- Stop-watch, digital, 1/100 s
- Burette, 10 ml, straight stopcock, Schellbach
- Crystallisation dish, 900 ml
- Erlenmeyer flask, 250 ml, narrow neck, SB 29
- Precision balance CPA 623S (620 g/0.001 g), set with software
- Weighing dishes, 80 x 85 x 14 mm
- Volumetric flask, 50 ml
- Volumetric flask, 100 ml
- Volumetric pipette, 10 ml
- Volumetric pipette, 20 ml
- Volumetric pipette, 50 ml
- Pipettor
- Pipette dish
- Funnel, glass, d = 55 mm
- Rubber stopper, 17/22 mm
- Rubber stopper, 26/32 mm
- Glass beaker, 50 ml, tall
- Microspoon
- Pasteur pipettes

What you can learn about
- Reaction rate constant
- Reaction order
- Rate law for first and second order reactions

Concentration-time diagram for the saponification of tert-butyl chloride in acetone/water.

Rubber bulbs
Wash bottle, 500 ml
Tert-butyl chloride, 250 ml
Caustic soda solution, 1.0 M, 1000 ml
Bromothymolblue, indicator, 1 g
Acetone, chem. pure, 250 ml
Water, distilled, 5 l
Reaction rate and activation energy of the acid hydrolysis of ethyl acetate

**What you can learn about**
- Reaction rate
- Rate law for first and second order reactions
- Reactions with pseudo-order
- Arrhenius equation
- Activation energy

**Principle and tasks**

Ethyl acetate is hydrolysed in an acid solution according to a pseudo-first order rate law to equivalent quantities of ethanol and acetic acid. Based on the alkalimetric determination of the acetic acid formed, conclusions can be made about the temporal concentration of ester.

The reaction rate constant for this reaction is determined at different temperatures, and the activation energy is calculated.

**What you need:**

- Immersion thermostat, 100°C
- Accessory set for immersion thermostat
- Bath for thermostat, 6 l, Makrolon
- Rubber tubing, \( d = 6 \) mm
- Hose clip, \( d = 8 \ldots 12 \) mm
- Digital thermometer
- Immersion probe NiCr-Ni
- Stopwatch, digital, 1/100 s
- Magnetic heating stirrer
- Magnetic stirrer bar, \( l = 15 \) mm
- Magnetic stirrer bar, \( l = 30 \) mm
- Support rod, \( h = 500 \) mm, M10 thread
- Retort stand, \( h = 750 \) mm
- Burette clamp, roller mounting
- Right angle clamp
- Universal clamp
- Burette, 50 ml, with Schellbach line
- Graduated cylinder, 100 ml
- Volumetric flask, 1000 ml
- Volumetric pipette, 5 ml
- Volumetric pipette, 100 ml
- Pipettor
- Pipette dish
- Pasteur pipettes
- Rubber bulbs
- Crystallisation dish, 1000 ml
- Erlenmeyer flask, 250 ml, wide neck
- Erlenmeyer flask, 100 ml, narrow neck, SB 19
- Rubber stopper, 17/22 mm
- Glass beaker, 250 ml, short
- Funnel, glass, \( d_i = 55 \) mm

**Graphic determination of the reaction rate constants for the acid hydrolysis of ethyl acetate at \( T_x = 299.15 \) K and \( T_o = 314.15 \) K.**
05.03 Kinetics of saccharose inversion

What you need:

<table>
<thead>
<tr>
<th>Item</th>
<th>Code</th>
<th>Quantity</th>
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<td>Accessory set for immersion thermostat</td>
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<tr>
<td>Retort stand, h = 500 mm</td>
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<tr>
<td>Right angle clamp</td>
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<td>Universal clamp</td>
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<td>Universal clamp with joint</td>
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<tr>
<td>Stopwatch, digital, 1/100 s</td>
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<td>Precision balance CPA 6235 (620 g/0.001 g), set with software</td>
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<td>Weighing dishes, 80 × 50 × 14 mm</td>
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<td>Pasteur pipettes</td>
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<td>Rubber bulbs</td>
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<td>Volumetric flask, 500 ml</td>
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<td>Glass beaker, 100 ml, tall</td>
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<td>Crystallisation dish, 1000 ml</td>
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<td>Funnel, glass, d₁ = 55 mm</td>
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<tr>
<td>Spoon</td>
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<tr>
<td>Wash bottle, 500 ml</td>
<td>33931.00</td>
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</tr>
</tbody>
</table>

What you can learn about:

- Reaction rate
- First order reaction
- Polarimetry
- Optical rotation

Principle and tasks

The inversion reaction of saccharose, which is catalysed by protons, produces inverted sugar, a mixture of glucose and fructose. This reaction is accompanied by a change in the optical rotation of the system: Glucose rotates the polarisation plane of linearly polarised light to the right, while inverted sugar rotates it to the left.

Using a half-shade polarimeter, the change in the angle of rotation of polarised light is measured, and the rate constant of the inversion of saccharose is determined.

Floating point representation of saccharose inversion as a function of time.

| D(+)-Saccharose, extra pure, 100 g                                  | 30210.10 | 1        |
| D(+)-Lactose, 100 g                                               | 31577.10 | 1        |
| Hydrochloric acid, for 1 l of 1 M standard solution, 1 ampoule    | 30271.00 | 1        |
| Water, distilled, 5 l                                             | 31246.81 | 1        |

Kinetics of saccharose inversion

P3050301
Principle and tasks

Alkyl halides experience rapid halogen exchange reactions in appropriate solvents. The velocity of these substitution reactions occurs according to an SN2 mechanism. It can be monitored via conductivity measurements if the number of charge carriers changes in the course of the reaction.

The change of conductivity during the reaction of propyl bromide with sodium iodide (Finkelstein reaction) is measured. With the help of a calibration curve, the temporal concentration of sodium iodide can be determined. Based on the experimental data, the valid order of reaction is established and the rate constant is determined.

Concentration-time diagram for the Finkelstein reaction between propyl bromide and iodide ions.

What you need:

- Conductivity meter 13701.93 1
- Conductivity / temperature electrode 13701.01 1
- Magnetic heating stirrer 35750.93 1
- Electronic temperature control 35750.01 1
- Magnetic stirrer bar, l = 25 mm 46300.01 1
- Magnetic stirrer bar, l = 50 mm 46299.03 1
- Stopwatch, digital, 1/100 s 03071.01 1
- Spring balance holder 03065.20 1
- Support rod with hole, l = 100 mm 02036.01 1
- Support rod, l = 750 mm, M10 thread 02023.20 1
- Right angle clamp 37697.00 3
- Universal clamp 37715.00 2
- Cristallizing dish, 1000 ml 46245.00 1
- Round flask, 100 ml, 2 × GL 25/12, 1 × GL 25/8 35677.15 1
- Condenser, Dimroth type GL 25/12 35815.15 1
- Glass tubes, straight, l = 80 mm 36701.65 1
- Rubber caps 02615.03 1
- Precision balance CPA 623S (620 g/0.001 g), set with software 49224.88 1
- Graduated cylinder, 100 ml 36629.00 1
- Syringe, 10 ml 02590.03 1
- Cannula, 0.6 × 60 mm 02599.04 1
- Pasteur pipettes 36590.00 1
- Rubber bulbs 39275.03 1
- Powder funnel, d = 65 mm 34472.00 1
- Glass beaker, 50 ml, tall 36001.00 1

What you need:
05.08 Conductometric measurements on the saponification of esters

**Principle and tasks**
Carboxylic acid esters are saponified in an alkaline medium according to a second order reaction rate. In the process, hydroxide ions with a high ion mobility are consumed in reaction with an ester. The temporal course of reaction can be monitored by using the measurements of the changing conductance.

What you can learn about
- Reaction rate
- First and second order reaction laws
- Conductometry

**What you need:**

**Experiment P3050811 with Cobra3 Basic-Unit**
- Cobra3 Basic-Unit, USB 12150.50 1
- Data cable, RS232 14602.00 1
- Software Cobra3 Chem-Unit 14520.61 1
- Measuring module, Conductivity 12108.00 1
- Measuring module, temperature NiCr-Ni, 330°C 12104.00 1
- Thermocouple, NiCr-Ni, sheathed 13615.01 1
- Conductivity probe K1 18151.02 1
- Conductivity temperature probe Pt1000 13701.01 1
- Magnetic heating stirrer 35750.93 1 1
- Electronic temperature control 35750.01 1 1
- Magnetic stirrer bar, l = 25 mm, oval 46300.01 1 1
- Magnetic stirrer bar l = 30 mm, cyclic 46299.02 1 1
- Spring balance holder 02036.01 1 1
- Support rod with hole 02023.01 1 1
- Support rod, l = 750 mm, M10 thread 02023.20 1 1
- Right angle clamp 37697.00 3 3
- Universal clamp 37715.00 2 2
- Crystallizing dish, 1000 ml 46245.00 1 1
- Round flask, 100 ml, 3 x GL 25 35677.15 1 1
- Condensor, Dimroth type, GL 25/12 35815.15 1 1
- Glass tubes, d = 8 mm, l = 80 36701.65 1 1
- Rubber caps, pack of 20 02615.03 1 1
- Volumetric pipette, 25 ml 36580.00 2 2

**Experiment P3050840 with Cobra3 Chem-Unit**
- Cobra3 Chem-Unit 12153.00 1
- Power supply12 VDC/2 A 12151.99 1 1
- Data cable, RS232 14602.00 1
- Software Cobra3 Chem-Unit 14508.61 1
- Measuring module, Conductivity 12108.00 1
- Measuring module, temperature NiCr-Ni, 330°C 12104.00 1
- Thermocouple, NiCr-Ni, sheathed 13615.01 1
- Conductivity probe K1 18151.02 1
- Conductivity temperature probe Pt1000 13701.01 1
- Magnetic heating stirrer 35750.93 1 1
- Electronic temperature control 35750.01 1 1
- Magnetic stirrer bar, l = 25 mm, oval 46300.01 1 1
- Magnetic stirrer bar l = 30 mm, cyclic 46299.02 1 1
- Spring balance holder 02036.01 1 1
- Support rod with hole 02023.01 1 1
- Support rod, l = 750 mm, M10 thread 02023.20 1 1
- Right angle clamp 37697.00 3 3
- Universal clamp 37715.00 2 2
- Crystallizing dish, 1000 ml 46245.00 1 1
- Round flask, 100 ml, 3 x GL 25 35677.15 1 1
- Condensor, Dimroth type, GL 25/12 35815.15 1 1
- Glass tubes, d = 8 mm, l = 80 36701.65 1 1
- Rubber caps, pack of 20 02615.03 1 1
- Volumetric pipette, 25 ml 36580.00 2 2

**Change in the specific conductivity during the saponification of ethyl butyrate in ethanol/water.**

- Pipettor 36592.00 1 1
- Syringe, 1 ml 02593.03 1 1
- Cannula, 0.60 mm × 60 mm 02599-04 1 1
- Pasteur pipettes 36590.00 1 1
- Rubber bulbs 39275.03 1 1
- Wash bottle, 500 ml 33931.00 1 1
- Rubber tubing, d = 6 mm 39282.00 3 3
- Hose clamp d = 5...12 40997.00 4 4
- Standard solution, 1413 µS/cm, 460 ml 47070.02 1 1
- Ethyl butyrate, 100 ml 48012.10 1 1
- Ethyl alcohol, absolute, 500 ml 30008.50 1 1
- Caustic soda solution, 0.1 M, 1000 ml 48328.70 1 1
- Water, distilled, 5 l 31246.81 1 1

**Conductometric measurements on the saponification of esters**

P3050811/40

**What you can learn about**
- Reaction rate
- First and second order reaction laws
- Conductometry
Enzyme kinetics: Determination of the Michaelis constant 05.09

What you can learn about

- Michaelis-Menten mechanism
- Reaction rate
- Enzyme kinetics
- Bodenstein principle
- Electrolytic conductivity

Principle and tasks

In the enzymatic hydrolysis of urea in aqueous solution, carbon dioxide and ammonia result. Their ions increase the conductivity of the solution. The velocity of the urea hydrolysis by the enzyme urease is measured via conductivity measurements at different substrate concentrations and the Michaelis-Menten constant is determined.

What you need:

**Experiment P3050940 with Cobra3 Chem-Unit**

- Cobra3 Basic-Unit, USB 12150.50
- Cobra3 Chem-Unit 12153.00
- Power supply, 12 VDC/2 A 12151.99
- Data cable, RS232 14602.00
- Software Cobra3 Chem-Unit 14520.61
- Software Cobra3 Conductivity 14508.61
- Conductivity probe K1 18151.02
- Retord stand, 210 x 130 mm, h = 750 mm 37694.00
- Right angle clamp 37697.00
- Universal clamp 37715.00
- Magnetic stirrer, mini 47334.93
- Magnetic stirring bar, 15 mm 46299.01
- Glass beaker, 100 ml, narrow neck 36418.00
- Rubber stoppers 17/22 39255.00
- Volumetric pipette, 20 ml 36579.00
- Pipettor 36592.00
- Microlitre syringe, 100 ml 02606.00
- Funnel, glass Ø = 50 mm 34457.00
- Pasteur pipettes, l = 145 mm 36590.00
- Rubber bulbs 39275.03
- Microspoon 33393.00
- Mortar with pestle, 70 ml 33931.00
- Urea, 250 g 30086.25

**Experiment P3050911 with Cobra3 Basic-Unit**

- Cobra3 Basic-Unit, USB 12150.50
- Cobra3 Chem-Unit 12153.00
- Power supply, 12 VDC/2 A 12151.99
- Data cable, RS232 14602.00
- Software Cobra3 Chem-Unit 14520.61
- Software Cobra3 Conductivity 14508.61
- Conductivity probe K1 18151.02
- Retord stand, 210 x 130 mm, h = 750 mm 37694.00
- Right angle clamp 37697.00
- Universal clamp 37715.00
- Magnetic stirrer, mini 47334.93
- Magnetic stirring bar, 15 mm 46299.01
- Glass beaker, 100 ml, narrow neck 36418.00
- Rubber stoppers 17/22 39255.00
- Volumetric pipette, 20 ml 36579.00
- Pipettor 36592.00
- Microlitre syringe, 100 ml 02606.00
- Funnel, glass Ø = 50 mm 34457.00
- Pasteur pipettes, l = 145 mm 36590.00
- Rubber bulbs 39275.03
- Microspoon 33393.00
- Mortar with pestle, 70 ml 33931.00
- Urea, 250 g 30086.25

Urea solution in 50% glycerol, 10 ml 31924.03
Standard solution, 1413 µS/cm 47070.02
Water, distilled, 5 l 31246.81
Set of Precision Balance Sartorius CPA 623S and measure software 49224.88

![Conductivity-time diagram for the urea hydrolysis by urease.](image-url)
**Enzyme kinetics: Inhibition and poisoning of enzymes**

In the enzymatic hydrolysis of urea in an aqueous solution, carbon dioxide and ammonia are produced; their ions increase the conductivity of the solution. Via the conductivity measurements, the velocity of the hydrolysis of urea induced by the enzyme urease is measured at different substrate concentrations. By adding an appropriate inhibitor, the enzyme can be poisoned so that no further substrate is converted.

**What you can learn about**
- Enzyme kinetics
- Competitive, non-competitive and uncompetitive enzyme inhibition
- Reversible and irreversible enzyme inhibition
- Catalysis
- Electrolytic conductivity

**Principle and tasks**
In the enzymatic hydrolysis of urea in an aqueous solution, carbon dioxide and ammonia are produced; their ions increase the conductivity of the solution. Via the conductivity measurements, the velocity of the hydrolysis of urea induced by the enzyme urease is measured at different substrate concentrations. By adding an appropriate inhibitor, the enzyme can be poisoned so that no further substrate is converted.

**What you need:**

**Experiment P3051011 with Cobra3 Basic-Unit**
- Cobra3 Basic-Unit, USB 12150.50 1 1
- Power supply, 12 VDC/2 A 12151.99 1 1
- Software Cobra3 Conductivity 14508.61 1 1
- Measuring module, Conductivity 12108.00 1 1
- Data cable, RS232 14602.00 1 1
- Software Cobra3 Chem-Unit 14520.61 1 1
- Conductivity probe K1 18151.02 1 1
- Retord stand, 210 × 130 mm, h = 750 mm 37694.00 1 1
- Right angle clamp 37697.00 1 1
- Universal clamp 37715.00 1 1
- Magnetic stirrer, mini 47334.93 1 1
- Magnetic stirring bar, l = 15 mm 46299.01 1 1
- Glass beaker, 10 ml, tall 36002.00 1 1
- Cristallizing dish, 320 ml 46243.00 1 1
- Weighing dishes, 80 × 50 × 14 mm 45019.25 1 1
- Erlenmeyer flask, 100 ml, narrow neck 36418.00 1 1
- Erlenmeyer flask, 250 ml, narrow neck 36424.00 7 7
- Erlenmeyer flask, 500 ml, narrow neck 36421.00 1 1
- Rubber stopper 26/32 89258.00 8 8
- Rubber stopper 17/22 39255.00 1 1
- Volumetric pipette, 50 ml 36581.00 7 7
- Volumetric pipette, 1 ml 36575.00 1 1
- Pipettor 36592.00 1 1
- Pipette dish 36589.00 1 1
- Microlitre syringe, 100 µl 02606.00 1 1
- Pasteur pipettes, l = 145 mm 36590.00 1 1
- Rubber bulbs 39275.03 1 1

**Experiment P3051040 with Cobra3 Chem-Unit**
- Power supply, 12 VDC/2 A 12151.99 1 1
- Software Cobra3 Conductivity 14508.61 1 1
- Measuring module, Conductivity 12108.00 1 1
- Data cable, RS232 14602.00 1 1
- Software Cobra3 Chem-Unit 14520.61 1 1
- Conductivity probe K1 18151.02 1 1
- Retord stand, 210 × 130 mm, h = 750 mm 37694.00 1 1
- Right angle clamp 37697.00 1 1
- Universal clamp 37715.00 1 1
- Magnetic stirrer, mini 47334.93 1 1
- Magnetic stirring bar, l = 15 mm 46299.01 1 1
- Glass beaker, 10 ml, tall 36002.00 1 1
- Cristallizing dish, 320 ml 46243.00 1 1
- Weighing dishes, 80 × 50 × 14 mm 45019.25 1 1
- Erlenmeyer flask, 100 ml, narrow neck 36418.00 1 1
- Erlenmeyer flask, 250 ml, narrow neck 36424.00 7 7
- Erlenmeyer flask, 500 ml, narrow neck 36421.00 1 1
- Rubber stopper 26/32 89258.00 8 8
- Rubber stopper 17/22 39255.00 1 1
- Volumetric pipette, 50 ml 36581.00 7 7
- Volumetric pipette, 1 ml 36575.00 1 1
- Pipettor 36592.00 1 1
- Pipette dish 36589.00 1 1
- Microlitre syringe, 100 µl 02606.00 1 1
- Pasteur pipettes, l = 145 mm 36590.00 1 1
- Rubber bulbs 39275.03 1 1

**Chemical Kinetics LEC 05**

**What you can learn about**
- Enzyme kinetics
- Competitive, non-competitive and uncompetitive enzyme inhibition
- Reversible and irreversible enzyme inhibition
- Catalysis
- Electrolytic conductivity
06.01 Charge transport in solids

What you need:

<table>
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<th>Quantity</th>
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<td>Digital thermometer</td>
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<td>Immersion probe NiCr-Ni, Teflon</td>
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<td>Support rod, $l = 250$ mm</td>
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<td>Scissors, $l = 180$ mm, straight</td>
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<td>Iron wire, $d = 0.2$ mm, 100 m</td>
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<td>Constantan wire, $d = 0.2$ mm, 100 m</td>
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</tr>
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<td>Water, distilled, 5 l</td>
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<td>1</td>
</tr>
<tr>
<td>PC, Windows® XP or higher</td>
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<td></td>
</tr>
</tbody>
</table>

Charge transport in solids

What you can learn about

- Electron conductivity
- Ion conductivity

Principle and tasks

The temperature coefficients of iron, copper and constantan wire are determined in the range of room temperature to 95°C. The temperature dependence of the resistivity of solids provides information on the mechanism of conduction and charge transport in solids.
**What you can learn about**
- Electrolyte solutions
- Conductivity
- Ionic migration

**Principle and tasks**
A potential difference between two electrodes in a liquid causes the flow of a current in the liquid. This current depends on the potential drop across the liquid and its conductivity. The measurement of the conductivity of electrolyte solutions yields knowledge about charge transport in liquids.

**What you need:**

<table>
<thead>
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<th>Item</th>
<th>Quantity</th>
<th>Unit</th>
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<tbody>
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<tr>
<td>Spoon</td>
<td>1</td>
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</tr>
<tr>
<td>Cristallizing dish, 320 ml</td>
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<td></td>
</tr>
<tr>
<td>Wash bottle, 500 ml</td>
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<td></td>
</tr>
<tr>
<td>Glass rod, ( l = 200, d = 5 ) mm</td>
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<td></td>
</tr>
<tr>
<td>Desiccator, diam. 150 mm</td>
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</tr>
<tr>
<td>Porcelain plate for desiccator 150 mm</td>
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<td></td>
</tr>
<tr>
<td>Silicon grease, 100 g</td>
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<td></td>
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<tr>
<td>Silica gel, orange, granular, 500 g</td>
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<tr>
<td>Potassium chloride, 250 g</td>
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<td></td>
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<tr>
<td>D(+)-Sucrose, 100 g</td>
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<tr>
<td>Standard solution, 1413 ( \mu )S/cm</td>
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<tr>
<td>Water, distilled, 5 l</td>
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<tr>
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**Charge transport in liquids**

**Experiment P3060240 with Cobra3 Chem-Unit**
- Cobra3 Basic-Unit, USB
- Cobra3 Chem-Unit
- Power supply, 12 VDC/2 A
- Software Cobra3 Conductivity
- Data cable, RS232
- Software Cobra3 Chem-Unit
- Thermocouple, NiCr-Ni, teflon
- Conductivity probe K1
- Measure module, Conductivity
- Cobra3, sensor, -20...110°C
- Magnetic heating stirrer
- Magnetic stirring bar, \( l = 15 \) mm
- Support rod, \( l = 500 \) mm
- Right angle clamp
- Universal clamp
- Support for two electrodes
- Support rod with hole
- Spring balance holder
- Burette clamp, roller mounting
- Burette, 50 ml, lateral stopcock
- Glass beaker, 150 ml, tall
- Glass beaker, 250 ml, tall
- Volumetric flask 1000 ml, IGJ24/29
- Funnel, glass, \( d_0 = 80 \) mm
- Pasteur pipettes, \( l = 145 \) mm
- Rubber bulbs
- Set of Precision Balance Sartorius CPA 623S
- and measure software

**Experiment P3060211 with Cobra3 Basic-Unit**
- Cobra3 Basic-Unit, USB
- Cobra3 Chem-Unit
- Power supply, 12 VDC/2 A
- Software Cobra3 Conductivity
- Data cable, RS232
- Software Cobra3 Chem-Unit
- Thermocouple, NiCr-Ni, teflon
- Conductivity probe K1
- Measure module, Conductivity
- Cobra3, sensor, -20...110°C
- Magnetic heating stirrer
- Magnetic stirring bar, \( l = 15 \) mm
- Support rod, \( l = 500 \) mm
- Right angle clamp
- Universal clamp
- Support for two electrodes
- Support rod with hole
- Spring balance holder
- Burette clamp, roller mounting
- Burette, 50 ml, lateral stopcock
- Glass beaker, 150 ml, tall
- Glass beaker, 250 ml, tall
- Volumetric flask 1000 ml, IGJ24/29
- Funnel, glass, \( d_0 = 80 \) mm
- Pasteur pipettes, \( l = 145 \) mm
- Rubber bulbs
- Set of Precision Balance Sartorius CPA 623S
- and measure software
06.03 Ion migration velocity

What you need:

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<td>1</td>
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<tr>
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<td>1</td>
</tr>
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</tr>
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</tr>
<tr>
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<td>1</td>
</tr>
<tr>
<td>Right angle clamp</td>
<td>07697.00</td>
<td>3</td>
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<tr>
<td>Analytical balance CPA 2245 (220 g/0.1 mg), set with software</td>
<td>49221.88</td>
<td>1</td>
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<tr>
<td>Weighing dishes, 80 ( \times ) 50 ( \times ) 14 mm</td>
<td>45019.25</td>
<td>1</td>
</tr>
<tr>
<td>Stopwatch, digital, 1/100 s</td>
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<td>1</td>
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<td>Volumetric flask, 100 ml</td>
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<td>Pasteur pipettes</td>
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<td>Rubber bulbs</td>
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<td>Funnel, glass, ( d_b = 55 ) mm</td>
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<td>Washbottle, 500 ml</td>
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<td>Potassium permanganate, 250 g</td>
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<tr>
<td>Potassium nitrate, 250 g</td>
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<tr>
<td>Water, distilled, 5 l</td>
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</table>

What you can learn about

- Charge transport in liquids
- Ion mobility
- Conductivity

Principle and tasks

The movement of ions is responsible for current flow in electrolyte solutions. The migration of coloured ions can be easily observed by the migration of the colour front in an electric field. In this experiment the migration of the permanganate anion is demonstrated and its ion velocity is measured at five different concentrations.
Principle and tasks
In accordance with their different mobilities in an electric field, cations and anions contribute to charge transport in electrolytic processes. Hittorf transference numbers are experimentally accessible via the resulting characteristic concentration changes occurring at the cathode and the anode. These characterise the proportion of a single type of ion on the total charge transport through the given electrolytes and enable the calculation of ionic conductivities which are important in electrochemical practice.

The Hittorf transference numbers of the oxonium and of the nitrate ion are determined for the electrolysis of a 0.1 molar nitric acid solution.

What you need:
- Power supply, universal 13500.93 1
- Multirange meter 07021.01 1
- Connecting cord, l = 750 mm, red 07362.01 1
- Connecting cord, l = 750 mm, blue 07362.04 1
- Connecting cord, l = 500 mm, blue 07361.04 2
- Double U-tube with frits and stopcock, GL25 44451.00 1
- Contact socket for bar electrodes 45283.00 2
- Carbon electrodes, d = 7 mm 44512.00 1
- Plate electrodes, copper 07854.00 2
- Holder for 2 electrodes 45284.01 1
- Retort stand, h = 750 mm 37694.00 3
- Right angle clamp 37697.00 2
- Universal clamp 37715.00 1
- Burette clamp, roller mounting 37720.00 1
- Precision balance CPA 623S (620 g/0.001 g), set with software 49224.88 1
- Digital thermometer, NiCr-Ni 07050.00 1
- Thermocouple, NiCr-Ni, sheated 13615.03 1
- Stopwatch, digital, 1/100 s 03071.01 1
- Burette, 10 ml, straight stopcock, Schellbach line 47152.01 1
- Burette, 50 ml, with Schellbach line 36513.01 1
- Erlenmeyer flask, 250 ml, wide neck 36134.00 4
- Glass beaker, 100 ml 36013.01 1
- Glass beaker, 250 ml, wide neck 36340.00 4
- Glass beaker, 500 ml, short 36272.00 1
- Volumetric flask, 1000 ml 36552.00 2
- Volumetric pipette, 5 ml 36577.00 3
- Volumetric pipette, 50 ml 36581.00 1
- Pipettor 36592.00 1
- Pipette dish 36589.00 1
- Pasteur pipettes 36590.00 1
06.05 The temperature dependence of conductivity

What you need:

- Experiment P3060511 with Cobra3 Basic-Unit
- Experiment P3060540 with Cobra3 Chem-Unit

<table>
<thead>
<tr>
<th>Item</th>
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<th>Quantity</th>
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<td>Data cable, RS232</td>
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<td>Cobra3 Basic-Unit, USB</td>
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<tr>
<td>Power supply, 12 VDC/2 A</td>
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<td>Measuring module, conductivity</td>
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<td>Measuring module, NiCr-Ni, 330°C</td>
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<td>Software Cobra3 Conductivity</td>
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<tr>
<td>Software Cobra3 Chem-Unit</td>
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<td>Immersion probe NiCr-Ni, Teflon</td>
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<td>Conductivity probe</td>
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</tr>
<tr>
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<tr>
<td>Spring balance holder</td>
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<td>Right angle clamp</td>
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<td>Universal clamp</td>
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<td>Magnetic stirring bar, l = 25 mm</td>
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<td>Round flask, 100 ml, 3 × GL25</td>
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<td>Glass beaker, 250 ml, tall</td>
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<td>Crystallizing dish, 560 ml</td>
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<td>Rubber tubing, d = 6 mm</td>
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<td>Hose clamp, d = 5...12 mm</td>
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<td>Sodium chloride, 500 g</td>
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<td>1</td>
</tr>
<tr>
<td>Water, distilled, 5 l</td>
<td>31246.81</td>
<td>1</td>
</tr>
<tr>
<td>Set of precision balance Sartorius CPA 623S and measure software</td>
<td>49224.88</td>
<td>1</td>
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</tbody>
</table>

The temperature dependence of conductivity with Cobra3

Diagram of the conductivity as a function of the temperature.

What you can learn about
- Electrolytic resistance
- Specific and molar conductivity
- Ion mobility
- Kohlrausch’s law
- Ostwald’s law of dilution

Principle and tasks
The electrical conductivity of an electrolytic solution depends not only upon the type and concentration of the electrolytes, but also other state values. Thus, an increase in conductivity is generally observed with an increase in temperature. This is fundamentally due to the exponential decrease of the solutions’ viscosity. In this experiment the temperature dependence of the conductivity of a sodium chloride solution is determined in the range of 20°C to 60°C.
Principle and tasks
It is possible to differentiate between strong and weak electrolytes by measuring their electrical conductance. Strong electrolytes follow Kohlrausch’s law, whereas weak electrolytes are described by Ostwald’s dilution law. The examination of the concentration dependence of the conductivity allows the molar conductivities of infinitely diluted electrolytes to be determined, and facilitates the calculation of the degree of dissociation and the dissociation constants of weak electrolytes.

What you can learn about
- Kohlrausch’s law
- Equivalent conductivity
- Temperature-dependence of conductivity
- Ostwald’s dilution law

What you need:

**Experiment P3060640 with Cobra3 Chem-Unit**
- Cobra3 Basic-Unit, USB
- Cobra3 Basic-Unit
- Power supply, 12 VDC/2 A
- Software Cobra3 Conductivity
- Measuring module, Conductivity
- Conductivity probe K1
- Cobra3, sensor -20…110°C
- Data cable, RS232
- Software Cobra3 Chem-Unit
- Conductivity temperature probe Pt1000
- Magnetic stirrer, mini
- Magnetic stirring bar, l = 15 mm
- Retort stand, h = 750 mm
- Right angle clamp
- Support rod with hole
- Holder for 2 electrodes
- Spring balance holder
- Glass beaker, 150 ml, tall
- Volumetric flask, 250 ml
- Volumetric flask, 500 ml
- Volumetric flask, 1000 ml
- Funnel, glass, d = 80 mm
- Volumetric pipette, 1 ml
- Volumetric pipette, 5 ml
- Volumetric pipette, 25 ml
- Volumetric pipette, 100 ml
- Pipettor
- Pipette dish
- Pasteur pipettes, I = 145 mm
- Rubber bulbs
- Weighing dishes, 80 × 50 × 14 mm
- Spoon
- Desiccator
- Porcelain plate for desiccators
- Crystallizing dish, 320 ml

**Experiment P3060611 with Cobra3 Basic-Unit**
- Cobra3 Basic-Unit, USB
- Cobra3 Basic-Unit
- Power supply, 12 VDC/2 A
- Software Cobra3 Conductivity
- Measuring module, Conductivity
- Conductivity probe K1
- Cobra3, sensor -20…110°C
- Data cable, RS232
- Software Cobra3 Chem-Unit
- Conductivity temperature probe Pt1000
- Magnetic stirrer, mini
- Magnetic stirring bar, l = 15 mm
- Retort stand, h = 750 mm
- Right angle clamp
- Support rod with hole
- Holder for 2 electrodes
- Spring balance holder
- Glass beaker, 150 ml, tall
- Volumetric flask, 250 ml
- Volumetric flask, 500 ml
- Volumetric flask, 1000 ml
- Funnel, glass, d = 80 mm
- Volumetric pipette, 1 ml
- Volumetric pipette, 5 ml
- Volumetric pipette, 25 ml
- Volumetric pipette, 100 ml
- Pipettor
- Pipette dish
- Pasteur pipettes, I = 145 mm
- Rubber bulbs
- Weighing dishes, 80 × 50 × 14 mm
- Spoon
- Desiccator
- Porcelain plate for desiccators
- Crystallizing dish, 320 ml

Conductivity of strong and weak electrolytes 06.06

Conductivity of a strong electrolyte as a function of the concentration.

Conductivity of a weak electrolyte as a function of the concentration.

Wash bottle, 500 ml 33931.00 1 1
Silicon grease, 100g 31863.10 1 1
Silica gel, orange, granular, 500 g 30224.50 1 1
Acetic acid, 1 M solution, 1000 ml 48127.70 1 1
Potassium chloride, 250 g 30098.25 1 1
Water, distilled, 5 l 31246.81 1 1
Set of Precision Balance Sartorius CPA 623S and measure software 49221.88 1 1
PC, Windows® XP or higher

Conductivity of strong and weak electrolytes with Cobra3 P3060611/40
06.07 Conductiometric titration

**What you need:**

Set pH titration with drop counter and Cobra3 Chem-Unit 43050.88 1
Conductivity/temperature electrode 13701.01 1
Precision balance CPA 6235 (620 g/0.001 g), set with software 49224.88 1
Weighing dishes, 80 × 50 × 14 mm 45019.25 1
Volumetric flask, 50 ml 36547.00 1
Volumetric flask, 100 ml 36548.00 1
Volumetric flask, 250 ml 36550.00 1
Volumetric pipette, 5 ml 36577.00 3
Volumetric pipette, 10 ml 36578.00 2
 Pipettor 36592.00 1
 Pipette dish 36589.00 1
 Funnel, glass, d₀ = 55 mm 34457.00 1
 Funnel, glass, d₀ = 80 mm 34459.00 1
 Spoon 33398.00 1
 Wash bottle, 500 ml 33931.00 1
 Pasteur pipettes 36590.00 1
 Rubber bulbs 39275.03 1
 Sulphuric acid, 0.5 M, 1000 ml 48462.70 1
 Hydrochloric acid, 0.1 M, 1000 ml 48452.70 1
 Acetic acid, 0.1 M, 1000 ml 48126.70 1
 Caustic soda solution, 0.1 M, 1000 ml 48328.70 1
 Barium hydroxide, 250 g 30034.25 1
 Standard solution, 1413 S/cm, 460 ml 47070.02 1
 Water, distilled, 5 l 31246.81 1
 PC, Windows® XP or higher

**Conductiometric titration with Cobra3 Chem-Unit**

**Titration diagram for the neutralisation of HCl solution with NaOH solution.**

**What you can learn about**

→ Electrolytes  
→ Specific conductance  
→ Ion mobility  
→ Ion conductivity  
→ Conductometry

**Principle and tasks**

The electric conductivity of aqueous electrolyte solutions is determined by the type and number of charge carriers at constant temperature. Characteristic changes in conductivity are connected with changes in the ionic composition of reacting systems. These can be used in the conductiometric titration as end point indicators. Using the Cobra3 system, the change in conductivity in several titrations is measured.
**Principle and tasks**

The equivalent conductance of strong electrolytes depends on their concentration. The quotient of the equivalent conductance at a certain concentration is the conductivity coefficient. Like the activity coefficient, the conductivity coefficient is the result of the interionic action.

The specific conductivities of diluted potassium chloride and calcium chloride solutions are determined and the equivalent conductances and conductivity coefficients are calculated.

**What you need:**

<table>
<thead>
<tr>
<th>Item</th>
<th>Code</th>
<th>Quantity</th>
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<tbody>
<tr>
<td>Digital conductivity meter</td>
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<td>Conductivity / temperature electrode</td>
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<td>Retort stand, h = 750 mm</td>
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<td>Right angle clamp</td>
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<td>Support rod with hole, l = 100 mm</td>
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<td>Spring balance holder</td>
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<td>Analytical balance CPA 224 S (220 g/0.1 mg), set with software</td>
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<td>Volumetric flask, 250 ml</td>
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<td>Volumetric flask, 500 ml</td>
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<td>Volumetric pipette, 5 ml</td>
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<td>Porcelain plate for desiccator</td>
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<td>Crystallizing dish, 320 ml</td>
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<td>Spoon</td>
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<td>Pasteur pipettes</td>
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</tr>
<tr>
<td>Rubber bulbs</td>
<td>39275.03</td>
<td>1</td>
</tr>
<tr>
<td>Wash bottle, 500 ml</td>
<td>33931.00</td>
<td>1</td>
</tr>
<tr>
<td>Silica gel, orange, granular, 500 g</td>
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<tr>
<td>Silicone grease, 100 g, 1 tube</td>
<td>31863.10</td>
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</tr>
</tbody>
</table>

**What you can learn about**

- Conductivity coefficient
- Ion mobility
- Equivalent conductance
- Interionic action
- Conductometry

![Graph](attachment:image.png)

\( \lambda_c \sim \frac{1}{c} \)-curves for potassium chloride and calcium chloride.

**Determination of the conductivity coefficient**

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<th>Item</th>
<th>Code</th>
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<td>Standard solution, 1413 S/cm, 460 ml</td>
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<td>Potassium chloride, 250 g</td>
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</tr>
<tr>
<td>Calcium chloride, 250 g</td>
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<tr>
<td>Water, distilled, 5 l</td>
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</table>

**P3060801**
06.09 The Nernst equation

**What you need:**

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<th>Unit</th>
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<td>Platinum electrode in protective tube</td>
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<tr>
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<tr>
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</tr>
<tr>
<td>Right angle clamp</td>
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<td>1</td>
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<tr>
<td>Universal clamp</td>
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<td>1</td>
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<tr>
<td>Support for two electrodes</td>
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<tr>
<td>Spring balance holder</td>
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<tr>
<td>Burette clamp, roller mounting</td>
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<tr>
<td>Burette, 50 ml, lateral stopcock</td>
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<tr>
<td>Analytical balance CPA 2245 (220 g/0.1 mg), set with software</td>
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<td>1</td>
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<tr>
<td>Weighing dishes, 80 × 50 × 14 mm</td>
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<tr>
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<tr>
<td>Glass beaker, 150 ml, tall</td>
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<td>Volumetric flask, 1000 ml</td>
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<td>Volumetric pipette, 50 ml</td>
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<tr>
<td>Pipette dish</td>
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<td>1</td>
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<tr>
<td>Funnel, glass, d = 55 mm</td>
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<td>1</td>
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<tr>
<td>Funnel, glass, d = 80 mm</td>
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<tr>
<td>Spoon</td>
<td>1</td>
<td>1</td>
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<tr>
<td>Pasteur pipettes</td>
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<td>1</td>
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<tr>
<td>Rubber bulbs</td>
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<td>1</td>
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<tr>
<td>Wash bottle, 500 ml</td>
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<tr>
<td>Potassium hexacyanoferrate(II), 250 g</td>
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<tr>
<td>Potassium hexacyanoferrate(III), 100 g</td>
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<td>1</td>
</tr>
<tr>
<td>Water, distilled, 5 l</td>
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</tbody>
</table>

**What you can learn about:**

- Electrode potentials and their concentration dependence
- Redox electrodes
- Electrochemical cells

**Principle and tasks**

The Nernst equation expresses how the electrical potential of an electrode in contact with a solution of ions depends upon the activities of these ions. The equation may be experimentally verified using an electrochemical cell formed from an inert indicator electrode coupled with a convenient reference electrode. The potential of the indicator electrode, and hence the e.m.f. of the cell, are monitored as the ionic composition of the electrolyte solution is changed.

Here a silver - silver chloride electrode is used as reference electrode measuring the potential of a platinum electrode in contact with solutions containing different concentrations of iron(II) and iron(III) complex ions.

**Verification of the Nernst equation for the Fe(CN)$_6^{4–}$, Fe(CN)$_6^{3–}$/H$_2$O redox electrode.**

![Graph showing verification of the Nernst equation](image-url)
Determination of the solubility products of the silver halides 06.10

**Principle and tasks**

A concentration cell is constructed from two half-cells which are identical except that the concentration of the ionic species to which the electrode is sensitive is different in the two sides of the cell. Such a cell may be used to measure the solubility product of a sparingly soluble salt. In one half-cell the concentration of one of the ions is known, in the other it is governed by the solubility product of the salt. The ratio of the two concentrations determines the e.m.f. of the cell.

Using a concentration cell made from two silver - silver chloride electrodes, the solubility products of the three silver halides AgCl, AgBr and AgI are determined.

### What you need:

- Digital pH-meter 13702.93 1
- Temperature probe Pt1000 13702.01 1
- Connecting cord, l = 500 mm, red 07361.01 1
- Connecting cord, l = 500 mm, blue 07361.04 1
- Crocodile clips, bare 07274.03 1
- Silver foil, 150 x 11003 mm, 0.1 mm, 25 g 31839.04 1
- Retort stand, h = 750 mm 37694.00 1
- Right angle clamp 37697.00 1
- Support for two electrodes 45284.01 1
- Spring balance holder 03065.20 1
- Salt bridge 37684.00 1
- Clay pins, d = 8 mm, l = 15 mm 32486.00 1
- Silicone tubing, d = 7 mm 39296.00 1
- Rubber caps 02615.03 1
- Cannula, 0.6 x 60 mm 02590.03 1
- Analytical balance CPA 224S (220 g/0.1 mg), set with software 49221.88 1
- Weighing dishes, 80 x 50 x 14 mm 45019.25 1
- Glass beaker, 50 ml, tall 36001.00 12
- Glass beaker, 150 ml, tall 36003.00 2
- Glass beaker, 250 ml, tall 36004.00 1
- Volumetric flask, 250 ml 36550.00 12
- Volumetric pipette, 25 ml 36580.00 8
- Graduated pipette, 5 ml 36595.00 1
- Pipettor 36592.00 1
- Pipette dish 36599.00 1
- Graduated cylinder, 100 ml 36629.00 1
- Funnel, glass, d = 55 mm 34457.00 1
- Spoon 33398.00 1
- Pasteur pipettes 36590.00 1

### What you can learn about

- Concentration cells
- Electromotive force
- Salt bridge

---

**Lab Equipment**

- Digital pH-meter 13702.93 1
- Temperature probe Pt1000 13702.01 1
- Connecting cord, l = 500 mm, red 07361.01 1
- Connecting cord, l = 500 mm, blue 07361.04 1
- Crocodile clips, bare 07274.03 1
- Silver foil, 150 x 11003 mm, 0.1 mm, 25 g 31839.04 1
- Retort stand, h = 750 mm 37694.00 1
- Right angle clamp 37697.00 1
- Support for two electrodes 45284.01 1
- Spring balance holder 03065.20 1
- Salt bridge 37684.00 1
- Clay pins, d = 8 mm, l = 15 mm 32486.00 1
- Silicone tubing, d = 7 mm 39296.00 1
- Rubber caps 02615.03 1
- Cannula, 0.6 x 60 mm 02590.03 1
- Analytical balance CPA 224S (220 g/0.1 mg), set with software 49221.88 1
- Weighing dishes, 80 x 50 x 14 mm 45019.25 1
- Glass beaker, 50 ml, tall 36001.00 12
- Glass beaker, 150 ml, tall 36003.00 2
- Glass beaker, 250 ml, tall 36004.00 1
- Volumetric flask, 250 ml 36550.00 12
- Volumetric pipette, 25 ml 36580.00 8
- Graduated pipette, 5 ml 36595.00 1
- Pipettor 36592.00 1
- Pipette dish 36599.00 1
- Graduated cylinder, 100 ml 36629.00 1
- Funnel, glass, d = 55 mm 34457.00 1
- Spoon 33398.00 1
- Pasteur pipettes 36590.00 1
06.11 Determination of diffusion potentials

**Principle and tasks**

At the interface between two solutions with different ion concentrations an electrochemical potential establishes itself. Its magnitude is determined by the concentration ratio and the transference numbers of the ions involved. This potential difference can be measured as a function of the concentration at semi-permeable and ion-selective membranes.

In this experiment we use a semi-permeable cellophane membrane and a cation-selective membrane to measure the diffusion gradients of different concentrations of HCl, NaCl and KCl solutions.

**What you need:**

- Osmosis / electrochemistry chamber 35821.00 1
- Gaskets for GL 25, 12 mm hole 41243.03 1
- Digital multimeter 07128.00 1
- Reference electrode, AgCl 18475.00 2
- Digital thermometer, NiCr-Ni 07050.00 1
- Thermocouple, NiCr-Ni, sheathed 13615.03 1
- Stopwatch, digital, 1/100 s 03071.01 1
- Magnetic stirrer, mini 47334.93 1
- Magnetic stirrer bar, l = 15 mm 46299.01 1
- Retort stand, h = 750 mm 37694.00 1
- Right angle clamp 37715.00 1
- Universal clamp 37715.00 1
- Precision balance CPA 623 S (620 g/0.001 g), set with software 49224.88 1
- Volumetric flask, 100 ml 36548.00 6
- Volumetric flask, 1000 ml 36552.00 6
- Volumetric pipette, 1 ml 36575.00 2
- Volumetric pipette, 5 ml 36577.00 1
- Volumetric pipette, 10 ml 36578.00 1
- Volumetric pipette, 20 ml 36579.00 3
- Volumetric pipette, 50 ml 36581.00 3
- Pipettor 36592.00 1
- Pipette dish 36589.00 1
- Glass beaker, 100 ml, tall 36002.00 4
- Glass beaker, 250 ml, tall 36004.00 1
- Syringe, 1 ml 02593.03 1
- Cannula, 0.6×60 mm 02599.04 1
- Funnel, glass, dₒ = 80 mm 34459.00 2
- Spoon 33398.00 1
- Pasteur pipettes 36559.00 1
- Rubber bulbs 39275.03 1
- Scissors, straight, l = 110 mm, pointed 64623.00 1
- Wash bottle, 500 ml 33931.00 1
- Membrane, permeable for cations 31504.02 1
- Cellophane, 200 × 200 mm 32987.00 1
- Potassium chloride, 250 g 30098.25 1
- Sodium chloride, 500 g 30155.50 1
- Hydrochloric acid, 0.1 M, 1000 ml 48452.70 1
- Water, distilled, 5 l 31246.81 1

**What you can learn about**

- Nernst equation
- Concentration cells
- Transference numbers
- Semi-permeable membrane
- Selectively permeable membrane

**Determination of diffusion potentials**

\[
\Delta \phi_D = \text{D for HCl as a function of } \ln \frac{c_2}{c_1} (0) \text{ and } \ln \frac{c_2}{c_1} (x) \text{ (for cellophane).}
\]

**Diffusion potential \( \Delta \phi_D \) for KCl as a function of \( \ln \frac{c_2}{c_1} \) (cation permeable membrane).**
Principle and tasks
The electromotive force is the potential difference of the single potentials of the according electrodes in a galvanic chain. It is equal to the difference of all the single potentials which can be calculated using the Nernst equation. Thermodynamic data of the gross reaction in a galvanic chain can be determined measuring the e.m.f. at different temperatures.

The usable reaction equivalent work of the Daniell element is determined by measuring the dependence of the electromotive force on temperature.

What you need:
- Digital pH-meter
- Copper electrode, \(d = 8\) mm
- Zinc electrode, \(d = 8\) mm
- Temperature meter, digital, 4-2
- Temperature probe, Pt100
- Protective sleeves for immersion probe
- H-base - PASS-
- Support rod, \(l = 250\) mm
- Support rod, \(l = 500\) mm
- Right angle clamp
- Universal clamp
- Universal clamp with joint
- Holder for two electrodes
- Immersion thermostat, 100°C
- Accessory set for immersion thermostat
- Bath for thermostat, 6 l, Makrolon
- Rubber tubing, \(d_i = 6\) mm
- Hose clip, \(d = 8...12\) mm
- Two-way switch, double pole
- Connecting cord, \(l = 500\) mm, red
- Connecting cord, \(l = 500\) mm, blue
- Connecting cord, \(l = 750\) mm, red
- Connecting cord, \(l = 750\) mm, blue
- Connecting cord, \(l = 100\) mm, black
- Holder for thermometer / tube
- Salt bridge
- Clay pins, \(d = 8\) mm, \(l = 15\) mm
- Silicone tubing, \(d_i = 7\) mm
- Rubber caps
- Syringe, 10 ml
- Cannula, 0.6×60 mm
- Glass beaker, 100 ml, tall
- Glass beaker, 150 ml, tall
- Glass beaker, 250 ml, tall
- Volumetric flask, 250 ml
- Graduated cylinder, 100 ml
- Pasteur pipettes
Principle and tasks
In a potentiometric titration the equivalence point is detected by monitoring the electromotive force (e.m.f.) of an electrochemical cell formed by an indicator electrode coupled with a convenient reference electrode. The potential of the indicator electrode, and hence the e.m.f. of the cell, is a measure of the activity (approximately the concentration) of the ionic species in the electrolyte solution. A potentiometric titration on the iron(II)/cerium(IV) redox system with a 0.1 molar iron(II) sulphate solution is performed to determine the concentration of an unknown iron(II) solution.

What you need:

- Electrochemistry LEC 06
- What you can learn about
  - Potentiometric titration
  - Redox reaction
  - Nernst equation
  - Quantitative analysis

Potentiometric redox titration curve for the Fe(II)/Ce(IV) system.
Principle and tasks
Precipitation reactions which occur stoichiometrically and rapidly and whose equilibrium lies on the side of the poorly soluble products can also be used titrimetrically. Consequently, a solution which contains both chloride and iodide ions can be titrated with a silver nitrate solution. The course of the titration is monitored potentiometrically and the equivalence points are determined from the inflection points of the potential curve.

What you can learn about
→ Electrode potential
→ Cell voltage
→ Electrodes of the 1st and 2nd type
→ Nernst equation
→ Argentometry
→ Solubility product

What you need:

Experiment P3061411 with Cobra3 Basic-Unit

<table>
<thead>
<tr>
<th>Item</th>
<th>Price</th>
<th>Quantity</th>
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<td>Cobra3 Basic-Unit</td>
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<td>Power supply, 12 VDC/2 A</td>
<td>12151.99</td>
<td>1</td>
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<td>Data cable, RS232</td>
<td>14602.00</td>
<td>1</td>
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<tr>
<td>Software Cobra3 Chem.Unit</td>
<td>14520.61</td>
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<tr>
<td>Measuring module pH/potential</td>
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</tr>
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<td>Reference electrode, AgCl</td>
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</tr>
<tr>
<td>Retord stand, h = 750 mm</td>
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</tr>
<tr>
<td>Right angle clamp</td>
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<tr>
<td>Universal clamp</td>
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<td>Burette clamp, roller mounting</td>
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<tr>
<td>and measure software</td>
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<td>Volumetric pipette, 10 ml</td>
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</table>

Precipitation titration

Course of the potential during the precipitation titration.
06.15  pH measurement

**What you need:**

- Digital pH-meter: 13702.93
- pH electrode, glass: 18452.00
- Reference electrode, AgCl: 18475.00
- Storage flask for pH-electrodes: 18481.20
- Platinum electrode in protective tube: 45206.00
- Antimony electrode: 18477.01
- Temperature probe, Pt1000: 13702.01
- Magnetic stirrer, mini: 47334.93
- Magnetic stirrer bar, l = 30 mm: 46299.02
- Retort stand, h = 750 mm: 37694.00
- Right angle clamp: 37715.00
- Support for two electrodes: 45284.01
- Spring balance holder: 03065.20
- Universal clamp: 37715.00
- Burette clamp, roller mounting: 37720.00
- Connecting cord, l = 500 mm, black: 07361.05
- Burette, 50 ml, lateral stopcock: 36513.01
- Silver nitrate, crystalline, 15 g: 30222.00
- Precision balance CPA 623S (620 g/0.001 g), set with software: 49224.88
- Weighing dishes, 80 × 50 × 14 mm: 45019.25
- Glass beaker, 150 ml, tall: 36003.00
- Graduated cylinder, 100 ml: 36652.00
- Volumetric flask, 1000 ml: 36552.00
- Volumetric pipette, 10 ml: 36578.00
- Volumetric pipette, 50 ml: 36581.00
- Graduated pipette, 25 ml: 36602.00
- Pipettor: 36592.00
- Pipette dish: 36589.00
- Pasteur pipettes: 36590.00
- Rubber bulbs: 39275.03
- Funnel, glass, d = 55 mm: 34457.00
- Funnel, glass, d = 80 mm: 34459.00
- Spoon: 33398.00
- Microscope: 33393.00
- Wash bottle, 500 ml: 33931.00

**What you can learn about**

- Potentiometric determination of pH
- Glass electrode
- pH indicators
- Acid-base titrations

**Principle and tasks**

The most important and common method to determine the pH value is to measure the potential of an electrode which is sensitive to hydrogen ion activity. Typically, an electrochemical cell is constructed from a pH sensitive electrode and a suitable reference electrode. The cell is then calibrated by measuring its e.m.f. in a series of solutions of known pH.

A glass electrode, an antimony electrode and a quinhydrone electrode are calibrated in buffer solutions and after that used to measure the pH of an unknown solution.

**Calibration curves for the antimony (o) and quinhydrone (x) electrode.** The cell e.m.f. E is measured using a Ag(Hg/AgCl/Cl−(aq)) reference electrode.

**What you need:**

- Quinhydrone, 100 g: 31195.10
- Methyl orange solution, 0.1%, 250 ml: 31573.25
- Bromthymol blue, 1 g: 31138.01
- Phenolphthalein solution, 1%, 100 ml: 31714.10
- Citric acid, 250 g: 30063.25
- Hydrochloric acid, 1 M, 1000 ml: 48454.70
- Sodium hydroxide solution, 1 M, 1000 ml: 48329.70
- Buffer solution, pH 4.62, 1000 ml: 30280.70
- Buffer solution, pH 7.01, 1000 ml: 46271.12
- Buffer solution, pH 9.00, 1000 ml: 30289.70
- Ethyl alcohol, absolute, 500 ml: 30008.50
- Water, distilled, 5 l: 31246.81

**pH measurement**

**P3061501**
Principle and tasks

pH values can be measured with the aid of electrochemical measurements and proton-sensitive electrodes (e.g. glass electrodes). The titration curves allow an exact determination of the equivalence point in titrations of strong and weak acids and bases.

Several strong and weak acids and bases as well as an ampholyte are titrated and the buffering capacities of various buffer mixtures are determined.

What you need:

- Titration curve of acetic acid with sodium hydroxide solution.

**Glass beaker, tall, 250 ml**
- 36004.00
- 1

**Glass beaker, tall, 150 ml**
- 36003.00
- 16

**Glass beaker, tall, 100 ml**
- 36002.00
- 1

**Glass beaker, tall, 50 ml**
- 36001.00
- 3

**Weighing dishes, 80 \times 50 \times 14 mm**
- 45019.25
- 1

**Funnel, \(d_o = 50 \, \text{mm} \)**
- 34457.00
- 2

**Funnel, \(d_o = 80 \, \text{mm} \)**
- 34459.00
- 3

**Spoon**
- 33398.00
- 1

**Wash bottle, 500 ml**
- 33931.00
- 1

**Acetic acid, 1 M solution, 1000 ml**
- 48127.70
- 1

**Caustic soda, 1.0 M solution, 1000 ml**
- 48329.70
- 1

**Hydrochloric acid, 1.0 M solution, 1000 ml**
- 48454.70
- 1

**Buffer solution, pH 4.62, 1000 ml**
- 30280.70
- 1

**Buffer solution, pH 9.00, 1000 ml**
- 30289.70
- 1

**Ortho-phosphoric acid 85%, 250 ml**
- 30190.25
- 1

**Glycine, 100 g**
- 31341.10
- 1

**Sodium acetate, 250 g**
- 31612.25
- 1

**Water, distilled, 5 l**
- 31246.81
- 2

**Set of Precision Balance Sartorius CPA 623S and measure software**
- 49224.88
- 1

**PC, Windows® XP or higher**
- 1

**Titrations curves and buffering capacity with Cobra3**

**Experiment P3061611 with Cobra3 Basic-Unit**

<table>
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<tr>
<th>Item</th>
<th>Code</th>
<th>Qty</th>
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<tr>
<td>Cobra3 Basic-Unit, USB</td>
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<td>1</td>
</tr>
<tr>
<td>Power supply, 12 VDC/2 A</td>
<td>12151.99</td>
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</tr>
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<td>Data cable, RS232</td>
<td>14602.00</td>
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<td>pH-electrode, gel, BNC</td>
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<td>Immersion probe NiCr-Ni, teflon</td>
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<td>Software Cobra3 Basic-Unit</td>
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<td>pH-electrode, gel-filled</td>
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<td>Software Cobra3 pH and potential</td>
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<td>Magnetic stirring, (l = 30 , \text{mm} )</td>
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<td>Retord stand, (h = 750 , \text{mm} )</td>
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<td>Holder for 2 electrodes</td>
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<td>Right angle clamp</td>
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<td>Burette clamp, roller mounting</td>
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<td>Burette, lateral stopcock, Schellbach, 25 ml</td>
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<td>Rubber bulbs</td>
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**Experiment P3061640 with Cobra3 Chem-Unit**

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<tr>
<td>Data cable, RS232</td>
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<td>Pipette dish</td>
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<td>Pasteur pipettes</td>
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</tr>
<tr>
<td>Rubber bulbs</td>
<td>39275.03</td>
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</table>
06.17 Potentiometric pH titration (phosphoric acid in a soft drink)

What you need:

- Set automatic titration with Cobra3 Chem-Unit: 43040.88
- Glass beaker, 50 ml, tall: 36001.00
- Volumetric flask, 100 ml: 36548.00
- Volumetric pipette, 5 ml: 36577.00
- Volumetric pipette, 50 ml: 36581.00
- Graduated pipette, 1 ml: 36595.00
- Pipette dish: 36589.00
- Pipettor: 36592.00
- Wash bottle, 500 ml: 33931.00
- Ortho-phosphoric acid, 85%, 250 ml: 30190.25
- Caustic soda solution, 0.1 M, 1000 ml: 48328.70
- Buffer solution, pH 4.62, 1000 ml: 30282.70
- Buffer solution, pH 7.01, 1000 ml: 46271.12
- Buffer solution, pH 9.00, 1000 ml: 30289.70
- Water, distilled, 5 l: 31246.81
- PC, Windows® XP or higher

What you can learn about:

- Galvanic cell
- Types of electrodes
- Nernst equation
- Potentiometry

Principle and tasks

The cell voltage and the Galvani voltage of the electrodes of an galvanic cell are dependent upon the concentration of the ions involved in the potential forming process. Measuring the change of the cell voltage in the titrations of phosphoric acid and a beverage containing phosphoric acid (E 338) conclusions can be made about the beverage's acid content.

Titration curve of a beverage containing phosphoric acid.
Electrode kinetics: The hydrogen overpotential of metals 06.18

Principle and tasks
Electrode polarization and the presence of overpotentials are important concepts in understanding electrode processes. They underlie the fact that galvanic cells always deliver current at less than the equilibrium e.m.f. and that an applied potential greater than the equilibrium e.m.f. is required in order to drive a reaction in an electrolytic cell.

The current-potential curve for the electrolysis of a 1 M hydrochloric acid solution is recorded using graphite rod electrodes, and the decomposition voltage is determined. By replacing the graphite rod cathode with a series of different metal rod electrodes, the overpotentials for hydrogen evolution at these metals can be compared.

What you can learn about
- Electrode kinetics
- Polarization
- Overpotential
- Voltammetry and current-potential curves
- Polarography

What you need:

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<td>1</td>
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<tr>
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<td>Lead electrode, d = 8 mm, l = 150 mm</td>
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<td>Nickel electrode, d = 8 mm, l = 150 mm</td>
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<td>Pencil</td>
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Electrode kinetics:
The hydrogen overpotential of metals 03061811
06.20 Amperometric equivalent point determination with the dead stop method

Principle and tasks
In amperometric titration, the current intensity is measured as a function of the added titrant. Here the content of an aqueous sodium thiosulphate solution is determined by titrating it with an iodine-potassium iodide solution. The equivalence point can be determined amperometrically with platinum electrodes.

What you need:

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<tr>
<td>Right angle clamp</td>
<td>37697.00</td>
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<tr>
<td>Holder for 2 electrodes</td>
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<td>Spring balance holder</td>
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</tr>
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<tr>
<td>Microspoon</td>
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</table>

What you can learn about

- Amperometric titration
- Electrode polarisation
- Maximum limiting diffusion current
- Overvoltage
- Polarography

Course of the current in the titration of thiosulfate solution with iodine solution.

Wash bottle, 500 ml                                                  | 33931.00 | 1        |
Sodium thiosulphate solution, 0.1 M, 1000 ml                        | 48345.70 | 1        |
Iodine, 25 g                                                         | 30093.04 | 1        |
Potassium iodide, 50 g                                              | 30104.05 | 1        |
Water, distilled, 5 l                                               | 31246.81 | 1        |

Amperometric equivalent point determination with the dead stop method P3062001
**Principle and tasks**

The correlation between the amounts of substances transformed in the electrode reaction and the applied charge is described by Faraday's laws. Faraday's constant, which appears as a proportionality factor, can be determined experimentally in this case from the dependence of the volumes of hydrogen and oxygen evolved on the applied charge in the hydrolysis of diluted sulphuric acid.

**What you need:**

- Power supply, universal 13500.93 1
- Digital multimeter 07128.00 1
- Electrolysis apparatus after Hofmann 44518.00 1
- Platinum electrode, protective sleeve, \( d = 8 \text{ mm} \) 45206.00 2
- On/Off switch 06034.01 1
- Connecting cord, \( l = 250 \text{ mm}, \text{ red} \) 07360.01 2
- Connecting cord, \( l = 500 \text{ mm}, \text{ red} \) 07361.01 1
- Connecting cord, \( l = 750 \text{ mm}, \text{ blue} \) 07362.04 1
- Retort stand, \( h = 750 \text{ mm} \) 37694.00 1
- Right angle clamp 37697.00 3
- Universal clamp 37715.00 2
- Stopwatch, digital, 1/100 s 03071.01 1
- Weather monitor, LCD 87997.10 1
- Precision balance CPA 623S (620 g/0.001 g), set with software 49224.88 1
- Beaker, 600 ml, short 36015.00 1
- Funnel, glass, \( d_o = 80 \text{ mm} \) 34459.00 1
- Pasteur pipettes 36590.00 1
- Rubber bulbs 39275.03 1
- Wash bottle, 500 ml 33931.00 1
- Sulphuric acid, 95…98 %, 500 ml 30219.50 1
- Water, distilled, 5 l 31246.81 1

**Determination of Faraday’s constant**

P3062101
## Principle and tasks
Electrogravimetry is an important analytical method for the quantitative determination or separation of species in solution. The technique involves the quantitative electrolytic deposition of an element, here copper, on a suitable electrode in a weighable form.

### What you can learn about
- Quantitative analysis
- Electrolysis
- Gravimetry
- Overpotential and electrode polarisation

### What you need:

<table>
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<tr>
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<th>Code</th>
<th>Quantity</th>
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</tr>
<tr>
<td>Digital multimeter</td>
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<td>Holder for two electrodes</td>
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<td>Right angle clamp</td>
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<tr>
<td>Water, distilled, 5 l</td>
<td>31246.81</td>
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</tr>
</tbody>
</table>

### Electrogravimetric determination of copper

P3062201
Photometry and Photochemistry

Contents
LEC 07.01 Absorption of light
LEC 07.03 Excitation of molecules
LEC 07.04 Absorption spectra and $pK_a$ values of $p$-methoxyphenol
07.01 Absorption of light

What you need:

- Spectrophotometer 190 – 1100 nm
- Cells for spectrophotometer
- Precision balance CPA 623S (620 g/0.001 g), set with software
- Weighing dishes, 80 \times 50 \times 14 mm
- Volumetric flask, 100 ml
- Funnel, glass, \(d_o = 55\) mm
- Volumetric pipette, 1 ml
- Pipette dish
- Pipettor
- Microlitre syringe, 100 ml
- Microspoon
- Wash bottle, 500 ml
- Methyl orange solution, 0.1 %, 250 ml
- Methyl alcohol, 500 ml
- Ethyl alcohol, 500 ml
- Ethylene glycol, 250 ml
- N,N-Dimethylformamide, 1000 ml
- Water, distilled, 5 l

Absorption of light

P3070101

What you can learn about

- Electron excitation
- Solvatochromism
- Hypsochromic and bathochromic shifts
- Lambert-Beer law

Principle and tasks

In dilute solution the solvent changes the binding relationships of the dissolved substance. This influence shows itself in the electron spectrum.

An UV-VIS absorption spectra of methyl orange is recorded in different solvent. The type of electron transition which causes the bands in the visible region can be determined via the decadic molar extinction coefficient.

Plot of the absorption maxima of methyl orange against the relative dielectric constants of different solvents.
What you can learn about
- Wave mechanical model of the atom
- Electron excitation spectroscopy
- Chemical colour theory
- Lambert-Beer law

Principle and tasks

In the spectral region between 200 and 800 nm, which is recorded by UV-VIS spectroscopy, transitions from the electronic ground state into electronically excited states occur. These transitions are induced by interaction of the investigated structures with high-energy electromagnetic radiation.

The absorption of the polyene dyestuff carotene is recorded in the visible region of the electromagnetic spectra. The wavelength for the absorption maximum is compared with the value calculated according to the model concept of the electron in a one-dimensional trough.

Absorption spectrum of carotene in acetone.

What you need:

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<th>Quantity</th>
<th>Price</th>
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Kitchen grater
Carrot

Excitation of molecules

P3070301
07.04 Absorption spectra and pKₐ values of p-methoxyphenol

What you need:

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What you can learn about

- Ground and excited states of molecules
- Jablonski diagram and Förster cycle
- Henderson-Hasselbalch equation
- Lambert-Beer law
- Photometry

Principle and tasks

For weak acids HA, the position of the Kₐ and pKₐ values, which characterise the dissociation equilibrium, can be determined in the ground state via photometric measurements in solutions having different pH values. Beyond this, the pKₐ* value for the excited state is accessible from spectroscopic data.

The absorption spectra from p-methoxyphenol in diluted HCl, NaOH and 5 different borate buffer solutions having known pH values are recorded in the near UV-region. From the measuring results, the pKₐ and pKₐ* values of the system can be calculated.

Absorption spectra of p-methoxyphenol at different pH values.

Graphic determination of the pKₐ value of p-methoxyphenol.
Computer assisted Experiments with Cobra3 Physics, Chemistry/Biology

Cobra3 Physics • No. 01310.02

84 described Experiments
Please ask for a complete equipment list Ref. No. 2.142 (13381)

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1.1 Frequency of a spring pendulum (13301)
1.2 Frequency of a thread pendulum (13302)
1.3 Free fall with a screen (13369)
1.4 The path-time law for free fall with the falling sphere apparatus (13371)
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1.6 Free fall, linear motion (13373)
1.7 Uniformly accelerated, linear motion, Newton's 2nd law (13374)
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2.6 Measurement of the speed of sound in metal rods (13364)
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2.8 Investigation of beats (13615)
2.9 Influence of damping on the spectrum of the characteristic oscillations of air columns (13619)
2.10 Characteristic oscillations in cavity resonators - Heimholtz's resonators (13620)
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Tone analysis
resonators - Heimholtz's resonators
oscillations of air columns
2.8 (13619)
Investigation of beats
2.6 (13365)
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PHYWE Systeme GmbH & Co. KG
D-37070 Göttingen
Federal Republic of Germany

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or contact our local representative

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Information / Quotation

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Please send detailed descriptions, free of charge
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