WP3| D3.2

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Work Package 3 | Deliverable 2

D3.2 Piloted, culturally adapted, teaching and learning IBSE units – Part II

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Name of lead partner for this report:	DCU

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A. Background to this report

This report is a deliverable of Work Package 3 (WP3) of the European FP7-funded project "European Science and Technology in Action: Building Links with Industry, Schools and Home" (ESTABLISH; 244749, 2010-2013). It meets the requirements of the Deliverable 3.2 by presenting the piloted, culturally adapted, teaching and learning IBSE units – Part II as developed by the beneficiaries of ESTABLISH are listed in the following table.

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B. The ESTABLISH consortium

Beneficiary short name	Beneficiary name	Country	Abbreviation
DCU	DUBLIN CITY UNIVERSITY	Ireland	IE
AGES	AG EDUCATION SERVICES	Ireland	IE
UCY	UNIVERSITY OF CYPRUS	Cyprus	CY
UmU	UMEA UNIVERSITET	Sweden	SE
JU	UNIWERSYTET JAGIELLONSKI	Poland	PL
CUNI	UNIVERZITA KARLOVA V PRAZE	Czech Republic	CZ
AL	ACROSSLIMITS LIMITED	Malta	MT
UPJS	UNIVERZITA PAVLA JOZEFA ŠAFÁRIKA V KOŠICIACH	Slovakia	SK
COUO	CARL VON OSSIETZKY UNIVERSITAET OLDENBURG	Germany	DE
UTARTU	TARTU ULIKOOL	Estonia	EE
UNIPA	UNIVERSITA DEGLI STUDI DI PALERMO	Italy	IT
MaH	MALMÖ UNIVERSITY	Sweden	SE
IPN	LEIBNIZ-INSTITUT FUER DIE PAEDAGOGIK DER NATURWISSENSCHAFTEN UND MATHEMATIK AN DER UNIVERSITAT KIEL	Germany	DE
CMA	CENTRE FOR MICROCOMPUTER APPLICATIONS	Netherlands	NL
MLU	MARTIN LUTHER UNIVERSITAET HALLE-WITTENBERG	Germany	DE

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European Science and Technology in Action Building Links with Industry, Schools and Home

Work Package 3
Designing a Low Energy Home: Heating and Cooling
A – Teacher Information

European Science and Technology in Action: Building Links with Industry, Schools and Home

Lead partner for deliverable: **University of Palermo, Italy**

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A. Teacher Information

1.1 I. Unit description

The Unit is aimed at engaging high school students in designing and building an energy-efficient scale model house through the understanding of relevant concepts in the content area of energy flow in thermal systems. It is developed into 4 sub-Units that analyse the different processes of thermal energy transfer (conduction, convection and radiation). The project intends also to introduce pupils to i**nfrared thermography**, **thermal imaging and thermograms**, i. e. **infrared imaging science**.

The content area of the Unit is energy and power in thermal systems. The sub-units are mainly devoted to 14-16 year old students and deepening is also designed for 16-18 year old students involving mathematization of data analysis and theoretical formalization.

The estimated duration of the whole unit is 30 hours. However, it can be used partially and at different deepening levels. Details of partial times are supplied for the single subunits.

The Unit uses hands-on activities, scientific simulations and probe-ware measurements as tools to develop an Inquiry Based Approach.

1.2 II. IBSE character

This unit can be used to develop students' ability to plan investigations, develop hypothesis, distinguish alternatives, searching for information, constructing models and debating with peers. It covers different types of inquiry activities, from interactive demonstration to open inquiry. The main problem dealt with the unit is divided in sub-problems faced in the different subunits that develop by increasing student participation and independence.

The unit can be implemented in different ways, and for each sub-unit emphasis can be placed on different elements of inquiry. However, in each sub-unit a progression in assigning autonomy to student is foreseen by making the suggested questions more general.

In each subunit, the teacher may start with either a series of questions or with an interactive demonstration, like in subunit 2, where the initial demonstration poses the problem to be investigated and inquiry can be developed in different steps (some of them are suggested by the activities that lead to questions for further investigations). All the activities may be guided, bounded or lead into open inquiry settings. However, the initial activities given in each sub-unit will form the background for further open inquiry activities to be performed by students.

In order to focus on the different skills connected with the inquiry process, the starting point of each activity is a well defined problem whose solution requires students' engagement, raising questions and developing hypotheses. The teacher control of students' activities is mainly connected with students' expertise in autonomous work and during the succession of the proposed activities the degree of teacher's guidance decreases.

Details about the inquiry types and E-emphasis will be supplied for each sub-unit.

III. Content Knowledge

Core physics concepts of this study are: thermal energy, heat and temperature. Such concepts involve many difficulties that often are connected with different definitions in textbooks. For this reason we, here, clarify the main definitions of the involved concepts.

In the Unit we discuss about Thermal Energy arising from the fact that particles of matter are in constant motion and that this motion relates directly to the state of matter of the object (solids, liquids, or gases). Temperature affects how fast these particles move. The higher the temperature the faster the particles move. Moving particles possess kinetic energy.

Temperature is defined as a measure of the *average kinetic energy of the particles of an object*.

Thermal Energy is the total sum of all the energies of the object particles.

As a consequence, thermal energy and temperature are related though different: temperature is proportional to the average kinetic energy of the particles; thermal energy is the total amount of the kinetic energy of the object particles.

Transfer of thermal energy between systems can happen through three different processes:

Conduction – *direct contact*

Convection – *through a fluid*

Radiation – *by electromagnetic waves*

The term **heat** involves the quantity of energy transferred from one place in a body or thermodynamic system to another place, or beyond the boundary of one system to another one due to thermal contact when the systems are at different temperatures. In this description, it is an energy transfer to the body in any other way than the mechanical work performed on the body

Transfer by conduction is the transfer of thermal energy between regions of matter due to a temperature gradient. Heat spontaneously flows from a region of higher temperature to a region of lower temperature, temperature differences approaching thermal equilibrium..

On a microscopic scale, conduction occurs as rapidly moving or vibrating atoms and molecules interact with neighboring particles, transferring some of their kinetic energy. Heat is transferred by conduction when adjacent atoms vibrate against one another, or as electrons move from one atom to another. Conduction is the most significant mean of heat transfer within a solid or between solid objects in thermal contact. Conduction is greater in solids because the network of relatively fixed spatial bounds between atoms helps to transfer energy between them by vibration.

Transfer by convection is the transfer of thermal energy through a substance by mean of currents of fluids (liquids and gases).

Transfer by radiation is transfer by electromagnetic waves. These waves may pass through all matter states and also through the vacuum space by transferring energy called radiant energy.

Transfer by conduction and convection involves a direct contact between bodies at different temperatures. In this case we say that heat is exchanged between the two bodies. Transfer by radiation involves interaction between one body and the electromagnetic radiation emitted by the other body.

Concerning the specific content objectives, these involve the ability to:

- Differentiate between heat and temperature;
- Understand the concept of thermal equilibrium and thermal process;
- Differentiate among conduction, convection, and radiation;
- Give examples of how conduction, convection, and radiation are considered in choosing materials for buildings and designing a house model;
- Explain how environmental factors such as wind, solar radiation, and temperature affect the design of a house and the choice of the materials.

IV. Pedagogical Content Knowledge

PCK involved in the Unit is related to the analysed physics topics, as well as to its IB approach. With reference to the domain of physics topics, relevant elements are the following:

- To make teachers aware of expected difficulties, misconceptions and/or alternative conceptions in the understanding of the content (as for example "*Heat as energy contained in a body", "Temperature as a measure of heat in a body", "Different bodies placed in the same environment have different temperatures"…………………..),*
- To gain ability in using Scientific Instructional Representations (models, mathematical representations,.....) by connecting them and making evident their rationale to fit students' reasoning.
- To be aware of students' learning difficulties in sketching microscopic behaviours.
- To connect physics concepts with everyday phenomena.
- To relate observation of phenomena with students' representations and models.

With regard to the features of IB approach, teachers especially need to gain pedagogical content knowledge enabling them to "engage students in asking and answering scientific questions, designing and conducting investigations, collecting and analyzing data, developing explanations based on evidence, and communicating and justifying findings" . This mainly involves to make teachers able to:

- Provide questions to frame unit and questions for discussion
- Suggest approaches for using technologies as laboratory and cognitive tools.
- Suggest approaches for collecting and analysing data.
- Support students in designing their own investigations.
- Suggest approaches to help students construct explanations Based on Evidence
- Provide approaches for promoting science communication Baseline feature.

1.3 V. Industrial Content Knowledge

Thermal insulation reducing of the effects of the various processes of heat transfer between objects in thermal contact or in range of radiative influence has a lot of industrial

applications : from clothing to building construction and mechanical insulation for pipes and aircrafts.
Information will be supplied in each sub-unit about appropriate industrial web-sites emphasizing the engineering characteristics of isolating materials. Moreover, examples will be supplied about how conduction, convection, and radiation are considered in choosing materials for buildings and designing a heating system and in explaining how environmental factors such as wind, solar angle, and temperature affect design of houses.

VI. Learning paths

The learning path is developed through 4 sub-units that face the different aspects of constructing an energy-efficient scale model house.

Sub-Unit_1 guides students in the construction of a model house and in making explicit the different factors that contribute in heat dispersion and energy consumption to maintain warm the house. Each factor is analysed in the other sub-units that are also developed around a particular problem that guides the inquiry.

Sub-Unit_2 analyses the role of different materials in heat dispersion by developing the relevant concepts connected with energy transfer through conduction.

Sub-Unit_3 analyses energy transfer in fluid material and the main concepts connected with the convection process.

Sub-Unit_4 introduces the concept of energy transfer by radiation, analysing the different effects of solar radiation spectrum.

VII. Assessment

In all Sub-Units the students' assessment should include both a theoretical test (understanding basic concepts) as a practical assignment. Assessments of students' understanding of operative procedures such as observation, hypothesizing, explaining, …, is also to be taken into account.
Examples of prototypical question are given in each sub-Unit.

VIII. Student learning activities

SUB_UNIT_1: Testing a house model

1.4 Learning Path

This sub unit introduces basic concepts such as heating/cooling rates, energy conservation, conduction, convection, and radiation, and engineering elements such as insulation, glazing, thermal storage, and passive heating and cooling. It also aims at recalling previous learned concepts of heat, temperature and thermal equilibrium by taking into account the well known misconceptions held by students at this school level.

At the end of this sub unit, students should have a basic understanding of some physical processes, such as how heat transfer occurs between the house and the environment under different weather conditions.

Students will be involved in constructing a scale model house using a hands-on kit supplied by the teacher. They will learn to use sensors to measure the heat gain or loss and evaluate insulation. They will explore different heating and cooling factors using the tools provided and other low-cost materials on hand. For instance, a light bulb (covered by an aluminium foil) models the heather, the effects of wind can be simulated using an electric fan, and sun shining heating by using a lamp .

The sub-unit involves 3 student learning activities:

a. Activity 1_1 aimed at the construction of different kinds of house models and at evaluating the main difficulties in maintain them warm;
b. Activity 1_2 aimed at analysing the distribution of temperature inside the house model;
c. Activity 1_3 aimed at analysing the heating effects of light on the house models.

The following table characterises the three activities from the point of view of the required type of inquiry and considering the 5E model of the Learning Cycle (Engage, Explore, Explain, Extend, Evaluate) (see the Guide for developing Establish Teaching and Learning Units for more detail).

Activity	***Student Task***	***Inquiry Type***	***E-emphasis***
1_1	Discussing and experimenting how to maintain warm a house model	Interactive demonstration Guided discovery	Engage Explore
1_2	Experimenting distribution of temperature inside the house model	Guided inquiry Bounded Inquiry	Engage Explore Explain
1_3	Hypothesizing and experimenting the sunshine effects on the house model temperature	Guided inquiry Bounded Inquiry Open Inquiry is also possible	Engage Explore Extend

Activity 1_1: How to maintain warm your house model

The Problem:

In winter we need energy to maintain warm our house. By using suitable designed house models it is possible to analyse how much energy it takes to warm each house model 5°C warmer than the air around it.

Learning aims:

The main objectives of such activity are to:

- design an experiments to measure the heating an cooling of different house models by using the same heating procedure;
- identify the different factors that can influence the heat dispersion and control them in the design;
- measure how much energy is necessary to warm each house model 5°C warmer than the environment.

Materials:

- Boxes of different materials (styrofoam, wood, glass, aluminum, plasterboard) and equal dimensions, modeling different kinds of houses.
- Temperature sensors to put in the wall opposite to the heater.
- Heaters (light bulbs covered by aluminium sheets)

Suggestions for use:

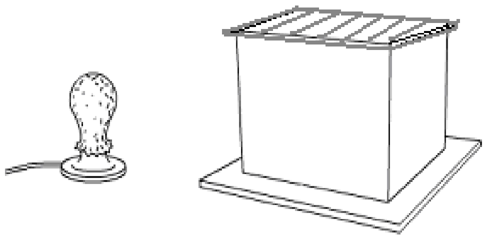


Figure 1_1a

Figure 1_1b

Different groups of students can be supplied with different house models having the same dimensions and constructed using different materials. The heater and the sensor are placed as reported in Fig 1:1b.

The main problem is to test how fast their house models heat up and then cool down with a known power source (the heater).

Students are asked to :

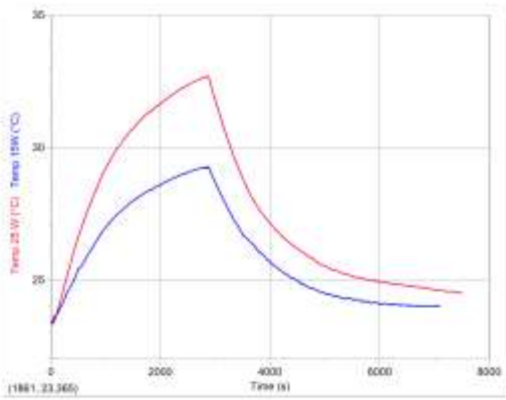
- turn on the heater and register the temperature until it reaches approximately the value of T_{env} +5°C.
- Then, turn off the heater so that the temperature lowers until Tenv.
- Record the times in which the heater is turned on and off.

- Calculate the time amount the heater has to be on to keep the house warm (T_{env} +5°C).

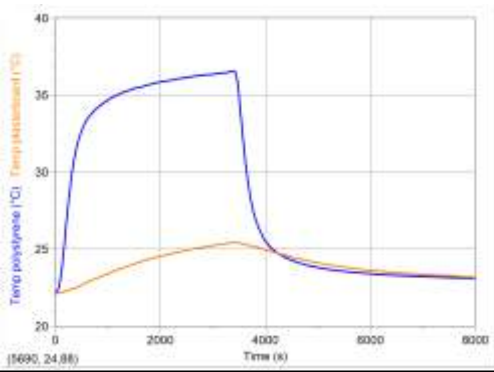
Each group will report to the whole classroom its results in order to point out what model is better for saving energy.

The following images show some temperature data from different houses under different thermal conditions.

1. Heating-cooling cycle of the wooden house model warmed by a 15 W lamp (blue line) and 25 W lamp (red blue line):



2. Heating and cooling curves of house models constructed with plasterboard core vs. polystyrene with a 25W heater.



NOTE

In this activity the teacher can introduce students to the different types of thermometers. Starting from the familiar mercury-in-glass one, the teacher can present and discuss the use of modern digital thermometers, based on semiconductor probes, and infrared ones, that allow to measure the temperature of distant objects, without having to have a "physical" contact with it.

Then, microcomputer based temperature sensors can be presented and, in particular, the surface type one, that will extensively used in this and in the following activities. As a last step, photos of thermograms can be shown, in order to introduce students to thermal/colour analysis, a subject that will be deepened in the fourth sub-unit.

Possible questions:

How do you think you could reduce the power necessary to maintain warm the house ? What would you change about your house to minimize the necessary power to keep the house warm and why?

Activity 1_2: How is the temperature distributed inside your house model ?

The Problem:

It is easy to observe that inside a heated room different places are not at the same temperature. How can we identify places at higher temperatures?

Learning aims:

The main goal of such an activity is in understanding that variations of temperature are present inside the house in places at different distances from the heater and at different heights from the floor.

Materials:

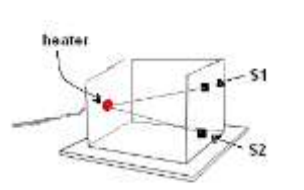
Materials are the same as Activity 1_1 , yet for each group of students two temperature sensors are necessary.

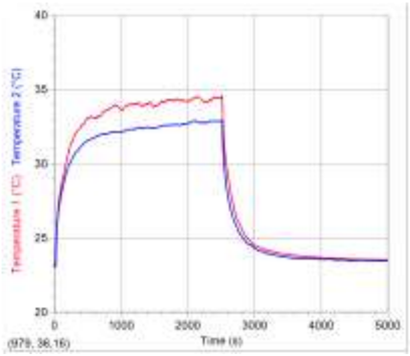
Suggestions for use:

Students are requested to analyse temperature distribution inside the house. A preliminary discussion will guide students to identify the factors that affect the temperature in a given position. Distance from the heater and height from the floor can be identified as relevant factors.

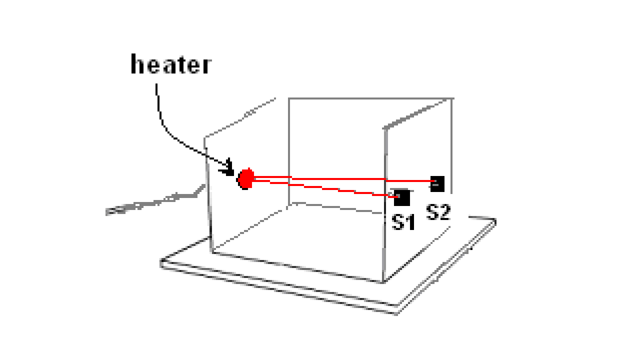
Students are requested to design appropriate experiments that take into account the control of the relevant variables.

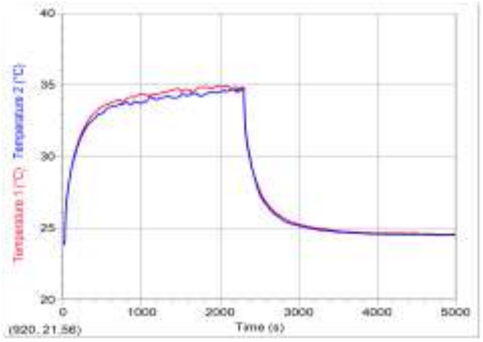
- **Two sensors at the same distance from the heater and at different height from the floor**





- **Two sensors at the same distance from the heater and at the same height from the floor**





Possible questions:

- What can you say about the efficiency of a heater mounted high on the wall of a room
- Can you infer a mechanism explaining why cool air goes upward?

Activity 1_3: What is the effect of sunlight on the temperature inside your house model?

The Problem:

It is easy to observe that bodies are heated by the sun shining. This can be also the case for walls of our house models. How materials can influence the temperature inside the house?

Learning aims:

The main goal of such an activity is the analysis of solar effects on the house temperature. Specific objectives are the following:

- to point out the effect of wall colours on the radiation absorption;
- to make evident that the house model temperature is affected by absorption and conduction of wall materials;
- to be able to make prediction on the basis of everyday experience;
- to be able to justify evidence on the basis of everyday experience.

Materials:

- Boxes of different materials (styrofoam, wood, glass, aluminum, plasterboard) and equal dimensions, modeling different kinds of houses (see Activity 1_1.
- Temperature sensors to put in the wall opposite to the heater
- A light bulb simulating the sun.

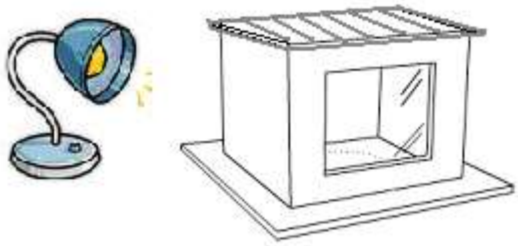
Suggestions for use:

In order to analyse the effect of an outdoor heating source we add a very bright light bulb (200 W) outside as the “sun”.
Students are requested to test the effect using a temperature sensor posed on the wall opposed

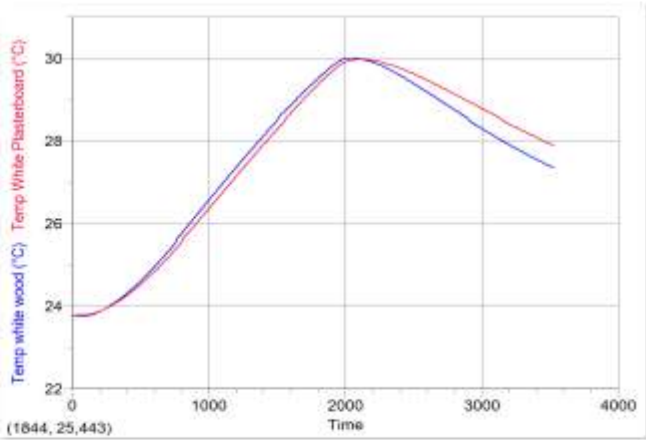
to the lightened wall.

A different experiment can be performed by using both the heaters (internal and external) , for example by turning the internal heater on and off, but leave the sun on all the time.

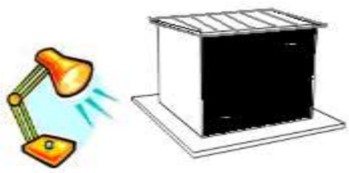
- **Two different boxes (wood and plasterboard) heated with the same "sun".**



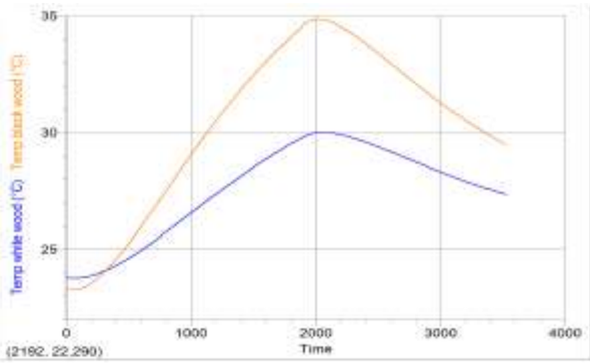
Two models with walls of different materials are heated by the same lamp. Figure shows two heating and cooling curves.



- **Two external wall of the same box painted of different colours**



The experiment is performed by painting black and white two outer walls of one house model and lightning them by the same lamp. The figure shows the two heating and cooling curves.



SUB-UNIT_2: Conduction

Learning path

This sub_unit analyzes the transfer of thermal energy between regions of matter due to a temperature gradient. Conduction characterizes the heat flows through the region of matter itself, as opposed to requiring bulk motion of the matter as in convection. Conduction takes place in all forms of matter, viz. solids, liquids, and gases but does not require any bulk motion of matter. However it mainly characterizes heat transfer in solids, since in liquids and gases convection is the main process of heat transfer.

OBJECTIVES OF THE SUB_UNIT:

- To be aware that the nature of material influence transfer of thermal energy between two thermal systems
- Students will rank the materials used, according to their thermal conductivity.
- Students will use experimental evidence to decide on an everyday problem.
- Students will work in groups in order to design and carry out an experimental investigation.
- Students will reflect on the purpose and nature of experimental activities they carried out in the unit

The sub-unit is developed in 2 activities.

The following table characterises the two activities from the point of view of the required type of inquiry and considering the 5E model of the Learning Cycle.

Activity	*Student Task*	*Inquiry Type*	*E-emphasis*
2_1	Observing ice liquefying in plates of different materials	Interactive demonstration Guided discovery	Engage Explore
2_2	Measuring isolation properties of different materials	Guided inquiry Bounded Inquiry Open Inquiry is also possible	Engage Explore Extend

Activity 2_1: Observing ice melting in plates of different materials

The Problem:

Activity 1_1 made evident that house models with wall of different materials warm up and cool down in different times. Moreover, by touching different materials in equilibrium with the environment it seems that they are at different temperatures since they supply different sensations of hot or cool. All these facts show different behaviours of materials in presence of a temperature gradient. This can be the starting point of the inquiry analyzing this kinds of behaviours.

As a first step, the melting time of equal ice cubes, at the same temperature and placed in different plates, will be analysed.

Learning aims:

- To be aware that the nature of material influences transfer of thermal energy between bodies at different temperatures.
- To be able to classify materials according to their capability to conduct heat.
- To identify variables that influence the heat conduction.

Materials:

- Squares of different dimensions (surfaces and thickness) and different materials.
- A set of ice cubes of almost the same dimension and at the same temperature (taken from the same refrigerator).

Suggestions for use:

The teacher can show the apparatus (see fig. 2_1a) and stimulate students to make predictions about the melting times

NOTE. It could be useful, at this stage, to discuss about the feeling of warmness and coldness coming from touching different bodies, and also ask students about their bodies' temperature.

At this stage, it is also interesting to discuss about the concept of thermal equilibrium.

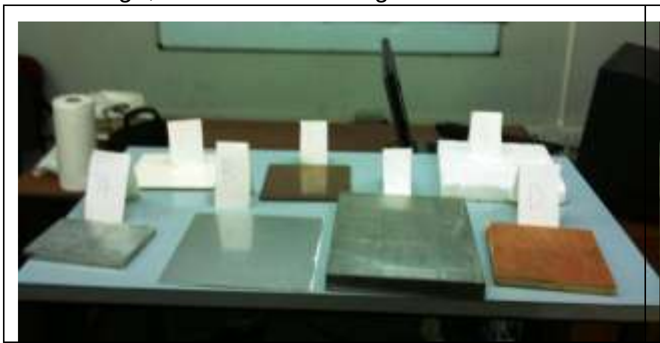


Figure2_1a

Figure2_1b

After the observation the whole class will discuss the results, by confronting them with their own predictions and making hypotheses about the influence of different parameters on melting times

Teachers will introduce the concept of thermal conduction by discussing with pupils how to analyse the different parameters influencing the results (see fig. 2_1b).

Possible questions:

Questions referring to materials commonly used in everyday life and allowing a discussion about thermal insulation and thermal exchanges between environments at different temperature.

Activity 2_2: Measuring insulation properties of different materials

The Problem:

Pick a test material from the available collection of sample squares (different materials and different thickness). Equal quantities of hot water are put in equal foam cups and the class will discuss how to organise the experimental analysis. Students will choice, in groups, 2 sample squares and will discuss with the teacher their choice by making predictions about the thermal insulation of the chosen squares.

Learning aims:

- To be aware that the nature of material influences transfer of thermal energy between bodies at different temperatures.
- To be able to classify materials according to their capacity to conduct heat.
- To identify variables that influence the heat conduction.

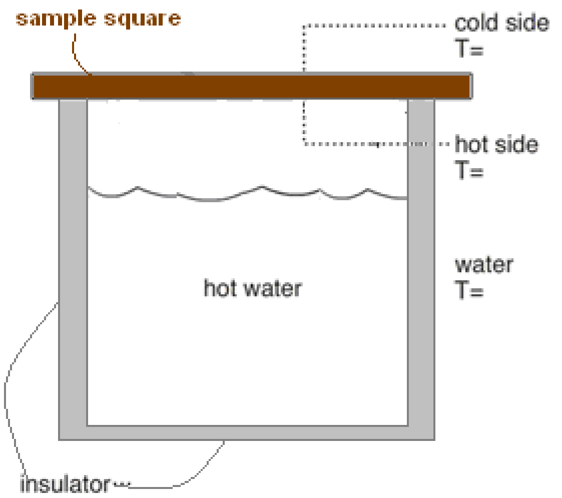
Materials:

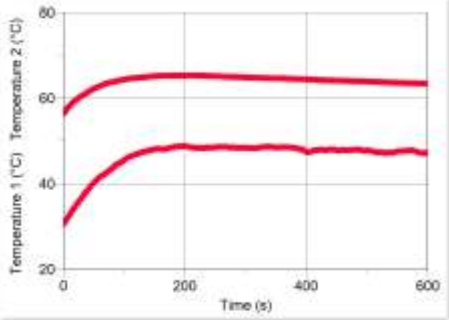
- Couples of squares of the same material and surface and different thickness.
- Cups of Styrofoam
- Temperature sensors to be put on the inner and outer surfaces (see Fig 2_2a) .

Suggestions for use:

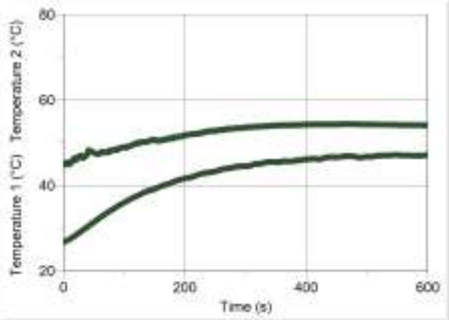
Students place in the cup, along with a thermometer, a given quantity of hot water. They can register temperature at fixed time instant. To use temperature sensors can speed up the procedures and it results more effective in the visualization of temperature data.

Students can analyse:
The difference between the inside and outside temperatures of all the materials (see fig. 2_2a) and verify that their temperature are almost constant (for a time of the order of some minutes). See figure 2_2b.





Plastic



Aluminium

Figure 2_2a	**Figure 2_2b**

The whole class can analyse the data of groups that used squares of the same thickness and order the materials from the greatest to the lowest temperature difference (see fig. 2_2_c) and define (on the basis of measurements) which material they think is the best conductor and the best insulator.

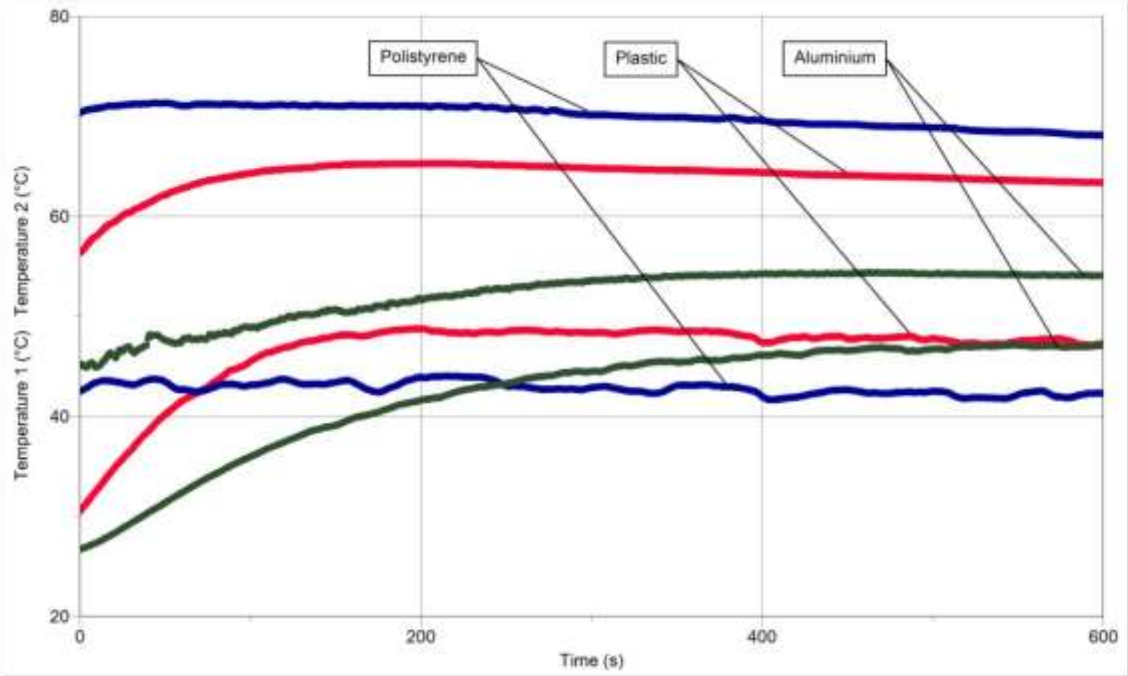


Figure 2_2c

Teachers will discuss with pupils how to analyse the different parameters influencing the results

NOTE

Students compare the results of their experiments to their predictions and proceed in identifying and justifying any differences.

Possible questions:

Outline differences of materials used in the construction of different kinds of buildings with respect to thermal insulation.

Sub_Unit_3: Convection

Learning path

This sub_unit analyses the transfer of thermal energy due to a bulk, macroscopic movement of matter (fluids or gases) from a hot region to a cool region.

The starting point is the analysis of Activity 1_2 of sub_Unit_1 that will be supported by further observations performed in Activity 3_1 whose objective is to make evident the currents of hot fluids moving from hot to cold regions.

This activity will end by supplying an explicative model, i.e. a qualitative mechanism of functioning explaining natural convection on the base of density differences among fluid volumes at different temperature. Such a model will be used in order to explain the “stack effect” or the “chimney effect”, where rising hot air pushes outward at the top of a building and cold air is drawn inward at the bottom.

A second activity (Activity 3_2) will analyse the effect of moving air on surface temperatures by confronting results of two experiments measuring natural cooling and forced cooling. Data can be analysed at different levels by characterising phenomena qualitatively or quantitatively in dependence of the classroom mathematical knowledge.

The following table characterises the two activities from the point of view of the required type of inquiry and considering the 5E model of the Learning Cycle.

Activity	*Student Task*	*Inquiry Type*	*E-emphasis*
3_1	Observing convection currents	Interactive demonstration Bounded Inquiry	Engage Explore
3_2	Experimenting different kinds of convection	Guided inquiry	Engage Explore Elaborate Extend

1.5

Activity 3_1: Observing convection currents
The Problem:
Activity 1_2 makes evident that different temperatures are measured in different places of our house model, where an heater is turned on. Now we will observe what happens in a basin where different sides are at different temperatures.
Learning aims:
• To be aware that temperature gradients in fluids produce convective currents. • To identify mechanisms of functioning” on the base of density differences among fluid volumes at different temperatures and buoyancy properties.
Materials:
• Two bowls filled of hot water and ice, respectively.

- A small fish tank filled with water at room temperature.
- Two small amount of red and blue dyes.

Suggestions for use:

		
Figure 3_1a	**Figure 3_1b**	**Figure 3_1c**

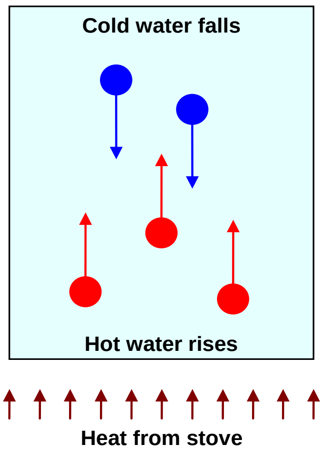
The fish tank filled with water is placed over the two bowls (see Fig. 3_1a) and two drops of red and blue dyes are gently posed on the tank surfaces (see Fig. 3_1b). At the following web site (http://www.youtube.com/watch?v=7xWWowXtuvA&feature=related) you can see the video of the experiment.

The teacher can perform the demonstration and put questions recalling every days phenomena stimulating students to identify variations of density in equal volumes of the same fluid at different temperatures and the consequent upward movement of hot fluid.

Possible questions:

1. **What happens if we put a drop of oil at the bottom of a basin containing water? Why?**
2. **Analyse the heating of a pot of water on a stove and describe what happens.**

*NOTE: A well known example of heat transfer by convection is provided by the heating of a pot of water on a stove. Turning on the stove thermal energy is transferred first by conduction from the stove to the bottom of the pot and from this latter to the water. After a given time some bubbles of hot water on the bottom of the pot appear. These bubbles, that actually are local regions of hot water less dense than the cold one, rise to the surface and by the mechanism of convection transfer heat from the hot water, at the bottom, to the cold water, at the top. At the same time, the cold water at the top, denser then the hot one, falls to the bottom and is heated to this latter. The following figure shows the **convection currents**.*



3. Why does this balloon move upward?

	The figure shows a popular toy The hot air balloon: when the candle is lighted the balloon begins to move upward. Can you explain why?

NOTE

By analysing students' answers to posed questions, the following kind of mechanism can be hypothesized.

Suppose we consider heating up a local region of air. As this air heats, the molecules spread out, causing this region to become less dense than the surrounding, unheated air. As a consequence, being less dense than the surrounding cooler air, the hot air will rise due to buoyant forces and this movement of hot air into a cooler region will transfer energy by heating the cooler regions.

Further questions can be posed through the analysis of the following phenomenon:

DAY TIME NIGHT TIME

Phenomena of breezes over land masses near to large basins of water supply a relevant example of convection currents. Water has a larger heat capacity than land. As a consequence it holds heat better than land and takes longer to change its temperature, either upward or downward. Thus, in the morning, due to the sun heating, the air above the water is cooler than that over the land. This creates a low pressure area over the land, with respect to the high pressure area over the water. Due to this pressure difference air is pushed from the water to the land as a blowing breeze. On the other hand, during the night water cools off more slowly than the land, and the air above the water is slightly warmer than over the land. This produces a low pressure area over the water with respect to the high pressure area over the land, and this time air is pushed from the land to the water.

Activity 3_2: Natural and forced cooling

The Problem:

In many cars the engine or the circuit of cooling water are cooled by forced convection. In fact, it is easily observable that the engine temperature goes down when the car is moving: air with a given velocity cools better the engine than air still with respect to the engine.

How can we verify the effect of moving air in a process of cooling?

Learning aims:

- Make students aware of different aspects of convection in air.
- Make students aware of how experimental evidence can help them to decide on an everyday problem.
- Gain abilities in collaborative work aimed at design and carry out an experimental investigation.
- Gain abilities in reflecting on the purpose and nature of experimental activities they carried out in the unit.

Materials:

- Two squares of aluminium (side ≅ 15 cm, depth ≅ 3mm),
- Two temperature surface sensors
- A bowl with hot water (about 90°C)

- Two plastic bags
- Two isolating supports (Styrofoam)

Suggestions for use:

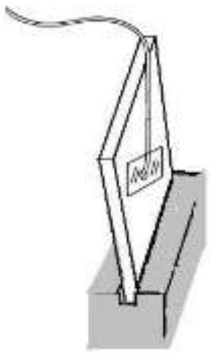


Figure 3_2a

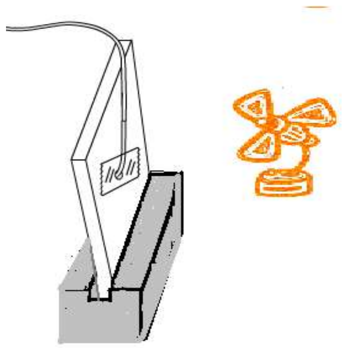


Figure 3_2b

Two squares of aluminium (side ≅ 15 cm, depth ≅ 3mm), previously heated at a temperature of about 90°C (for details see Classroom activities) are set on Styrofoam isolating blocs (see figs 3_2a) and 3_2b)) and are leaved cooling by air at room temperature. Fig. 3_2a) shows the case of natural cooling and Fig. 3_2b) the case of forced cooling. Temperature are registered by two surface sensors previously posed in contact with one square surface using two pieces of scotch.

Figure 3_2c) shows typical cooling curves for natural and forced convection. Date for forced convection refer to different values of the fan power (P1 < P2).

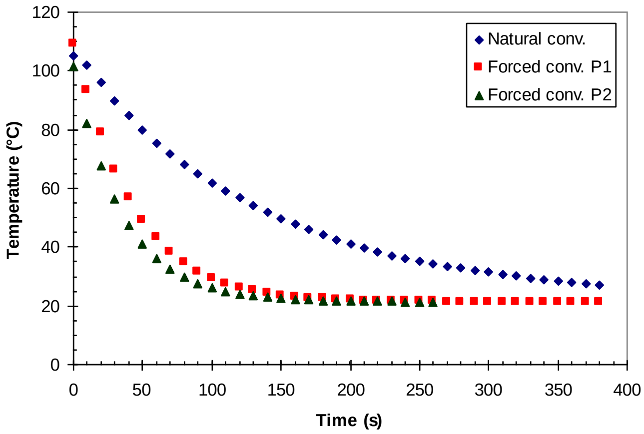


Figure 3_2c

Possible questions:

1. Compare the three curves shown in figure 3_2c and say what are the main differences?

2. What are the main differences between the two curves representing forced convection?

NOTE
An analytical expression for the cooling curves can be obtain through fitting procedures (Figure 3_2d) or by representing data in a different format. Figure 3_2e) give an example of data fitting obtained by plotting the opposite of the temperature to time difference ratios ($-\Delta T/\Delta t$) as a function of the temperature increase with respect to the environmental (T-T_e) (see Classroom materials).

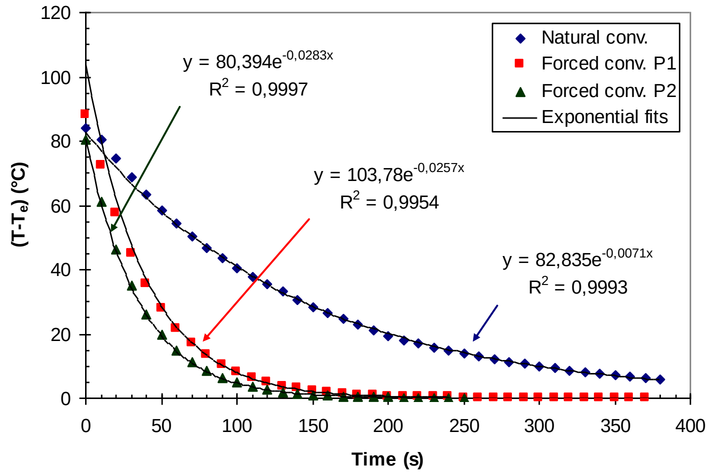


Figure 3_2d

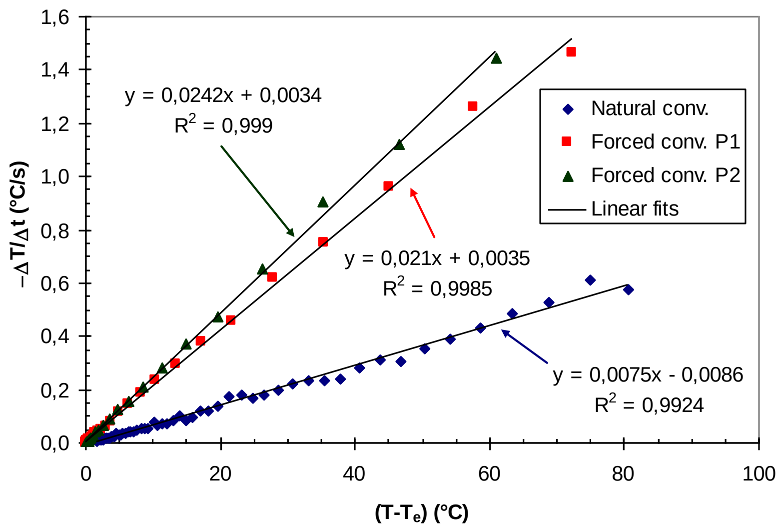


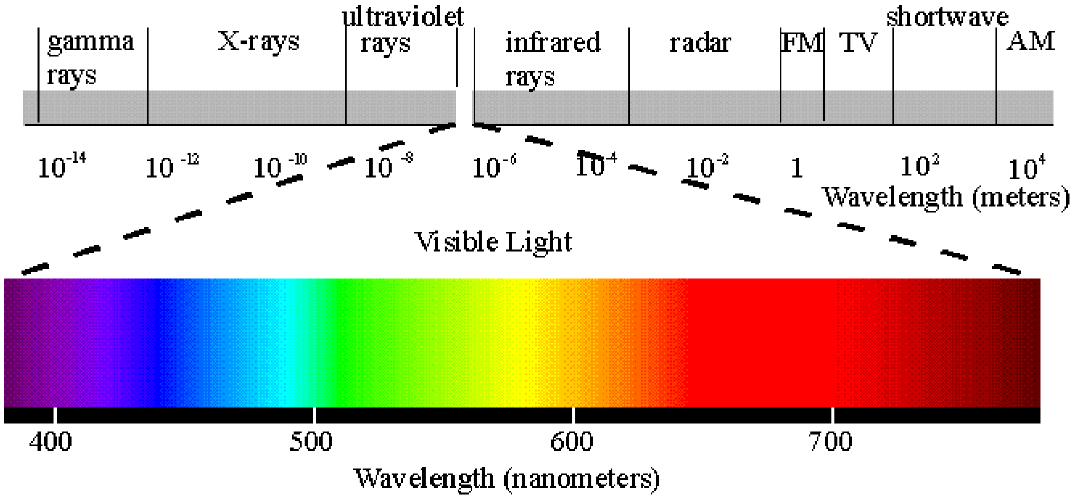
Figure 3_2e

Sub_Unit_4: Thermal Radiation

Learning path

This sub-unit analyses the transfer of energy due to radiation and explores thermal radiation. In dependence of classroom curriculum, the development of activities here described needs a recall or introduction of the main concepts connected with electromagnetic radiation. The deepening level of such introduction is dependent from the knowledge level of the classroom as well as from previous students' curriculum.

Usually pupils are more familiar with heat transfer by conduction because of their experiences of everyday-life phenomena. The physical concept of energy propagation by radiation is introduced to the class usually by reporting the example of the light radiation travelling from the Sun to the Earth across the empty space, without any support from conduction and convection, which both need a medium. This example, even if quite convincing, is not strong enough to persist into the student imagery of energy propagation, probably because of the absence of any practical activity which can help the class to directly experience the transfer of energy by radiation. The following experimental activities are proposed as an inquiry based learning path aimed at the practical exploration of energy transmission by thermal radiation.
The main concepts to recall can be synthesised as follows.
Radiation is the common name for electromagnetic energy travelling through space. It can travel very fast (the light speed c = 2.998 x 10^8 m/s), also through the vacuum. It doesn't need material to travel in. It has many forms, including visible light, infrared (IR), ultraviolet (UV), X-rays, microwaves, and radio waves. These are all the same form of energy, just with different frequencies and amounts of energy.



www.yorku.ca/eye/spectru.htm

Different frequencies of radiation interact with matter differently and this fact makes them seem more different to us than they really are. In many everyday situations we observe bodies heated by radiation gaining thermal energy, which is mostly transferred by infrared (IR) and visible radiation.

During the development of the subunits, new instruments will be analysed: the infrared thermometers and cameras.

The starting point is the analysis of Activity 1_3 of sub_Unit_1 that pointed out that light can warm the walls of our house models and this warming effect is increased if the wall colour is dark or black.

The first problem to face is that to better measure the heating effects of radiation by constructing a simple “radiometer” (see Activity 4_1).

Activity 4_2 will measure the heating effect of sun radiation on bodies of different colours.

Activities 4_3 will show that our radiometers are able to make evident a radiation different than the visible one and introduce the IR radiation.

One of the last two activities can be chosen by the teacher according to the level of the classroom.

Activity 4_4 will propose an open inquiry approach to the analysis of IR apparatuses (video, images, thermometers,….)

Activity 4_5 proposes a video were the same experiment is performed in presence and absence of atmospheric air in order to deepen the knowledge of IR radiation.

The following table characterises the activities from the point of view of the required type of inquiry and considering the 5E model of the Learning Cycle.

Activity	***Student Task***	***Inquiry Type***	***E-emphasis***
4_1	**Build and use home-made radiometers**	Interactive demonstration	Engage Explore
4_2	**Illuminating objects of different colours.**	Interactive demonstration Guided inquiry Bounded Inquiry	Engage Explore Elaborate
4_3	**Radiation from hot and cool bodies**	Guided inquiry Bounded Inquiry Open Inquiry is also possible	Engage Explore Extend
4_4	**An open Inquiry about Infrared thermography**	Open Inquiry	Engage Explore Elaborate Extend
4_5	**Analysis of the cooling processes of an hot body in different conditions. Cooling in air and in a vacuum environment.**	Bounded Inquiry Open Inquiry is also possible	Engage Explore Elaborate Extend

Activity 4_1: Build and use home-made radiometers
The Problem:
How can radiation energy heat a body? How is this heating connected with the body properties?

Learning aims:

The aim of this activity is to show the evidence of the energy transmission by thermal radiation, with respect to heat conduction and convection, between a source of radiation and a home-made radiometer.

Materials:

We assemble three home-made radiometers and carry out our experimental activities by using the following materials:

- N. 3 thin aluminium plates (for example, obtained by cutting some "Pepsi" cans);
- N. 3 surface temperature sensors, interfaced to PC;
- N. 1 halogen lamp (400 W)
- N. 1 visible light filter. It is possible to build a visible light filter in a simple and economical way by using two layers of color film impressed to sunlight and developed. The layers can then be fixed to a transparent plastic support (crilex) for a more practical use.

Suggestions for use:

Building procedure:

We cut the cans in order to obtain three aluminium plates of equal surface 4x7 cm^2. We paint one of these plates of a black gloss paint and another one of a white paint; the last one is left unpainted. We connect the back of each plate with the tip of the surface temperature sensor by a small piece of scotch tape. After that, we mount the three plates on polystyrene supports. The reason of painting the plate surface of our home-made radiometers is based on the everyday experience of dark object exposed to solar radiation that show higher surface temperatures with respect to lighter ones.

Home-made radiometer

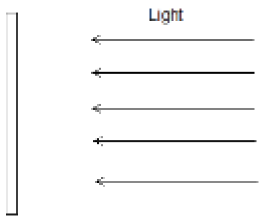
Commercial visible light filter

Halogen lamp

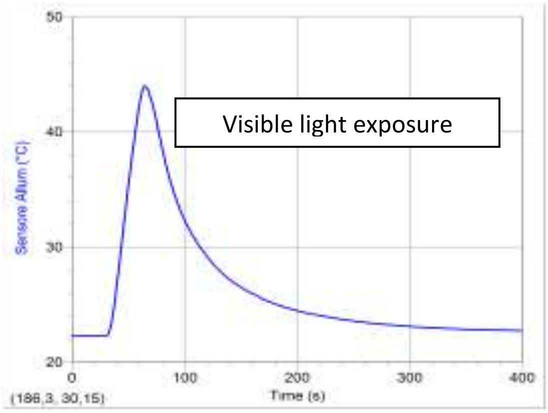
"Home made" visible light filter

First experimental activity (performed by the teacher)

The unpainted aluminium radiometer faces the halogen lamp at a distances of 25 cm from the light source.



The lamp is switched on and the radiometer is illuminated for 30 seconds, after that the lamp is switched off and removed. The temperature of the radiometer plate is recorded as a function of time: it rises until a maximum value is reached and subsequently starts a decreasing cooling trend.



Possible questions:

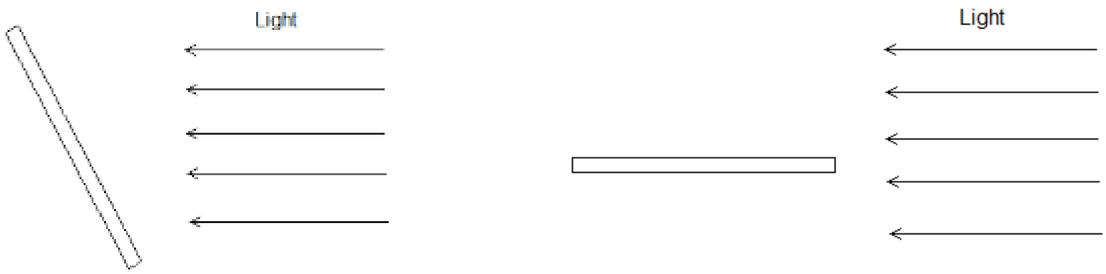
- First question: "why does the surface temperature of the radiometer increase?"
- Second question: "which is the main mechanism of energy transfer during this experiment?"
- Third question: we know that the energy could reach the surface of the radiometer by heat conduction, convection and radiation, but which of these mechanism is dominant here? How can we discriminate among the various mechanism?

In order to answer these questions the teacher can repeat the experiment by using also a classical thermometer (not illuminated) which is used to measure the temperature of the surrounding air. After 30 seconds of light illuminating the radiometer in the same condition as before, we measure the temperature of the air between the halogen lamp and the radiometer plate and find that there is not any significant change on the air temperature with respect to the room temperature measured few seconds before the light transmission.

NOTE:

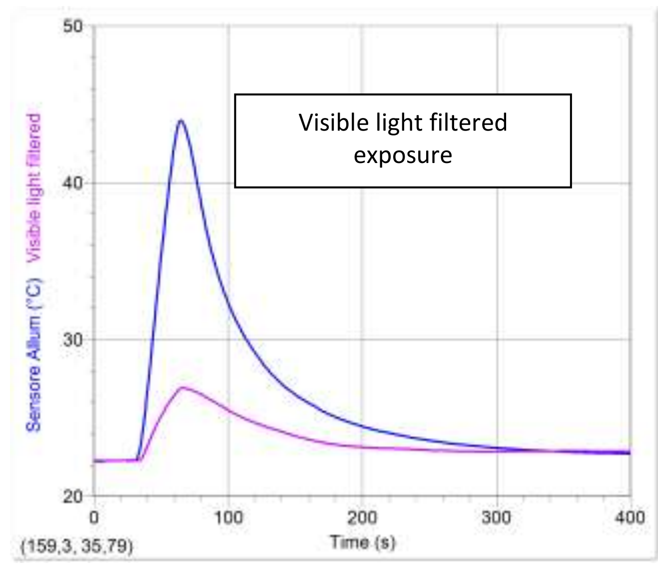
If a change of air temperature in the space between the lamp and the radiometer is not observed, this means that the transfer of energy from the lamp to the radiometer plate is not due to heat conduction or convection in the air. Therefore, the dominant mechanism of energy transmission is different and can be ascribed to lamp radiation.

It is also possible to answer the third question by repeating the experiment so that the surface of the radiometer is not frontally exposed to light of the lamp, but the lighting is made at a certain angle of inclination (see figure). For example, first the plate of the radiometer is placed at 45 ° with respect to the incident light and then at 90 ° with it, without significantly affecting the total distance between the light source and the radiometer.



The experiment will show that the greater the angle between the surface of the radiometer and the incident light, the lower the temperature change detected by the radiometer. If the heating was to be ascribed to conduction through the air, there should be no significant difference between the various cases of inclination of the radiometer, while in case of irradiation the angle formed between the radiometer and the incident light should critically influence the variation of temperature detected by the radiometer, as it happens.

- **Fourth question:** the temperature increase of object exposed to solar light is a well known phenomenon. We already know that the solar light propagates through empty space and heats up the atmosphere and the objects on the Earth surface. What happens if we eliminate the visible component of the radiation emitted by the lamp?



In order to further explore the transmission of energy by thermal radiation the teacher can repeat the same experiment as before, but now filtering the visible light incoming on the radiometer plate. An increase of the radiometer surface temperature, even in the case of total absence of visible light, is evident.

The temperature increase and the following cooling trend is recorded as a function of time and compared with that observed in the presence of light. The maximum value of the temperature reached in this latter case is lower than the one measured without filter (see figure).

Questions:

“In this case the light is absent, who is now transmitting the energy?”

Teacher can invite some students to experience this “invisible radiation” by putting their hands in front of the filtered source.

“When the lamp is switched on, you don’t see any light but you can feel a warming sensation on your hand. When the filtered lamp is switched off, the heating sensation on your hand immediately disappears.”

Activity 4_2: Illuminating objects of different colours

The Problem:

The temperature increase of object exposed to solar light is a well known phenomenon. What happens to objects that are equal except that for their colours?

Learning aims:

- To analyse different aspects of the radiation absorption from bodies of different colors.
- To use experimental evidence to decide on everyday problems.
- To design and carry out an experimental investigation by controlling variables.

Materials:

- Materials prepared for activity 4_1

Suggestions for use:

The three home-made radiometers face the halogen lamp at equal distances (25 cm) from the light source (see Fig 4_2a). The lamp is switched on and the radiometers are simultaneously illuminated for 30 seconds, after that the lamp is switched off and removed.
Results show the black sensor reaching the higher temperature, the white sensor the lower temperature and the unpainted aluminium sensor an intermediate temperature (see Fig_4_2b). Students assert that the black painted radiometer is the most sensitive to changes on surface temperature induced by the energy transmission of light because it is able to absorb more energy with respect to the white-painted and aluminium sensors, which are both interested by a reflection phenomenon of the incident radiation.

Figure 4_2a

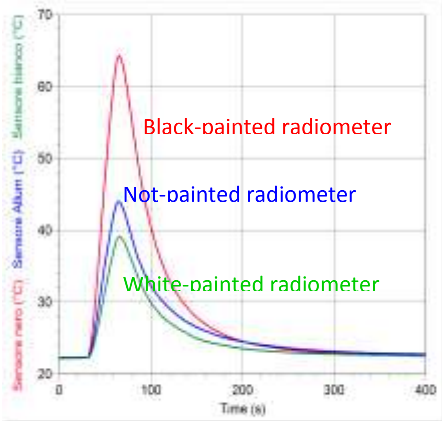


Figure 4_2b

Possible questions:

- What happens if we obscure the radiation, using the previous filter? ,
- What is the role of the “invisible light”?

Note:

Results of both previous activities can be discussed by introducing also analogies with the case of warm sensation in proximity of hot objects.

Infrared radiation (IR), i.e. the thermal radiation (not visible) emitted by hot objects can be introduced as well as the different times characterizing the transfer of energy by thermal radiation with respect to that with heat exchange by conduction and convection (which both appear to be slower processes).

Activity 4_3: radiation from hot and cool bodies

The Problem:

When we come near a hot body (for example the radiators of our house) we have a sensation of heat. Are we sure that is only due to conduction and convective current of air?

What is our sensation if we approach a cold body?

Learning aims:

The aim of this activity is to show the relevance of the energy transmission by thermal radiation, with respect to heat conduction and convection.

Materials:

- N. 2 plastic bottles (one filled with hot water and the other with cold water)
- N. 1 home-made radiometer (see Activity 4_1).

Suggestions for use:

First experimental activity (it can be performed by the teacher or a couple of students guided by the teacher)

The black radiometer faces the hot bottle at a distances of approximately 20 cm (see Fig 4_3_a). The temperature of the radiometer is registered and shown to the classroom (see Fig 4_3_b). After almost 500 seconds the radiometer is rotated by 90° with its plate facing upward (see inset of Fig 4_3_b). The temperature starts to decrease even in presence of the hot bottle. At a time of about t≈1300 s the bottle is removed and a further decrease of the radiometer temperature is observed.

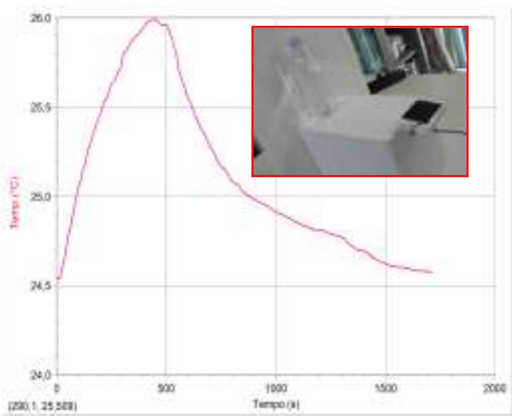


Figure 4_3a	Figure 4_3b

Second experimental activity (it can be performed by the teacher or a couple of students guided by the teacher)

The black radiometer faces the cold bottle at a distances of approximately 20 cm (see Fig 4_3c). The temperature of the radiometer is registered and shown to the classroom. After almost 800 seconds the cold bottle is removed and the temperature of the radiometer starts to approach the ambient temperature. At the time of about t≈1400 s the hot bottle is placed in front of the radiometer, as in the previous activity, and a further increase of the radiometer temperature is measured. Finally the radiometer surface is rotated again by 90° with its plate facing upward. All the measured changes of the radiometer surface temperature with the time are shown to students (Fig 4_3d).

Figure 4_3c

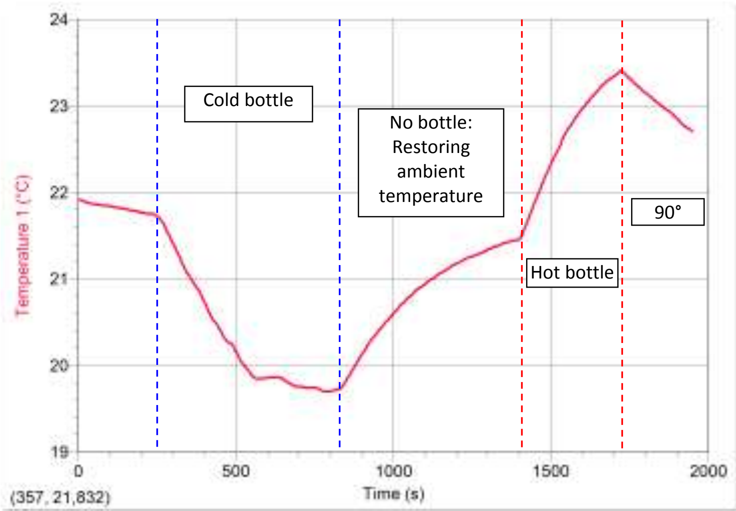


Figure 4_3d

Possible questions:

- First question: "why does the surface temperature of the radiometer increase in the case of Fig. 4_3b ?"
- Second question: "which is the main mechanism responsible of the heating? Explain your answer."
- Third question: "what do you think about the cooling process shown in Figure 4_3d ?"

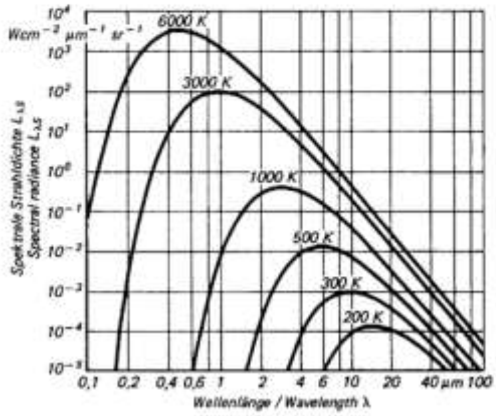
Activity 4_4: An open Inquiry about Infrared Thermography

The Problem:

Temperature plays an important role as an indicator of the condition of a product or piece of machinery, both in manufacturing and in quality control. Accurate temperature monitoring improves product quality and increases productivity.

Infrared technology has been utilized successfully in industrial and research settings for decades but now new innovations have resulted in non-contact infrared sensors offering faster and better measurements. In particular measurements can be taken of hazardous or physically inaccessible objects (high-voltage parts, great measurement distance); measurements of high temperatures (greater than 1300°C) present no problems (in similar cases, contact thermometers cannot be used). Furthermore there is no risk of contamination and no mechanical effect on the surface of the object.

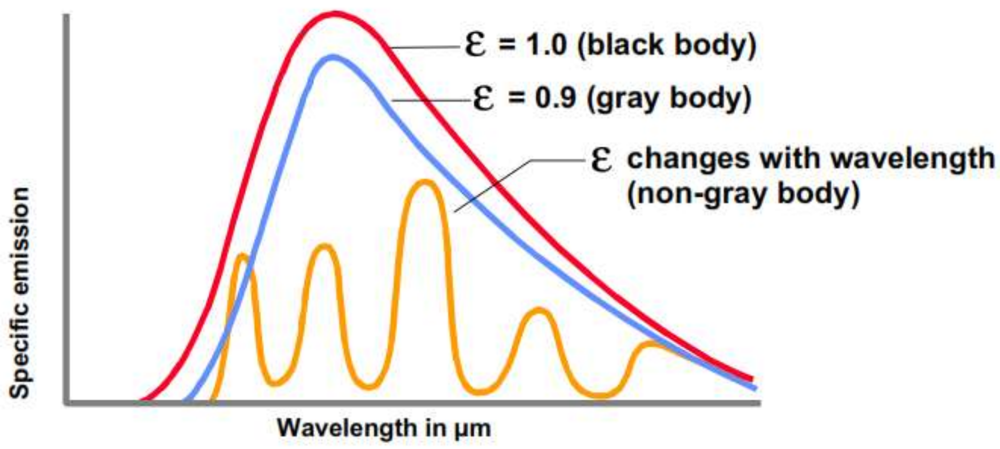
Every form of matter with a temperature above absolute zero emits infrared radiation according to its temperature. This is called *characteristic radiation*. The cause of this is the internal mechanical movement of molecules. The intensity of this movement depends on the temperature of the object. Since the molecule movement represents charge displacement, electromagnetic radiation is emitted. The spectrum of this radiation ranges from 0.7 to 1000 µm wavelength. For this reason, this radiation cannot normally be seen with the naked eye. Typical radiation of a body at different temperatures is shown in figure.



The radiation maximum move toward ever-shorter wavelengths as the target temperature rises, and that the curves of a body do not overlap at different temperatures. The radiant energy in the entire wavelength range (area beneath each curve) increases to the power of 4 of the temperature. These relationships were recognized by Stefan and Boltzmann in 1879.

The goal should be to set up the IR thermometer for the widest range possible in order to gain the most energy (corresponding to the area below a curve) or signal from the target. The greater the radiance difference per temperature difference, the more accurately the IR thermometer works.

Previous figure shows the ideal case, the so-called "blackbody" radiation. Many bodies, however, emit less radiation at the same temperature. The relation between the real emissive power and that of a blackbody is known as emissivity ε and can be a maximum of 1 (ideal blackbody) and a minimum of 0. Bodies with emissivity less than 1 are called gray bodies. Bodies where emissivity is also dependent on temperature and wavelength are called non-gray bodies. A further reason for having devices for different wavelength ranges is the emissivity pattern of some non-gray bodies (glass, metals, and plastic films).



Determining Emissivity

There are various methods for determining the emissivity of an object. You can find the emissivity of many frequently used materials in a table. Emissivity tables also help you find the right wavelength range for a given material, and, so, the right measuring device. Particularly in the case of metals, the values in such tables should only be used for orientation purposes since the condition of the surface (e.g. polished, oxidized or scaled) can influence emissivity more than the various materials themselves.

It is possible to determine the emissivity of a particular material yourself using different methods:

First method: Heat up a sample of the material to a known temperature that you can determine very accurately using a contact thermometer (e.g. thermocouple). Then measure the target temperature with the IR thermometer. Change the emissivity until the temperature corresponds to that of the contact thermometer. Now keep this emissivity for all future measurements of targets on this material.

Second method: At a relatively low temperature (up to 260°C), attach a special plastic sticker with known emissivity to the target. Use the infrared measuring device to determine the temperature of the sticker and the corresponding emissivity. Then measure the surface temperature of the target without the sticker and re-set the emissivity until the correct temperature value is shown. Now, use the emissivity determined by this method for all measurements on targets of this material.

Measuring the temperature of metals:

The emissivity of a metal depends on wavelength and temperature. Since metals often reflect, they tend to have a low emissivity which can produce differing and unreliable results. In such a case it is important to select an instrument which measures the infrared radiation at a particular wavelength and within a particular temperature range at which the metals have the highest possible emissivity.

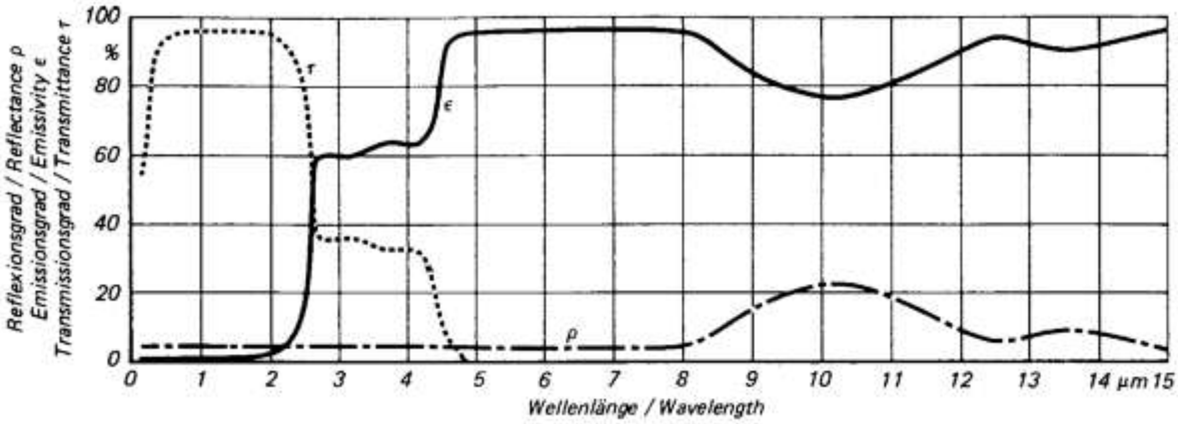
Measuring the temperature of plastics:

The transmittance of a plastic varies with the wavelength and is proportional to its thickness. Thin materials are more transmissive than thick plastics. In order to achieve optimal temperature measurement it is important to select a wavelength at which transmittance is nearly zero. Some plastics (polyethylene, polypropylene, nylon, and polystyrol) are not transmissive at 3.43 µm; others (polyester, polyurethane, Teflon FEP, and polyamide) at 7.9 µm.

Measuring the temperature of glass:

When measuring the temperature of glass with an infrared thermometer, both reflectance and transmittance must be considered. By carefully selecting the wavelength, it is possible to measure temperature of both the surface and at a depth. When taking measurements below the surface, a sensor for 1.0, 2.2, or 3.9 µm wavelength should be used. We recommend you use a sensor for 5 µm for surface temperatures. At low temperatures, 8-14 µm should be used with the emissivity set to 0.85, to compensate for reflectance. Since glass is a poor conductor of heat, and can change surface temperature rapidly, a measuring device with a short response time is recommended.

Spectral transmittance of glass:



Suggestions for use:

Activity 1: Comparisons among different kinds of thermometers including infrared thermometers.

Activity 2: Investigation on Infrared thermography applications for building inspection to improve energy efficiency, non-destructive testing of parts, materials or systems through the imaging of the thermal patterns at the object's surface, safety driving systems based on night vision assistant with pedestrian detection and warning, searching the darkness for missing people. Analysis of Infrared images and inferences about their thermal conditions.

(See the slideshow at www.uop-perg.unipa.it/establish/videoIR1_eng2.wmv)

Activity 4_5: analysis of the cooling processes of an hot body in different conditions. Cooling in air and in a vacuum environment.

The Problem:

The heating / cooling rate of a body strongly depends on the environment with which the body itself can exchange energy. It is easy to observe that the cooling rate is higher if a fan is placed near the body. The problem we investigate here is: what happens if we leave the hot body in a vacuum camera?

We will present some experiments analyzing the cooling processes in three different conditions: in a vacuum camera, in air and in air, but near a fan. This involves to analyze cooling only through irradiation or through irradiation as well as natural and forced convection.

The experiments are relatively simple and the needed equipment is readily available. The complex aspect of the experiment is certainly related to the implementation of the vacuum as this requires the use of more sophisticated equipment.

Learning aims:

The aim of this activity is to study the way a body cools in different environmental situations.

Materials:

- A 150 Ω, 10W ceramic resistor.
- A K type Thermocouple;
- Transducer voltage - temperature module for thermocouple (for example Fluke 80TK already prepared for type K thermocouple);
- Multimeter with a resolution of at least 0.1 mV in d.c.;
- Electrical cables;
- d.c. 40 V power supply
- Bell vacuum glass;
- Vacuum grease;
- Rubber hose vacuum;
- Rotary vacuum pump;
- Pressure gauge;
- PC software for data acquisition (for example, LabView, Coach, LoggerPro, DataMate)

Suggestions for use:

The analysis of heating and cooling in different environment conditions is performed by using a ceramic heating element (see figure 4_5a).

Figure 4_5a

As a first step, the resistance is secured to a rigid support set on a teflon base, where all the electrical connections (rigid wires) that are necessary both to the heating of the resistance and the reading of the temperature values are also anchored (see Fig. 4_5b and Fig. 4_5c).

Figure 4_5b

Figure 4_5c

As a second step, the edge of a vacuum bell is greased by using vacuum grease, so that it can adhere well to the base (generally a glass disk), eliminating all the inevitable roughness that would not allow a good seal of the vacuum.

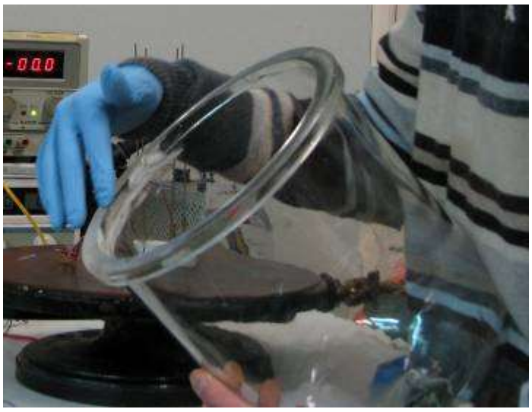


Figure 4_5d

The resistance is then enclosed into the bell which is resting on a base which in turn is resting on a metal platform in order to provide high rigidity.

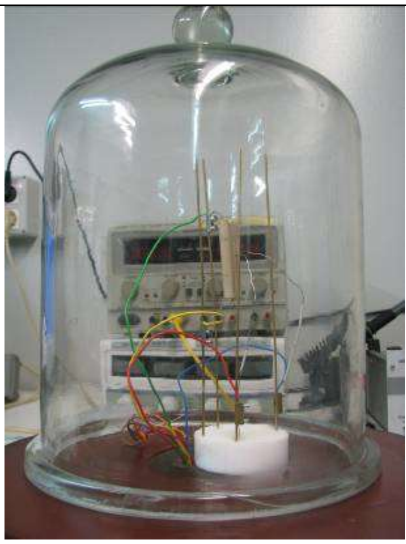


Figure 4_5e

Then, we are ready to turn on the pump starting the vacuum procedure.

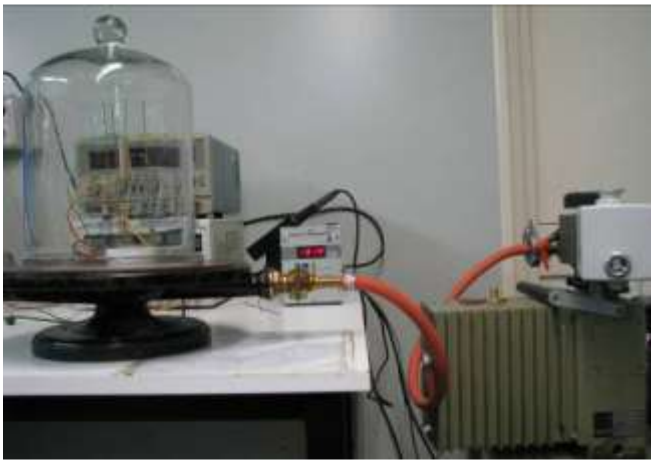


Figure 4_5f

This phase needs some time (usually 30/40 min) in order to obtain a vacuum of about 0.1 mbar. The bell is, then, isolated from the pump with a special valve and the pump can be turned off.

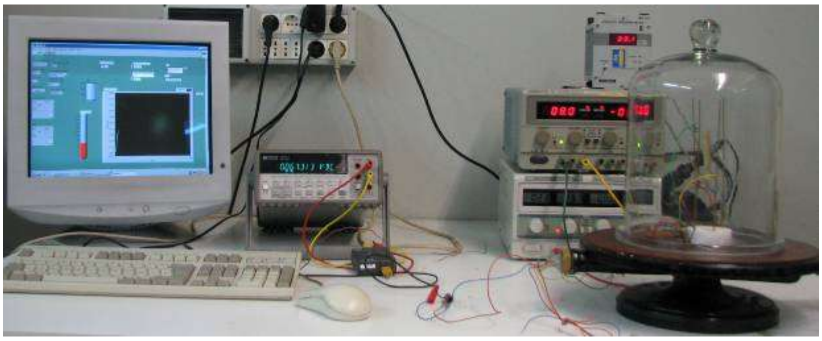


Figure 4_5g

The heating of the resistance is obtained by simply turning on the current (Joule effect) and the values of temperature are directly obtained from the output signal of the thermocouple placed in contact with the resistance. Such a signal is suitably amplified and calibrated by the Fluke module which provides values of voltages in mV directly interpreted as Celsius degrees (1mV/1°C).

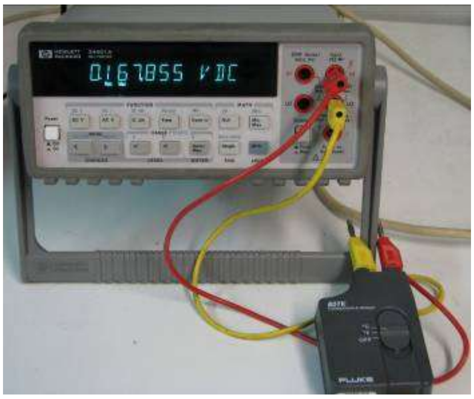


Figure 4_5h

The measures to be carried out for the three different conditions (radiation, free convection and forced convection) are performed on the base of the following protocol. For each condition, the resistance is heated by using the same electrical power (for example 8 W), so we are able to compare the maximum temperatures reached (the plateaux of curves in Figure 4_5k). Then, the current is turned off and the cooling process is analyzed.

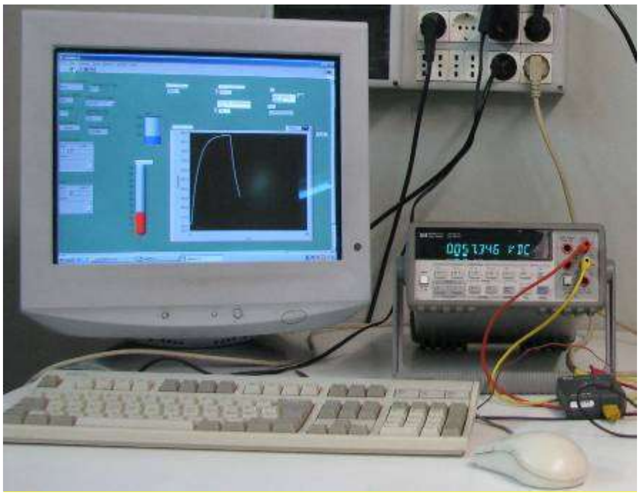


Figure 4_5i

The same procedure can be performed allowing air to enter up to atmospheric pressure and then doing the measurement in free convection and in forced convection without the bell and with a fan placed in the direction of the resistor just during the cooling phase.

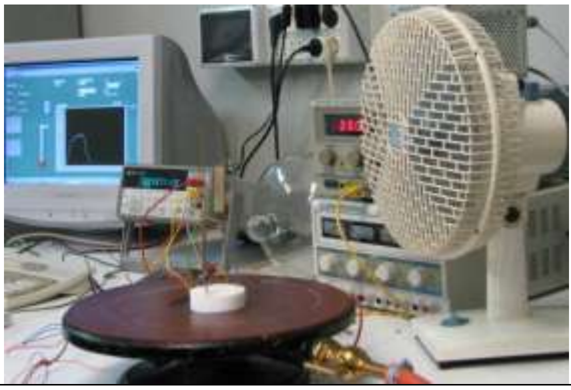


Figure 4_5j

The results

The following graph shows the results at constant power in the three experimental situations:

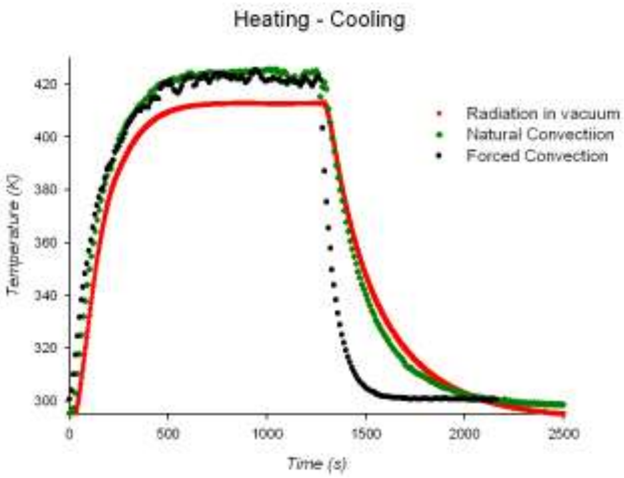


Figure 4_5k

It can be observed that the equilibrium temperatures of equilibrium are very close for heating in a vacuum and in open air and differ significantly with respect to the forced convection.

The following figure represents only the cooling processes and allows us to easily compare the different cooling rate in the three different situations.

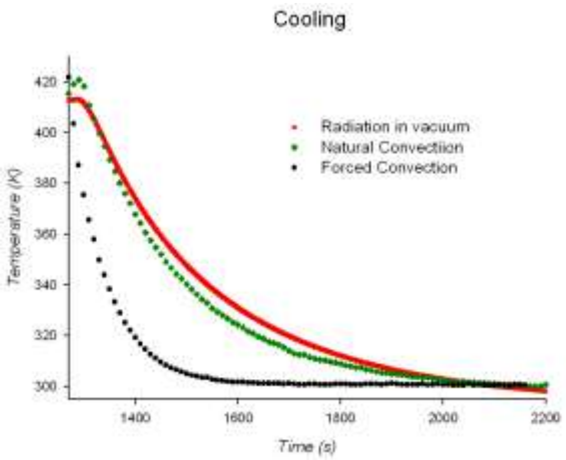


Figure 4_5l

Figure 4_5l shows that the cooling rate for the natural convention and irradiation are almost the same, whereas the cooling rate in the case of the forced convection is much greater.

Deepening the analysis:

An additional analysis of the results may be performed by using the numerical derivatives of the temperature with respect to time.

In fact, for finite variation, the rate of temperature variation is described by the following differential equation:

$$C\frac{\Delta T}{\Delta t} = -e\sigma S\left(T^4 - T_b^4\right)$$

where C is the body heat capacity, e is the emissivity, σ is the Stefan's constant and T_b is the room temperature, and by the following differential equation

$$C\frac{\Delta T}{\Delta t} = -hS\left(T - T_b^4\right)$$

where h is the coefficient of convection and S is the surface of the hot body, respectively for radiation in vacuum and for natural or forced convection cooling.

The graph of the ratio of finite differences - ΔT/Δt as a function of temperature allows us to obtain very important information (see the attached Excel file: Cooling – Radiation and Convection.xls).

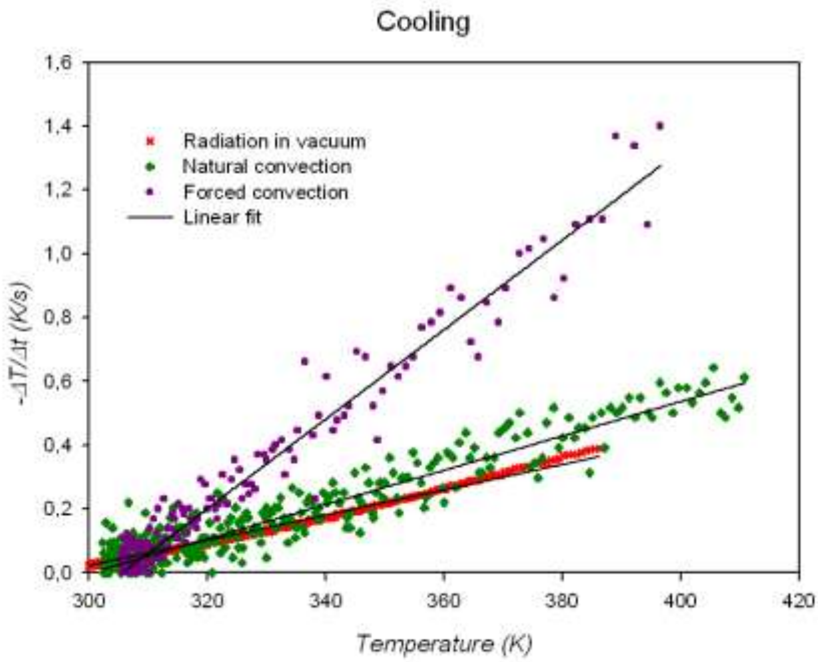


Figure 4_5m

In fact, in this graph, the slope of the straight lines represents the speed with which the cooling takes place for the three cases.

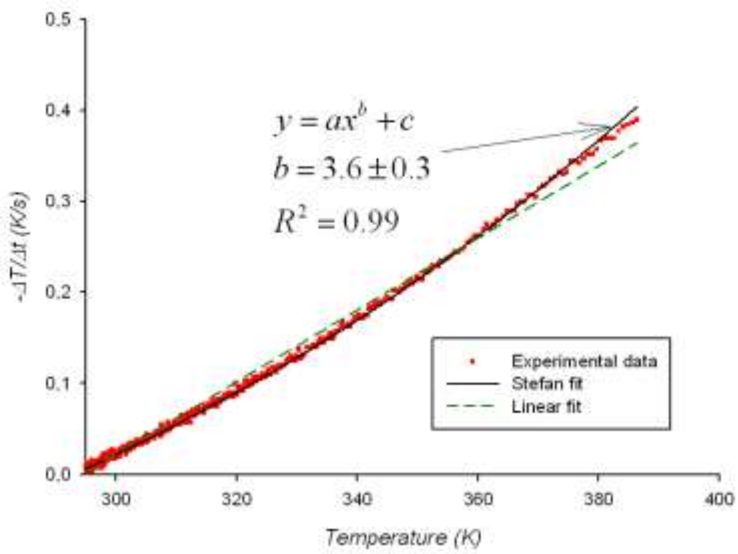


Figure 4_5n

It is also worth to note that, as shown in figure 13, in the case of irradiation the best fit are not the linear function but is represented by a polynomial of degree b = 3.6 ± 0.3 in good agreement with the Stefan's law.

WP3 | Designing a Low Energy Home: heating and cooling

European Science and Technology in Action Building Links with Industry, Schools and Home

Work Package 3

Designing a Low Energy Home: Heating and Cooling

B – Classroom Materials

European Science and Technology in Action:
Building Links with Industry, Schools and Home

Lead partner for deliverable: **University of Palermo, Italy**

The ESTABLISH project has received funding form the European Community's Seventh Programme [FP7/2007-2013] under grant agreement n° 244749

Start Date: 1st January 2010 Duration: 48 months

Designing a Low Energy Home

The project we want to develop in this Learning Unit deals with the idea of a model house that uses less energy to heat the rooms and makes use of scientific discoveries and technological resources to minimize energy consumption. The house analysis will be the starting point to explore some important scientific concepts related to heating and cooling of bodies and to heat transfer.

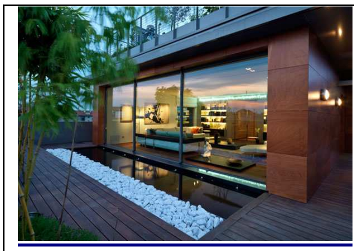
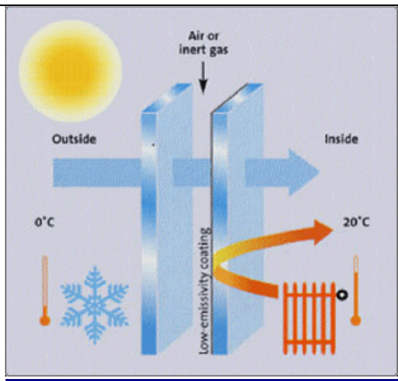
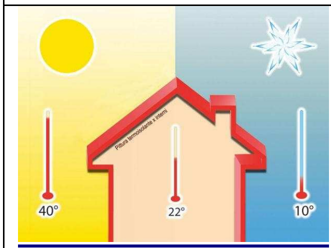
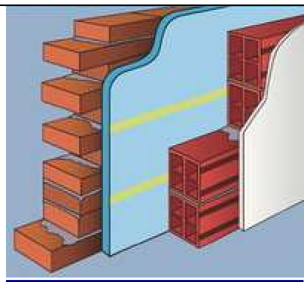
Even if we will work with models of polystyrene, wood, plastic and cardboard, warmed by a light bulb placed inside, we will apply the same principles of science and engineering that are taken into account in the construction of a real house.

In many countries a large percentage of energy consumption is due to heating and cooling of buildings. Therefore, the search for more efficient methods of construction to improve the energy efficiency of buildings is extremely important. Less energy means less fossil fuels and thus a lower amount of carbon dioxide in the atmosphere. Your generation has the task of doing something about energy efficiency and then you need to know the problem to make responsible choices.

Some initial considerations

We begin our work by observing the characteristics of some houses. Then, we try to understand why they are very different from each other.

		The houses in mountainous areas are often made of wood or have very thick walls
		The Mediterranean countries and the souks of the desert have whitewashed houses and narrow streets

		The houses with large windows often use double (or even triple) glass window panes separated by an air or other gas filled space to reduce heat transfer across a part of the building envelope.
		Companies that sell thermal insulation material for walls show as layers of different materials can be more successful at maintaining a constant temperature inside a room than walls made of only a material
		Photocameras are available that can show and highlight the different temperature of various parts of the outer wall of a house (thermocameras).

Although our goal is to build a model home that is efficient from an energy point of view, that has a constant temperature and can also be heated by the sun, we will start working with models to familiarize with the materials, construction methods, and measures necessary to evaluate the project.

Your teacher will provide you with the models on which we will use standard procedures for measuring the thermal performance of a house.

In order to cool a house (or as it is commonly said losing heat), there must be a difference in temperature between the inside and the outside. The inside of the house must be warmer than the outside. Because you cannot cool your classroom at 0 ° C, we will try to heat your model house at 15 ° C above the environment temperature. This is done with a heating bulb placed inside the model.

As in a real home, what matters is how long the heater must stay switched on to keep the house warm. The higher the inner temperature, the more energy is used and the more you heating bill will be. To mimic this situation, we will record the percentage of time the heating lamp should stay turned on to maintain the house at 15 ° above ambient temperature. We will perform the same test in other conditions, trying to understand why different results are obtained.

Activity 1_1: How to maintain warm your house model

The problem:

In the winter we need energy to maintain warm our house. By using suitable designed house models it is possible to analyze how much energy it takes to have the inner part of each house model 15°C warmer than the air outside it.

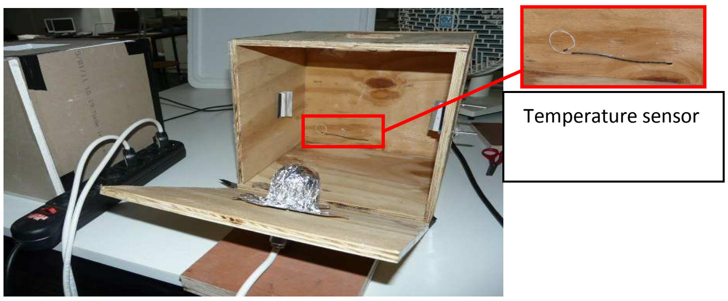
Material needed for each group:

- Boxes of different materials (of equal dimensions) modeling different kinds of houses.
- Temperature sensors to put in the wall opposite to the heater.
- Heaters (light bulbs covered by aluminium sheets)

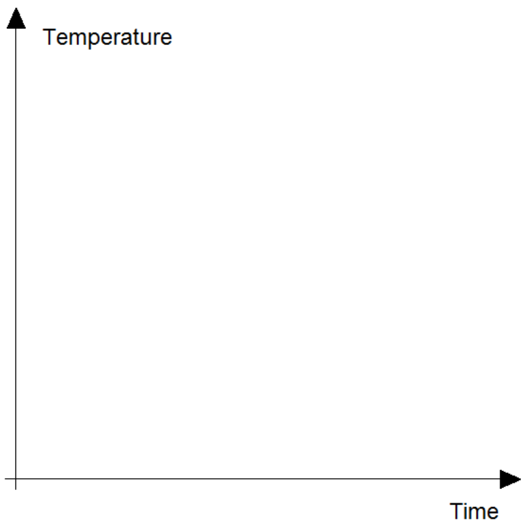
Suggestions for use:

Follow the suggestions of the teacher and place the heater and the thermometer as shown in figure.

In this experiment you will switch on the heater and start recording the inner temperature of the model house as a function of time.



Before actually performing the experiment, give your prediction of the Temperature-Time graph you are going to obtain and draw it on the right.



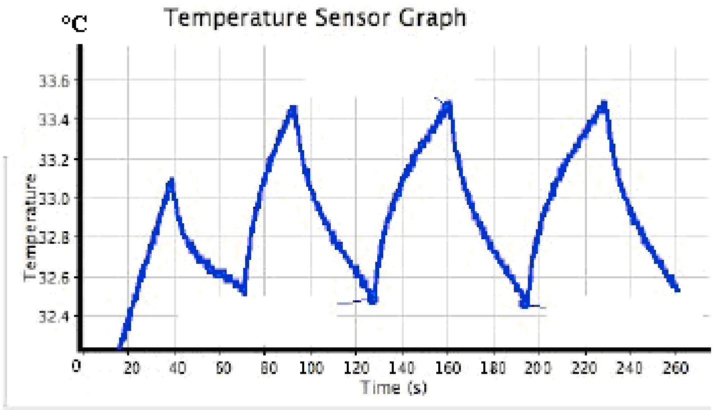
Now turn on the heater and record the inner temperature of the model house until it reaches a value of about +15 ° C above the external temperature, T_e. Turn off the heater so that the temperature decreases until T_e.

DATA ANALYSIS

Take note of the time intervals during which the heater is turned on and off and say how much energy was used to heat the house?

Compare your data with those of your schoolmates. What conclusions can you draw with regard to energy saving?

In depth analysis:



The graph above shows an experiment performed by a student that repeatedly switched on and off the heater, aiming at maintaining the temperature of the house at about 33 ° C. Try to calculate how much energy has been used if the heater was a 40W light bulb.

Activity 1_2: How is the temperature distributed inside your house model ?
The problem:
It is easy to observe that inside a heated room different places are not at the same temperature. How can we identify places at higher temperatures? Think about the model house you used in the previous activity.
Use two temperature sensors and design an experiment to test your hypothesis. Discuss your ideas with your classmates and the teacher
A group of students has suggested that the temperature in the upper part of the house will be higher than the bottom because "*heat always goes up*". What does it mean in your opinion the expression "*heat always goes up*"?
Design an experiment that can be used to investigate your classmate hypothesis, and describe accurately the various stages of the design.

After discussing your project with the teacher, carry out the experiment and report below the most significant data.

	An heat pump is a machine able to transfer thermal energy from a body at a lower temperature to a body at a higher temperature or vice versa, using different forms of energy, usually electrical. What problems can be incurred if the pump is placed on the wall as shown in Figure?

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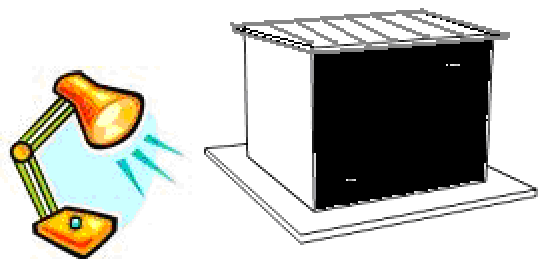
Activity 1_3: What is the effect of sunlight on the temperature inside your house model?

Surely you have heard that being exposed to sunlight by wearing a dark shirt makes you feel warmer than if you wear a white shirt. Is, in your opinion, this only a rumor or the statement has scientific basis?

How could you verify this?

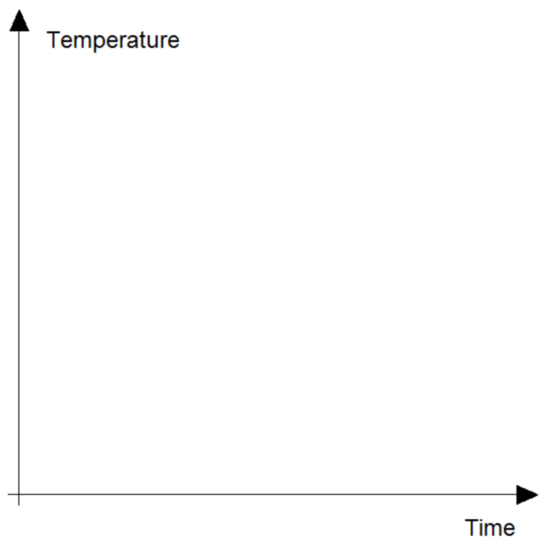
The problem we want to study now is how sunlight can affect the internal temperature of our model house. To do this we will simulate solar illumination with a high power lamp.



Consider the model house that the teacher shows you. Design an experiment to test whether the color of the illuminated wall affects the internal temperature of the house.

Describe in detail your experimental project

Draw in the graph below which type of Temperature-Time relationship you'd expect



After running the experiment, compare the graphs obtained with the predicted ones. Are there similarities or discordances? Explain your results

Conclusions:

Try to summarize, for each of the activities you have performed, what you learned at the end of each activity and how you came to the different conclusions you have drawn.

Designing a Low-Energy Home

ACTIVITY 2_1: Observing ice melting in plates of different materials

Introduction:

Whenever we touch objects made of different materials we receive feelings of warmth or coldness. Consider the different feelings we have by walking barefoot upon a woollen carpet or upon a marble floor. In the same way, when we touch a metal object we have a feeling of cold quite different from the feeling that we have by touching a piece of wood. Can you explain why this happens?

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How could you perform a classroom experiment in order to prove what you answered to the previous question? Describe this experiment:

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The problem:

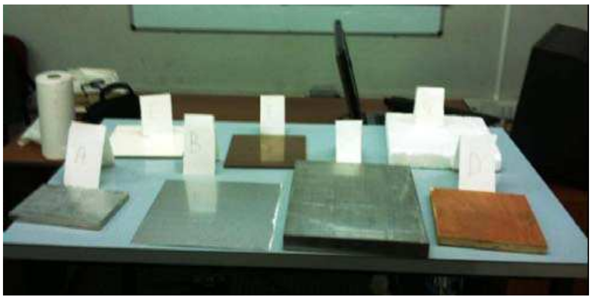
If we want that the ice cream or deep-frozen food we have bought do not melt during the time took to cover the distance between the store and home, we have to use special containers assuring thermal insulation. Which material makes the container a better insulator? Is it better to use metal, glass or plastic? By a simple experiment we shall try to give an answer to these questions.

Materials:

- 6 different plates (3 of aluminium with different thickness and area, 1 of wood, 1 of plexiglas and 1 of styrofoam)
- 1 surface temperature sensor
- Many ice cubes approximately identical

Suggestions for the experiment:

On the desk you can see six different plates. Each plate is identified by a letter (from A to F). The first three plates (A, B and C) are made of aluminium and differ in area and thickness. The D is a wooden plate, the E is plexiglas, while the last one (F) is styrofoam.



Touch the plates and describe the thermal feelings you are receiving.

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Now your teacher will pick up from the fridge six ice cubes approximately identical and will put down each cube upon a different plate. Before observing what happens, try to predict the melting order of ice cubes, starting from the quickest one. Insert into the following table the order number (from 1 to 6) for each plate. Try to explain your choice (if you want, you can ask your teacher to help you in measuring the plate temperature by means of the temperature probe).

A	B	C	D	E	F

Now observe the ice cubes melting. Describe what you have observed and make a comparison with your predictions.

DISCUSSION

Why the ice cubes melt when they are put down upon the plates?

Which properties of the plates do you think may affect the melting rate of ice cubes?

Do you think that the melting rate may depend on the initial temperature of the plates?

Which plate is, in your opinion, the best insulator and which is the best conductor?

Is the heat absorbed by each ice cube the same for all the cubes?

In depth analysis

The transfer of heat through solid material is known as **thermal conduction**. The rate of heat transfer by conduction through a layer with area *A* and thickness *d* when the temperature difference between external faces is ΔT is described by the Fourier law, which is mathematically written as:

$$\frac{\Delta Q}{\Delta t} = \frac{k}{d} A \Delta T$$

where $\Delta Q/\Delta t$ is the rate of heat transfer and *k* is the ***thermal conductivity***. This is a typical parameter of the material of the layer. The unit is watt/m °C. Thermal insulators, like air, show low values of conductivity (order of 10^{-2} W/m°C), while good conductors, like metals, have high values of conductivity (order of 10^{2} W/m°C).

Thermal conductivity is a property very different from heat capacity. Heat capacity represents the required amount of heat to produce a 1°C change in the temperature of an object. On the other hand, conductivity is the amount of heat flowing in the unit time through a layer with unit area and thickness when between the layer faces there is a difference of temperature of 1°C. In other words, we could say that the heat capacity of an object is associated to the capacity of the object to be warmed up or cooled down, while the conductivity represents the capacity to conduct heat. Insulators, for example, have low values of conductivity and also low values of heat capacity. For this reason, they warm up and cool down very quickly, but the heat flows across them very slowly. Also metals change their temperature rapidly because of low heat capacity, but the heat flow is much more higher than in insulators. Other materials, like water, have an high heat capacity and then they are used as cooling liquids (consider for example a liquid-cooled stroke engine).

By taking into account these try to explain data related to the ice melting time for the three aluminium plates. Do you think that these data may be interpreted only in terms of Fourier Law? Can you consider relevant the heat capacity of the plates? Make your comments below.

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ACTIVITY 2_2: Measuring insulation properties of different materials

The problem:

Thermal insulation of a house is a crucial problem when we want to minimize energy losses. But, which material it is better to use to build the walls or the roof of our house? Which material properties are the most suitable? The argument we are going to study will allow us to find some answers to these questions. We start by analysing with the aid of simple experiments the different behaviour of solid materials with respect to the transfer of heat by conduction.

Material for each group:

- 2 surface temperature sensors
- Styrofoam cup
- 5 squares of thickness 1 cm of different materials (aluminium, plexiglas, wood, plasterboard and styrofoam)
- 3 aluminium squares of different thicknesses (0,1 cm, 1 cm and 3 cm)
- Masking tape

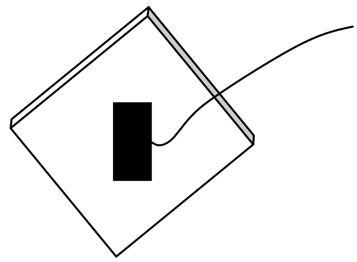
Suggestions for the experiment:

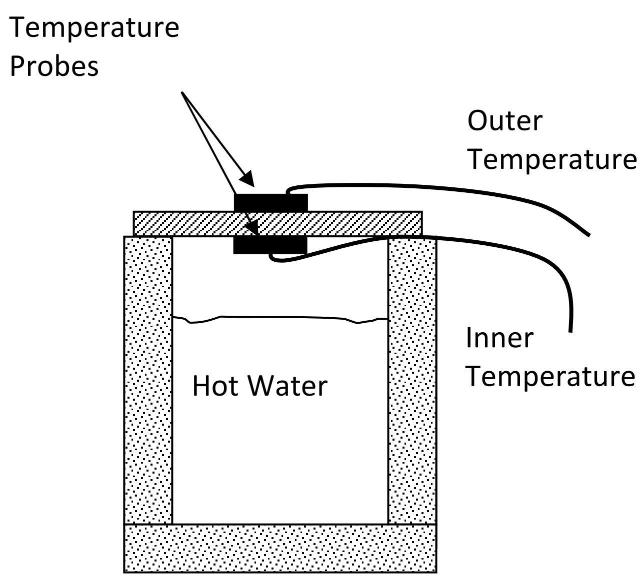
This experiment consists in measuring the difference of temperature across a square plate when there is a net heat flow. We shall use the setting shown in figure. We shall place the plate upon the cup filled with hot water and by means of temperature probes we shall measure the temperature of inner and outer faces versus time.

Pick a square of thickness 1 cm and tape a temperature sensor to each side of a piece of material. Fill the foam cup with very hot water until reaching ¾ of the height. By using a thermometer, measure the room temperature (T_{room}) and the temperature of the water (T_{water}). Write down the measurements

T_{room} = T_{water} =

Place the square on top of the cup, as shown in figure, and hold it firmly in place. Connect the two probes to the computer. Start to collect data.





Observe the graph of temperature vs. time and wait until the two curves (the inner and outer temperatures) reach a stable value. Read these values and report them in the table below.

Repeat the previous procedure with the other squares of different materials with thickness 1 cm. At the end, complete the table with the required data.

Material	Inner Temperature	Outer Temperature	Temperature Difference (ΔT)
Wood			
Plexiglas			
Styrofoam			
Plasterboard			
Aluminium			

DISCUSSION

Why is there a difference of temperature between the faces of the squares?

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List the materials in order from highest to lowest temperature difference.

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Which material do you think is the best conductor? And the best insulator?

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Try to explain why, although water temperature and room temperature do not change, the inner temperature of the squares is different depending on the material.

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Now, we shall analyse how the thickness of the squares affects the heat conduction. To do this, repeat the previous measurements by using, this time, the three aluminium squares of thicknesses 0,1, 1 and 3 cm. Report data in the following table.

Material	Inner Temperature	Outer Temperature	Temperature Difference (ΔT)
Aluminium 0,1 cm			
Aluminium 1 cm			
Aluminium 3 cm			

DISCUSSION

How does the difference of temperature change when thickness increases?

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In order to make thermal insulation of a house more effective do you think is it better to use thicker walls or not? Explain.

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In depth analysis:

The rate of heat transfer by conduction through a layer with area *A* and thickness *d* when the temperature difference between external faces is ΔT is described by the Fourier law, which is mathematically written as:

$$\frac{\Delta Q}{\Delta t} = \frac{k}{d} A\Delta T = KA\Delta T$$

where ΔQ/Δt is the rate of heat transfer and *k* is the ***thermal conductivity*** of the material.

The parameter $K = k/d$ is measured in Kcal/m^2 °C and represents the heat amount transferred trough a layer with unit area (1 m^2) per hour and per unit difference of temperature.

In the table below, we have reported the parameter *K* for some materials commonly used in home-building.

External wall	26 cm air brick	1,2
Internal partition wall	12 cm air brick	1,5
Floor	Concrete and squares	1,0
Window	4 mm glass	4,3
Door	Wood	3,6

Based on the data in the table, try to estimate the heat loss by conduction across the walls, the floor, the windows and the doors of your classroom during an half-day (5 hours) lesson session in a winter day (assume a room temperature of 20 °C and an outer temperature of 5° C) . Which elements of your classroom lose the most heat by conduction?

Conclusions:
For each activity summarize what you have learned at the end of the activity and explain how you have drawn your conclusions.

Designing a Low Energy Home

Activity 3_1: Observing convection currents

Introduction:

Have you ever tried to get your face (or hand) above an operating stove or a heater? If yes, what have you noticed in particular?

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Do you think that a similar effect could also be present in a container of water which is heated from below? What might you observe?

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Think about how you could create an in-class experiment to give an experimental answer to the above question and describe the experiment:

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The problem:

When in a room a heater plate or stove starts operating it is possible to note a movement of air from bottom to top. This can be highlighted by means of some smoke (e.g. cigarette) blown in the vicinity of the radiator, which tends to go upwards. This is due to the temperature difference between the lower and the upper wall of the room. We now want to see what happens in a container full of water when its left and right parts are kept at different temperatures.

Material needed for each group:

- Two bowls filled of hot water and ice, respectively.
- • A small fish tank filled with water at room temperature.
- • Two small amount of red and blue dyes.

Suggestions for the experiment:

Fill one of the two containers with ice and water and the other with hot water, at about 70 ° C. Fill the fish tank at half level with water at room temperature and put it on the two containers, as shown in figure.	
Now, pour a drop of red ink in the fish tank, on the side of the vessel with hot water and one drop of blue ink on the other side. What do you observe? Describe what happens as time flows.	______________________________ ______________________________ ______________________________ ______________________________ ______________________________ ______________________________ ______________________________
Try to explain the behavior of the red and blue ink drops? Have you already seen something similar in other real-life situations?	______________________________ ______________________________ ______________________________ ______________________________ ______________________________ ______________________________

What physical variable might be responsible for what you have observed? (Hint: think about what water features may vary with temperature ...).	____ ____ ____ ____ ____ ____
Another experiment:	
The figure shows a popular toy: the "hot-air balloon". A small candle is secured to the open end of a paper or plastic balloon. When the candle is lit the balloon begins to rise, soaring into the air. Do you think that this phenomenon can be related to the experiment we made with water and ink or with the considerations we made for the smoke blown over a radiator? What physical quantities are involved in this case?	 ____ ____ ____ ____ ____ ____

Discuss your findings with your group mates. Share your conclusions with the whole class and the teacher, trying to identify the physical quantities that are more relevant for description and interpretation of the situations analyzed. Report below the conclusions to which the entire class group has come.

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In depth analysis:

The phenomena of "sea breeze" and "land breeze" occur over land near coasts, close to large amounts of water such as lakes or seas. It is observed that during the day air currents blow from the sea, or lake, to the land. This phenomenon is known as sea breeze.
At night, however, the opposite happens: the currents of air blow from the land to the mass of water, giving rise to the land breeze.

DAY TIME

NIGHT TIME

Do you think that these phenomena can be explained by taking into account what the class group has concluded with respect to the phenomena previously analyzed? Try to identify the physical quantities that you feel are relevant to describe and explain phenomena.

Explanation:

Phenomena of breezes over land masses near to large basins of water supply a relevant example of convection currents. Water has a larger heat capacity than land. As a consequence it holds thermal energy better than land and takes longer to change its temperature, either upward or downward. Thus, in the morning, due to the sun heating, the air above the water is cooler than that over the land. This creates a low pressure area over the land, with respect to the high pressure area over the water. Due to this pressure difference air is pushed from the water to the land as a blowing breeze. On the other hand, during the night water cools off more slowly than the land, and the air above the water is slightly warmer than over the land. This produces a low pressure area over the water with respect to the high pressure area over the land, and this time air is pushed from the land to the water.

Activity 3_2: natural and forced cooling

The problem:

In many cars the engine or the circuit of cooling water are cooled by forced convection. In fact, it is easily observable that the engine temperature goes down when the car is moving: air with a given velocity cools better the engine than air still with respect to the engine.

Many cars, make up for the lack of air in motion through a fan which, in effect, sets in motion the air, blowing it towards the engine.

We will try now to verify the effect of air movement in the cooling process with an experiment.

Material needed for each group:

- Two plates of aluminium (side □ 15 cm, depth □ 3mm),
- Two surface temperature sensors
- A bowl with hot water (about 90°C)
- Two plastic bags
- Two isolating supports (Styrofoam)
- A multi-speed fan

Suggestions for the experiment:

In this experiment we are going to fix, with adhesive tape, a temperature sensor on each aluminum plate and connect the sensors to the measuring system. Then, we will put the two supports of polystyrene on two tables not too close. The aluminium plates will be placed in the supports and the fan will be pointed towards one of them, facing the side where the sensor is not present.

Each plate, well sealed in a plastic bag, will be inserted into the hot water, and the temperature data collection started, waiting at least one minute, until the temperature indicated by the sensors has reached the water temperature and is stable. Then, the plates will be extracted from the water, quickly removing the bag and each plate will be put on an insulating base, as in figure

The fan will be powered and we will observe the temperature data as a function of the time that will be recorded for both plates.
The experiment is to be repeated, for the sole plate cooled by the fan, by adjusting the speed selector switch to a different fan speed.

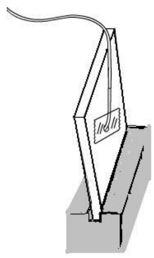


Plate 1

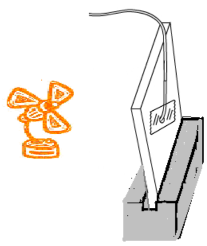
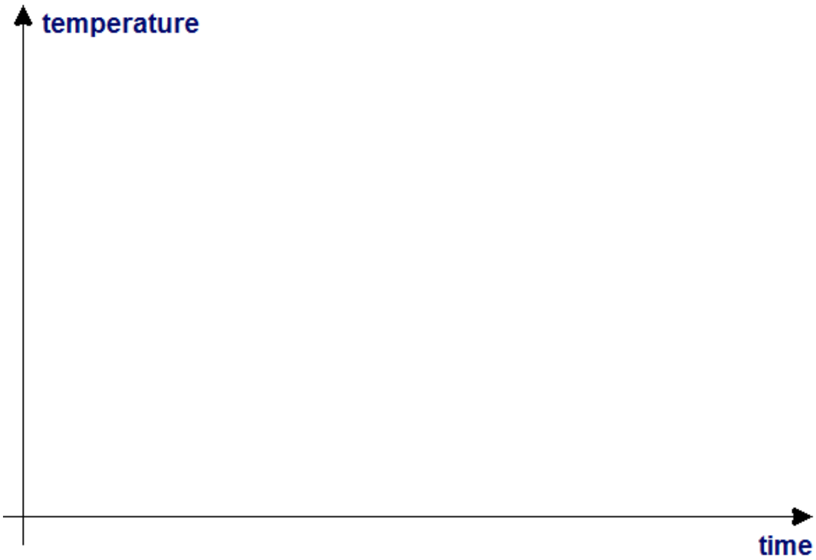


Plate 2

Make a prediction of what you are going to observe by means of the sensors. In particular, say what do you expect with respect to plate 1 and plate 2 temperatures and compare the speed with which the two temperatures will vary. Can the fan speed affect the results to be obtained for plate 2?

Now perform the experiment, as described above, and report in graphical form the results you obtained, clearly showing to which plate (1 or 2) the data refers and, in the case of plate 2, the fan speed (high, medium, low ...)



Were your prediction correct? Try to identify the points of agreement and those of disagreement between your predictions and the results you actually found.

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What are the physical quantities that, in your opinion, may have influenced the results you obtained?

Briefly explain your answer, trying to differentiate between what happens during "natural" cooling (plate 1) and the "forced" one (plate 2) .

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In depth analysis: experimental data fitting

It is possible to obtain an analytical expression for the cooling curves through a process of adaptation, or fitting, of a mathematical function to experimental data. This procedure is called *data fitting*.

To do this it can be useful to build a graph that reports the values of the differences, ΔT, between the values of temperature, T, detected by the sensors and the ambient temperature, T_e, as a function of time. T_e is obtained from the data table and a new column is built in the Data Logger with the values $\Delta T = (T - T_e)$. The new graph should show the trends of ΔT approaching zero and the analysis functions of the Data Logger can be used to fit the function

$$T - T_e = (T_0 - T_e)e^{-kt}$$

to the experimental data (note that T_0 is the temperature value measured by the sensor at t=0, i.e. at the beginning of data collection).

Are the mathematical functions well fitted to your experimental data? Are there values that do not adapt well to the fitting functions?
Try to discuss separately the two cases of natural and forced cooling.

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Describe the meaning of the variables and parameters *T*, T_0, T_e, *k* e *t* in the fitting functions, with respect to the characteristics the functions should have to well fit your experimental data.

In particular, highlight the variables/parameters that, in your opinion, give information about the cooling speed.

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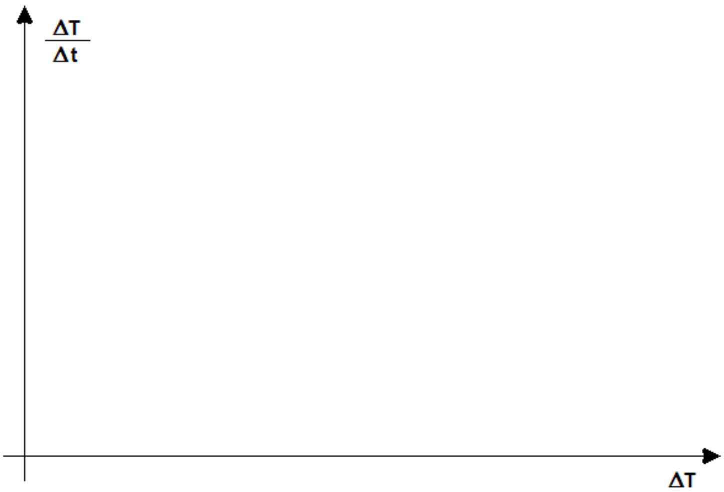
Another way to represent your experimental data is to plot with a spreadsheet the "cooling speed", $\Delta T / \Delta t$, as a function of ΔT, where Δt represents the time interval (constant) between two temperature, T, data. Remember that $\Delta T = (T - T_e)$, where T_e is the temperature that is reached by the plates at thermal equilibrium with the environment (i.e. the environmental temperature...).
To do this it is convenient to use the Excel file " cooling speed – data analysis.xls" that the teacher will provide you.
Report below the graphs you obtain by using produced by the spreadsheet.



Do you think that the data above represented may be fitted with linear functions?

If yes, write a mathematical relationship between ($\Delta T/\Delta t$) and ΔT ?

Is it possible to say from the experimental data and the fittings what the parameters of the linear functions (i.e. the Y-axis intercept and the line slope) actually mean?

Are there data intervals that highlight a better fitting between data and the lines than other? Try to explain.

Explanation:

From the linear dependance of (*ΔT/Δt*) vs. *ΔT* we obtain a relationship between the two variables that can be written as:

$$\frac{\Delta T}{\Delta t} = -k\Delta T$$

here k is a constant depending from the nature and shape of the cooling object and also from the way the object cools (natural or forced cooling).

The upper equation is an approximation of the differential equation

$$\frac{dT}{dt} = -kdT \quad ,$$

that has, as a solution:

$$T - T_e = \left(T_0 - T_e\right)e^{-kt} \quad .$$

This is actually, as we have already seen before, the mathematical function that best fits the experimental data of *ΔT* vs. *t*.

Conclusions:
Try to summarize, for each of the activities you have performed, what you learned at the end of each activity and how you came to the different conclusions you have drawn.

Designing a Low Energy House

Activity 4_1: Light heats up objects. Why and how?

General problem:

Building a low energy house needs a very accurate planning Step in which all possible heat dispersion phenomena must be carefully investigated in order to realize appropriate devices to save the thermal energy produced both by traditional heating systems and/or from direct exposure to the Sun.

The design of a thermodynamically efficient house needs knowledge and competences in several topics. In particular, it is important to know the characteristics of the building materials for what concerns the storage of thermal energy and even more important the understanding of all those factors which contribute to the collection of thermal energy available from the surrounding environment.

Introductive questions:

1) Describe some cases of heating produced by a light source:

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2) How is it possible to measure the effects produced by the light incident on an object surface?

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3) Can the same light source, placed at the same distance from two different objects, produce heating up to different temperatures?

YES, because:____

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NO, because:____

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4) Think about an experiment you could realize in your classroom in order to give an experimental answer to the previous question:

Sketch your experimental setup of measurement in the following:

Target of your experiment:

Construction of an home-made radiometer

Material needed for each group:

- 2 aluminium cans;
- 3 surface temperature sensors, with PC interface;
- White and black paint;
- Scissor, scotch tape and ruler.

Procedure:

Use the scissor to cut an aluminium can and make three rectangular plates having the same dimensions (7 cm) x (4 cm), measured by the ruler. Paint of black one of the plates and white another one and leave unpainted the third. As soon as the paint dries, scotch the tip of the surface temperature sensor to the back of each plate and fix them on a polystyrene support suitably shaped (see figure). Connect the temperature sensor to the PC through the laboratory interface and you will be ready to start your measurements of light radiation.

A 400 W halogen lamp, as that one shown in figure, can be used as light source to be placed at a certain distance from the plate of the home-made radiometer.

2) Design your experiment to measure the effects of light radiation; describe briefly which experiment you intend to perform using an home-made radiometer:

Sketch your experimental setup of measurement in the following:

Target of your experiment:

Experiment:

Required: home-made radiometer, halogen lamp, ruler, chronometer.

Procedure: Place the unpainted radiometer at an horizontal distance of 30 cm from the halogen lamp switched off, with the surface of the plate placed vertically and centred in front of the lamp. Start the measurement of the surface temperature of the radiometer plate and wait 10 seconds before switching on the lamp for further 30 seconds, illuminating the radiometer. Then switch off the lamp and remove it from the view of the radiometer. Continue the measurement until the temperature of the radiometer does not reach again the initial temperature.

<u>Question n. 1</u>: Why the radiometer increases its surface temperature?

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<u>Question n. 2</u>: Which transport mechanisms of light energy do you think could be responsible of the rise in temperature observed during this experiment?

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<u>Question n. 3</u>: Which is, in your opinion, the most relevant transport mechanism of light energy during this experiment?

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<u>Question n. 4</u>: How is it possible to distinguish between the several transport mechanism of light energy during this experiment?

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Discuss the results of your experiment with the other members of your working group. After that, share your conclusions with the other students in the classroom and with your teacher, trying to find the physical quantities which are more relevant to the description and to the interpretation of the observed phenomena. Report, in the following, the final conclusions coming from the discussion within the extended group of students.

Generalize the results:

Activity 4_2: Not only visible light heats up the objects!

Problem question:

Could the heating of a house be produced by external sources of energy different from the visible light?

Questions:

1) Describe some cases of heating produced by sources of energy different from the visible light:

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2) Design your experiment to measure the effects of thermal radiation produced by a not-visible light source; describe briefly which experiment you could perform by using the home-made radiometer previously described:

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Sketch your experimental setup of measurement in the following:

Suggested experiment:

Required:

Home-made radiometer, halogen lamp, ruler, chronometer, filter for visible light. In the absence of the filter, it is possible to realize an home-made filter for visible light by assembling sun-exposed and developed color photographic film or the opaque magnetic support inside a floppy disk.

Procedure:

Step 1: Place the radiometer at an horizontal distance of 30 cm from the halogen lamp switched off, with the surface of the plate placed vertically and centred in front of the lamp. Start the measurement of the surface temperature of the radiometer plate and wait 10 seconds before switching on the lamp for further 30 seconds, illuminating the radiometer. Then switch off the lamp and remove it from the view of the radiometer. Continue the measurement until the temperature of the radiometer does not reach again the initial temperature.

Step 2: Repeat the experiment exactly as described in step 1, but this time by filtering completely the visible light coming from the halogen lamp.

Step 3: Compare the results with those obtained in the presence of visible light.

Question n. 1: Why the surface temperature of the radiometer increases even in the absence of visible light?

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Question n. 2: Try to put your hand in front of the lamp with visible light filtered. What do you feel when the lamp is switched on and then back switched off?

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Question n. 3: In the absence of visible light, who transmits the energy that causes the rise of surface temperature of the radiometer?

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Activity 4_3: Who suffers more from the effects of thermal radiation?

Problem question:

Which characteristics should a material have in order to absorb more thermal radiation?

Experiment:

Required:

Home-made radiometers (black painted, white painted and an unpainted one), halogen lamp, ruler, chronometer, filter for visible light.

Procedure:

Step 1: Place the three radiometers at the same horizontal distance (30 cm) from the halogen lamp switched off, with the surface of the plates placed vertically and centred in front of the lamp. Start the measurement of the surface temperature of the radiometer plate and wait 10 seconds before switching on the lamp for further 30 seconds, illuminating the radiometer. Then switch off the lamp and remove it from the view of the radiometer. Continue the measurement until the temperatures of the radiometers do not reach again the initial temperatures.

Step 2: Compare the results obtained by using different radiometers.

Questions:

Question n. 1: Why the surface temperature of the black-painted radiometer increases more than the white-painted one?

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Question n. 2: Why the surface temperature of the white-painted radiometer increases less than the unpainted one?

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Step 3: Repeat the experiment as described in step 1, but this time by filtering completely the visible light coming from the halogen lamp.

Question n. 3: In the absence of visible radiation, which of the three radiometers reaches the highest temperature? Motivate your answer.

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Suggestion for an in depth experiment:

1) Execute the same experiment as described in part (I), using this time two home-made radiometers with the plates made of the same material (aluminium), having the same surface area exposed to visible radiation but different thickness.

Question: Which of the two radiometers, exposed to visible light for the same amount of time, reaches the highest temperature? Why?

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2) Execute the same experiment as described in part (I), using this time two home-made radiometers with the plates having the same surface area exposed to visible radiation and same thickness but made of two different materials.

Question: Which of the two radiometers, exposed to visible light for the same amount of time, reaches the highest temperature? Why?

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List the characteristics that your home-made radiometer should have in order to be the most efficient detector of thermal radiation:

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Activity 4_4: Do we measure invisible radiation?

Problem question:

We have measured the effects of the transfer of thermal energy by the radiation coming from a lamp switched on. What happens in the presence of hot objects?

Experiment:

Required:

Home-made radiometer, 50 cl plastic bottle, ruler.

Procedure:

Step 1: Start the measurement of the surface temperature of the radiometer plate and wait 10 seconds before placing the plastic bottle filled with hot water at an horizontal distance of 20 cm from the radiometer plate, vertically and centred with respect to the bottle (see figure).

Step 2: After 500 seconds from the beginning of the experiment, turn the radiometer up to 90 degrees with its plate facing upward (see figure) and continue to measure the surface temperature of the radiometer for further 500 seconds.

Step 3: After 1000 seconds from the beginning of the experiment, remove the bottle from the radiometer view and continue the measurement of the surface temperature of the radiometer for further 500 seconds.

Compare the temperature variation measured during the step 1 with those observed in step 2 and 3; discuss what observed during the whole experiment with the other members of the working group.

Report your comments in the following:

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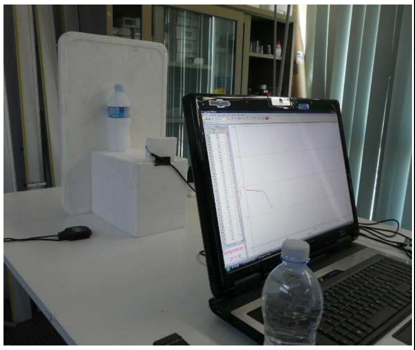
Problem: We have experienced the transfer of thermal energy by the radiation coming from hot objects. What happens in the presence of cold objects?

Suggestion for an experiment of deepening:

Required:

Home-made radiometer, 2 plastic bottles (50 cl), ruler.

Procedure:



Step 1: Measure the ambient temperature for 200 seconds without placing any object in front of the radiometer. After this time interval, place a plastic bottle filled with iced water at an horizontal distance of 20 cm from the radiometer (see figure). In this configuration, continue to measure the radiometer temperature for further 500 seconds.

Step 2: After 700 seconds from the beginning of the experiment, remove the bottle from the radiometer view and continue the measurement of the surface temperature of the radiometer for further 500 seconds.

Step 3: By continuing the measurement, place a plastic bottle filled with hot water at an horizontal distance of 20 cm from the radiometer and continue the measurement of the surface temperature of the radiometer.

Step 4: After further 300 seconds, turn the radiometer up to 90 degrees with its plate facing upward and continue the measurement of the temperature for the last 200 seconds.

Compare the temperature variation measured during step 1 up to step 4 and discuss what observed during the whole experiment with the other members of the working group.

Report your comments in the following:

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Activity 4_5: Can we see the Infrared radiation?

Problem question:

All objects with a temperature above the absolute zero emit thermal radiation. But, what is thermal radiation? Thermal radiation is the light which is emitted by an object because of the thermal motion of its atoms and it depends on the object temperature. An object at a very high temperature (above 600° C) emits visible thermal radiation. At lower temperatures, an object do not emit visible light but it radiates an invisible light called Infrared radiation. We cannot see Infrared radiation by our naked eyes, but some special electronic devices can. What instruments can we use to see Infrared radiation? Why could be so important to see Infrared radiation?

Experiment:

Required: Computer with webcam, a television with its IR remote control.

Procedure:

Step 1: Start the experiment by observing the front of a IR remote control. You can see a very little lamp (led) which must be pointed towards the television in order to select your favourite channel. When you press the button of the remote control an infrared signal is transmitted from the led to the television.

Question 1: By looking at the remote led, can you see any light when pressing the button?

Question 2: Can the infrared signal of the remote control cross the glass of a window? Try with different materials (transparent plastic bottle, black plastic bag, etc.)

Step 2: Point the remote control in front of the webcam and press a button.

Question: Can your webcam see any light by looking at the remote led?

Step 3: Switch off all the visible light sources (total darkness) and point the remote control in front of your eyes.

Question: Can you see any light?

Step 4: With all the visible light sources still switched off (total darkness), point the remote control towards a book placed on the table.

Question: Can you see the book by using your webcam?

Discuss what observed during the whole experiment together with the other members of the working group and report your comments in the following:

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Problem: We have experienced the source of invisible infrared light from a remote control. But any object with a temperature above the absolute zero emits infrared radiation. Can we use some special instruments to see infrared radiation coming from warm objects? What kind of applications could we think about the detection of infrared radiation?

See the slide-show movie at: www.uop-perg.unipa.it/establish/videoIR1_eng2.wmv

Discuss what observed during the slide-show together with the other members of your working group.

Report your comments in the following:

A deepening question: Why the webcam cannot see the infrared radiation coming from warm objects? Investigate the physics of near and far infrared.

FINAL DISCUSSION AND CONCLUSION

Let's go back to the initial problem: A low energy house

For any of the developed activities, summarize what did you learn at the end of each one and the path you have followed to draw your conclusions:

In light of what experienced, which expedients could you suggest to the designer of a low energy house in order to project a house that is efficient from the energy saving point of view:

WP3 | Chitosan: Fat Magnet!? Unit

European Science and Technology in Action Building Links with Industry, Schools and Home

Work Package 3
Chitosan: Fat Magnet!?
A – Teacher information

European Science and Technology in Action:
Building Links with Industry, Schools and Home

Lead author for unit	Wolfgang Graber et al (Leibniz- Institute for Science and Mathematics Education (IPN))

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Start Date: 1st January 2010 Duration: 48 months

Total Number of Pages: **11**

A. Teacher Information

Unit description

There is much advertising on chitosan (Poly-β-1,4-D-glucosamin) as a fat magnet. What is chitosan? Does it really work as described in the advertisements? Should we use it to avoid gaining weight? Students look for answers to these questions by researching the internet, and other sources, and doing own experiments. They learn how to produce chitosan, about its properties and several kinds of its application. The newly gained knowledge and competences form the base for the final discussion and students' own decision making.

Student level: students aged 16-19
Discipline(s) involved: Chemistry, biology
Estimated duration: 12 lessons

The Chitosan project can be taught as an advanced course deepening the knowledge on carbohydrates, but also extent it to more everyday life topics like healthy nutrition/ balanced diet with a focus on digestion and metabolism.

In the Schleswig-Holstein (Germany) chemistry curriculum the area 3 in grade 12/13 in the field of carbon hydrates refers to the topic handled here. It can also be used in the field of analytics (area 9). The sequence can suit each of the following topics:

- Carbon hydrates
- Structure-property interdependencies

IBSE Character

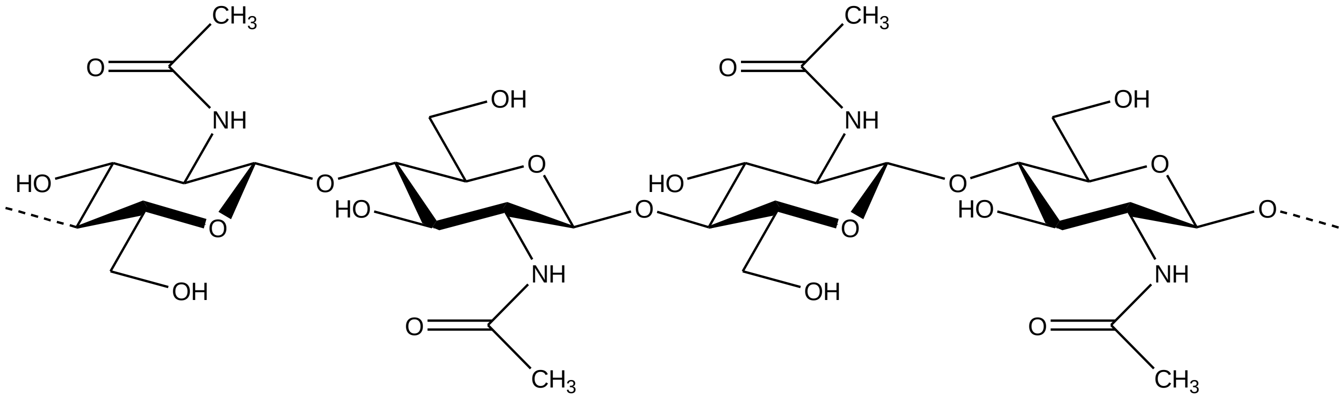
In this unit normally the teacher introduces the problem. S/he has found advertisements referring to chitosan as a slimming agent: "Chitosan: Fat Magnet!" Perhaps s/he had found the product itself and presents it to the students. While showing how s/he has found the information from the internet the class is also confronted with information claiming the uselessness of chitosan for reducing weight. So there are two contradicting contributions, one in favour of chitosan as slimming agent, and another describing that it does not work. So there is a leading question for this unit: "Who is right?" which is the starting point for the class' inquiry process. The students need

- to define the problem,
- develop and carry out a plan of how to investigate the problem (which includes
- the searching for further information,
- formulate and test hypotheses,
- plan and carry out experiments,
- communicate and discuss their findings with peers)
- and create coherent arguments supporting their findings.

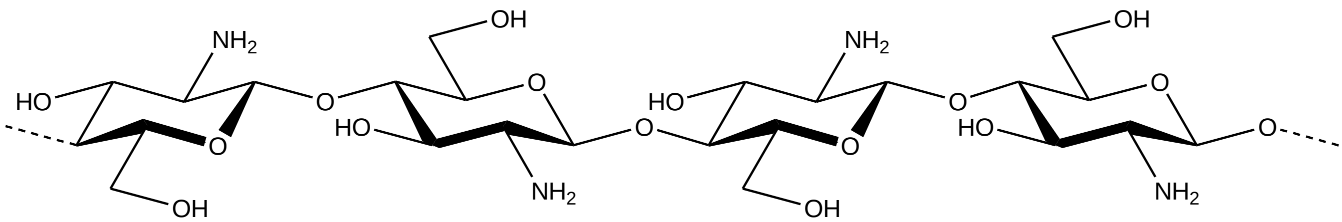
In addition they are asked to make and discuss own decisions whether to use chitosan themselves or recommend it to others.

Science Content Knowledge

Many nations with coastal regions involved in fishing or breeding crustaceans (crabs, shrimps...) are confronted with the problem of millions of tons of waste in the form of crab shells. Intensive research has found several applications for the main ingredient chitosan (from chitin) to solve this environmental problem producing valuable products from waste. This module will focus mainly on the application of chitosan as slimming aid.



Chitin: Poly-β-1,4-N-acetyl-D-glucosamin



Chitosan: Poly-β-1,4-D-glucosamin

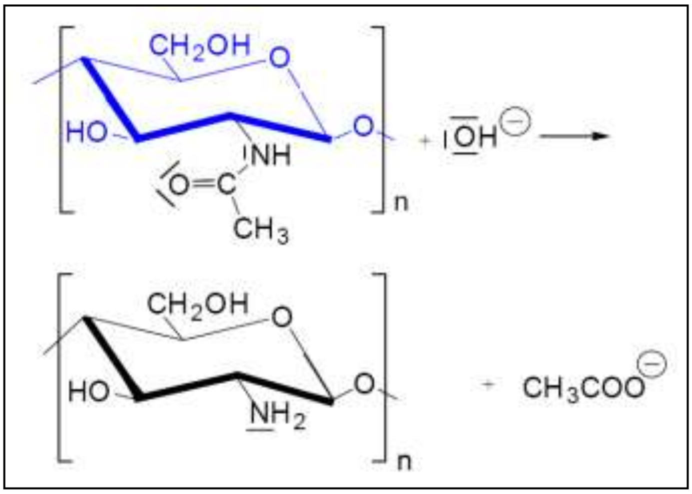
The effectiveness of chitosan is an adequate problem to work on in chemistry classes. Chitosan can easily be gained from chitin, the structural substance of crab- or shrimp shells. From the structural formula it is easy to learn that chitosan is very similar to cellulose: there is only one OH-group per glucose–unit replaced by an amino(NH_2)-group. Following cellulose chitin is the second frequently met naturally produced polymeric worldwide, so it‘s no exotic substance but quite common and with many application opportunities. For teaching chemistry it is also important that it can easily be used to demonstrate structure-property interdependencies.

Bader and Birkholz in their contribution to the Chitin Handbook (R.A.A. Muzzarelli and M.G. Peter, eds. (1997): Chitin Handbook. European Chitin Society) wrote: “The use of polysaccharides as renewable materials is a new subject in chemistry courses. Like in other cases the aim is to show the origin of a product, that has a link with everyday life of the pupils, by developing practical and suitable school experiments for this field (Sommer-feld and Bader 1995/ Insektenpanzer als Rohstoffquelle. Zur Didaktik der Physik und Chemie. Behrendt, H. (ed) Leuchtturm, Alsbach, pp 341. Full version: (1995) c + b (Chemie und Biologie) 39: 18.). In this context the subject chitin is a completion and enlargement. Contrary to former examples, now a polysaccharide is isolated from animal sources for school experiments as well as for industrial use. In addition chitin can be an example for the intelligent use of a waste product, without any conflict of interests, e.g. using it as food or as raw material. Finally, the chitosan made from chitin is a polysaccharide with canonic character (with the possibility to compare it with alginic acid and with neutral polysaccharides like starch or galactomanans.).”

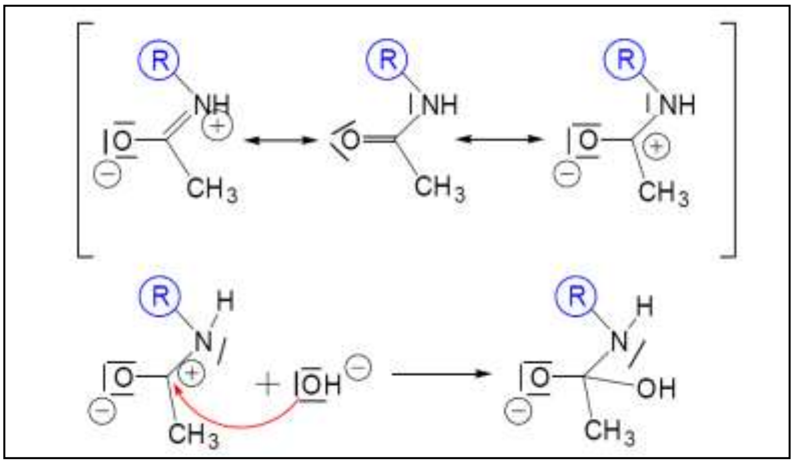
Through a simple process of deacetylation chitosan (Poly-β-1,4-D-glucosamin) is produced from chitin (Poly-β-1,4-N-acetyl-D-glucosamin):

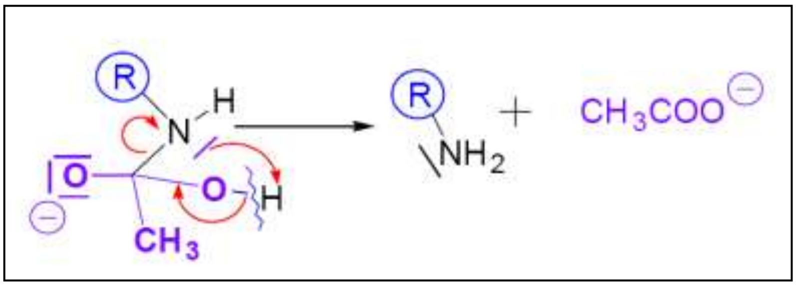
Deacetylation of chitin:

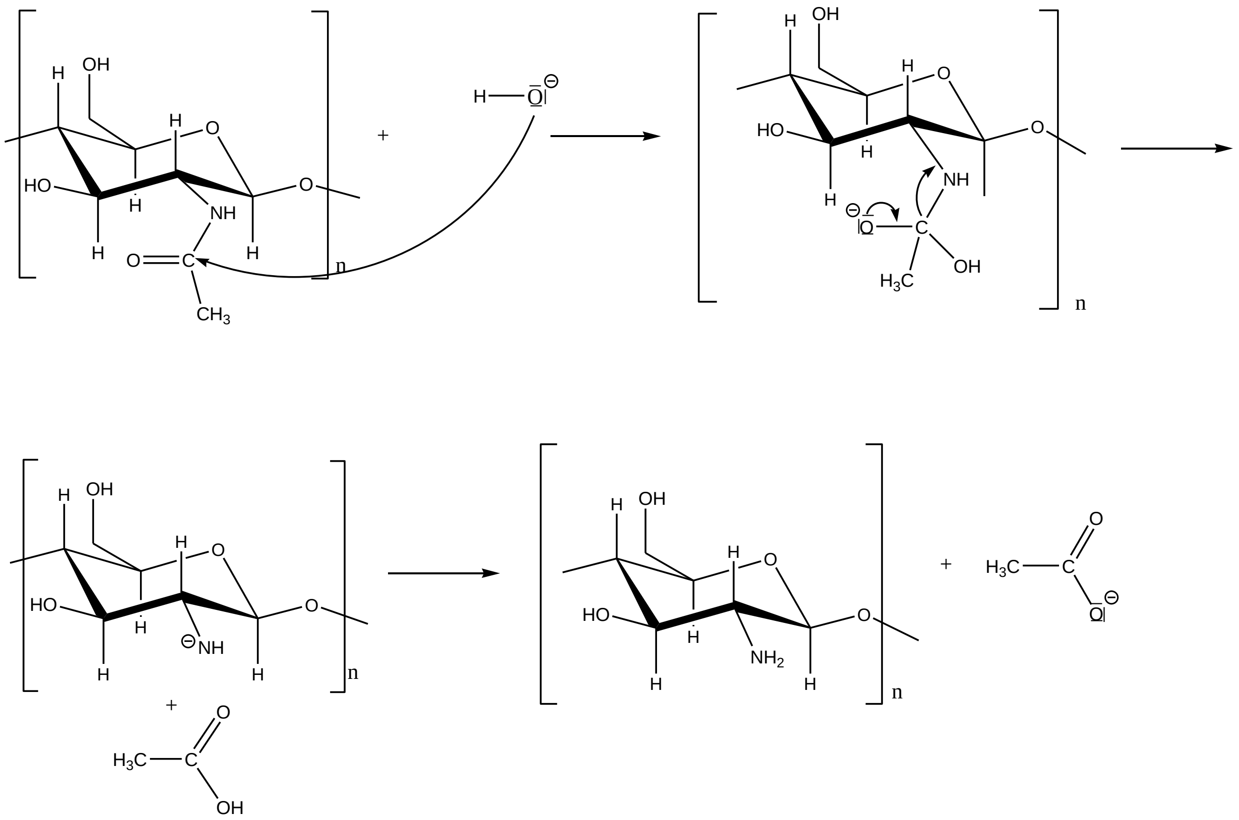
Summary:



Mechanism:







The shells have to be washed with water, dried and grinded. In a second step the protein needs to be removed with sodium hydroxide solution, and the calcium carbonate with hydrochloric acid. The obtained chitin will be deacetylised with sodium hydroxide solution, washed with water and dried. The product is a dim pink-beige chitosan looking very similar to chitin.

Shells

↓ Coarsely cleaning and breaking,drying, grinding

Protein removal ← 2 mol/l sodium hydroxide

↓ Washing (H_2O)

Calcium carbonate removal ← 4 mol/l hydrochloride acid

↓ Washing (H_2O)

Deacetylation ← 50 % sodium hydroxide

Washing (H_2O)

Solute/precipitate of Chitosan ← 2 % acetic acid

Washing (H_2O)
Drying /grinding

Chitosan according to its structure and properties has many possibilities of application. Bader and Birkholz (1997) published the following list:

- The clarification and cleaning of protein-containing waste water of fruit, meat, fish and milk industry as well as of breweries were the biggest and for a long time the only use of these polysaccharides. Chitosan causes the coagulation of the proteins found in waste water. As a naturally occurring polymer the chitosan is degradable and non-toxic, so it should be preferable to synthetic polymers.
- Analogously, fruit and vegetable juice are clarified with the aid of chitosan.
- Chitosan and chitin are chelating agents showing complexing ability for many metal ions. The cations coordinate to free electron pairs of nitrogen and oxygen atoms. The affinity of chitosan to metal ions obeys the following order: $Cr^{3+} < Co^{2+} < Pb^{2+} < Mn^{2+} \ll Cd^{2+} < Ag^{+} < Ni^{2+} < Fe^{3+} < Cu^{2+} < Hg^{2+}$. With the aid of appropriate acids (e.g. diluted sulphuric acid) chitosan is regenerated and reused. One field of application is the purification of heavy-metal contaminated waste water.
- Membranes made of chitosan are suitable for water softening, because they are impermeable to calcium ions.
- Paper impregnated with a solution containing 3 % chitosan shows a significant higher tear resistance, abrasion resistance and moisture resistance compared to untreated paper.
- Due to the antibacterial character of chitosan, it is possible to use packaging films of chitosan for preservation.
- In technology chitin and chitosan are used for the production of membranes, fibres and films. At present composites, e.g. materials partly made of cellulose, are studied. Chitosan has an outstanding film-forming property caused by intra- and intermolecular hydrogen bonding.

Chemical modification of chitin and chitosan leads to further applications, just to mention a few:

- Since chitin, chitosan and different derivatives of these compounds are degradable by endogenous enzymes and have no allergic effects, they are used in different medical and pharmaceutical fields. Examples are suture materials, wound dressings as well as synthetic skin.
- Recently, derivatives of chitosan are used in hair-care products, thanks to their setting, conditioning and caring properties. In creams and ointments chitosan derivatives are used because of their water-binding ability and adhesiveness.
- Chitosan salts are formed by reaction of chitosan with a multitude of inorganic and organic acids. For example, if chitosan is heated to boiling in the presence of hydrochloric acid, water soluble chitosan hydrochloride precipitates on cooling, which is one of the starting materials in the cosmetics.

- Coating with a film made of N,0-carboxymethyl chitosan improves the storage stability of seeds and fruits. The low oxygen permeability and the antibacterial effect of these films guarantee preservation for a long time.
- Under basic conditions chitosan reacts with alkyl halides to N,0-alkylchitosan. So the reaction with chloroacetic acid yields water soluble N,0-carboxymethyl chitosan. This can be used for films.

There are several more possibilities of application. During this course we will focus on chitosan as slimming agent. Because of its property to bind 8 times its weight of fat it is advertised as slimming agent or “Fat Magnet”. In an acidic milieu the amino groups will be protonized and thus charged positively. These poly-kations are able to bind the negatively charged fatty acid anions, what is irreversible and the fat cannot be metabolized and so the captured fat leaves the body undigested and does not enter the organism. When less fat is available for the organism, the body draws the necessary fat from its fat reserves, which automatically leads to a loss of weight.

But:

Pharmaceutical studies show no positive effect of chitosan for weight loss (Google: chitosan Pharmaceutical studies): E.g.: “The new study, published in the September issue of the International Journal of Obesity (28, 1149-1156), is one of the largest to date. The researchers assigned 250 adults, with an average body mass index of 35.5, to receive either 3g of chitosan daily or a placebo for 24 weeks. All participants received standardised dietary and lifestyle advice for weight loss. The researchers from the Clinical Trials Research Unit in the University of Auckland report that the chitosan group lost more body weight than the placebo group "but the effects were small". The chitosan group lost an average of 0.4kg compared to a 0.2 kg gain in the placebo group.” (24.08.2004: http://www.nutraingredients-usa.com/news/ng.asp?id=54318-chitosan-fails-to)

Pedagogical Content Knowledge

Teaching/Learning goals

Scientific concepts: Chemical structures of chitin and chitosan and its properties, Chitosan’s possible reactions in the human body, applications of chitosan in different areas (biochemistry/medicine, cleaning water, preparing fruit juice ...) and its explanations based on the substances’ structures and properties.

Skills: Formulating an inquiry question and a hypothesis, planning and performing an inquiry, planning and performing an experiment, communicating and presenting ideas and results, managing information and knowledge, identifying, evaluating and using information from the internet and other sources, using digital mind mapping to support one’s performance, communicate with partners from industry, make own decisions based on scientific knowledge and personal values

Pre-Requirement Knowledge:

Contents:

The students had been taught a sequence on carbon hydrates and learned about cellulose as a poly-saccharide.

- Properties of glucose, composition and structure of the glucose molecule
- Some mono-saccharides and its appearance in nature
- Glycosidic bonding
- Starch and cellulose as polymeric compounds

Skills:

The students are familiar with conducting experiments on their own. They can operate computers, and are to some extend able to research information. Since the focus should be very much on the improvement of competencies like information management, communication, evaluation and decision making, a well planned support by the teacher is needed. Particularly in traditional German classrooms the focus had been on learning facts and concepts, while the promotion of the mentioned competencies had been neglected. This is to be changed since the new education standards have been introduced in 2004, where explicit foci are laid on four areas of competencies: discipline knowledge, nature of science, communication and evaluation.

Linkage to the Syllabus:

The Chitosan project can be taught as an advanced course deepening the knowledge on carbohydrates, but also extent it to more everyday life topics like healthy nutrition/ balanced diet with a focus on digestion and metabolism.

In the Schleswig-Holstein (Germany) chemistry curriculum the area 3 in grade 12/13 in the field of carbon hydrates refers to the topic handled here. It can also be used in the field of analytics (area 9). The sequence can suit each of the following topics:

- Carbon hydrates
- Structure-property interdependencies

Industrial Content Knowledge

Though there are a lot of different applications of chitosan in many areas of our daily life there are not many companies dealing with the production and processing of chitosan. We contacted the Co. BioNova in Büsum and the Seehof Laboratorium in Wesselburen, both situated in Schleswig-Holstein, the northern part of Germany, and we as well as our students learnt a lot about chitosan. As one can see from the science content part chitosan is used for the clarification and cleaning of protein-containing waste water of fruit, meat, fish and milk industry as well as of breweries, also fruit and vegetable juice are clarified with the aid of chitosan. One field of application is the purification of heavy-metal contaminated waste water. Membranes made of chitosan are suitable for water softening, because they are impermeable to calcium ions. Paper impregnated with a solution containing 3 % chitosan shows a significant higher tear resistance, abrasion resistance and moisture resistance compared to untreated paper. Due to the antibacterial character of chitosan, it is possible to use packaging films of chitosan for preservation. In technology chitin and chitosan are used for the production of membranes, fibres and films. Since chitin, chitosan and different derivatives of these compounds are degradable by endogenous enzymes and have no allergic effects, they are used in different medical and pharmaceutical fields. Examples are suture materials, wound dressings as well as synthetic skin. Derivatives of chitosan are also used in hair-care products. In creams and ointments chitosan derivatives are used because of their water-binding ability and adhesiveness.

The Seehof Lab Company is particularly interested in medical applications and besides others they have developed Photosan (from Chitosan), a photosensitizer used for photodynamic therapy (PDT) of skin cancer.

When the students work on the “Fat-Magnet” problem they ask: Can Chitosan bind fat? This is not so difficult to answer through school lab experiments. But then they have to investigate whether this is possible in the human body and whether this can lead to weight loss. At this point our students contacted the company, got new information about their problem, but got to know much more information about chitosan, its applications and new developments in this field. They were able to start a cooperation with the company where they tried out new research activities like an alternative way to gain chitosan from crab shells through enzymatic processes.

Through the cooperation students and teachers learned more about chitosan, about new research and application developments, they learned how chemists and other related professionals work in practice, and they became convinced that their own work at school is of life relevance.

Learning Path(s)

Lesson sequence

Engagement

The teacher motivates the students to work on this topic by showing advertisements referring to “Chitosan – Fat Magnet!”

Exploration

During this phase the teacher explores together with the students the following questions and introduces the students to the new content (chemistry of chitosan, poly-saccharide) and (if necessary) to the strategies and tools needed to work on these questions (internet browser, search engine, mind manager)

- Is there any useful information about chitosan as fat blocker on the web?
- What is Chitosan?
- Which properties characterize Chitosan?
- How does Chitosan interact with fat?
- Where do we find Chitosan in nature?
- How can we produce Chitosan?

The teacher leaves many open questions but has provided the students during the first phase (as a kind of advance organizer) with some content knowledge and adequate learning strategies.

During this phase the students work in small groups on the open questions. They try to find information (mainly from the internet) about chitosan as fat magnet, about the structure, production and properties of chitosan. They had to identify relevant information, evaluate and understand the content, relate it to previous knowledge and store it in a structured way in mind maps.

Explanation

They carry out own experiments e.g. to produce chitosan from shrimp (crab) shells and try to find out how it reacts with fat and also with other substances (see students' activities and experiments) to find out more about chitosan's properties.

Now they start to answer the questions of the starting phase. The students have learnt how to produce chitosan from shrimp shells, they have learnt how chitosan reacts with fat or fatty acids. They have read some papers on chitosan as fat blocker giving differing information. Does it work or does it not work? They reflect their findings, discuss them with their classmates and prepare a public presentation with posters, experiments and Powerpoints.

Extension

The overall question is not only about its chemical functioning but also about should we use this substance ourselves or recommend it to friends to control weight? This question leads beyond pure science, includes general problems with drugs/ pharmaceuticals and balanced diets and healthy way of living.

Evaluation

After having discussed the results and problems also extending the chemical content students are asked to make personal decisions whether they would use this drug for supporting the process of reducing weight or whether they would recommend it to friends. They gather arguments pro and contra chitosan and defend their decision.

Pro's	**Con's**
Easy to administer	There are no serious studies to prove its effectiveness
Life quality: You don't need to miss fat in your food	It works only in acidic environment, but the intestine is basic
You avoid quite easily unhealthy overweight	Fat soluble medications can be compromised in its effectiveness (oral contraceptiva, estrogen)
Creative method of using waste	The missing fat will also hinder vitamines from entering the metabolism
	Producing more shrimps in Asia will destroy mangrove woods
	It's much more healthy to eat balanced food and do exercises

Assessment

Provide items and suggestions for student assessment. Assessment is very much dependent on the really taught way and the elaborated content. This will differ in each school, each level and each country. Assessment tasks have to be constructed together with the teacher in charge.

Student Learning Activities

Students will plan and do the following experiments guided by the teacher (and worksheets):

Activity	**Inquiry type**	**E-emphasis**
Chitin from Crab Shells	Guided inquiry	Explanation
Chitosan from Chitin	Guided inquiry	Explanation
Solubility of Chitosan	Guided inquiry	Exploration
Chitosan binding Fat	Guided Inquiry	Exploration
Preparation of Chitosan Films	Guided/open inquiry	Exploration
Clarification of Fruit Juices	Guided inquiry	Extension

WP3 | Chitosan: Fat Magnet!? Unit

European Science and Technology in Action Building Links with Industry, Schools and Home

Work Package 3
Chitosan: Fat Magnet!?
B – Classroom Materials

European Science and Technology in Action: Building Links with Industry, Schools and Home

Lead author for unit	Wolfgang Graber et al (Leibniz- Institute for Science and Mathematics Education (IPN))

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B. Classroom Materials

A. School experiments on chitin and chitosan
B. Student worksheets related to the experiments
C. Some articles given more background information about chitosan as slimming agent (found in the internet)

A. School experiments on chitin and chitosan

(Following you find parts of a publication by H.J. Bader/ E. Birkholz in: R.A.A. Muzzarelli and M.G. Peter, eds., Chitin Handbook, European Chitin Society. 1997. ISBN 88-86889-01-1)

"The school experiments described below, were developed with the aim of showing the complete chitin/chitosan path: starting with the isolation of chitin, the preparation of chitosan is introduced as well as characterization methods for both compounds, ending with examples for their use. Depending on teaching needs it is possible to make a selection, because the experiments are not interdependent. Simple experiments, e.g. analysis of the solubility of chitin and chitosan, are not included, but may be performed additionally without problems.

Isolation of chitin and chitosan

Generally, the isolation of chitin and chitosan from crab shells is possible (experiment 1 and 2). If market products are used, cheap products of technical grade are recommended, because they are suitable for the experiments described below.

Experiment 1: Chitin from crab shells

Duration: First step: 20 minutes without drying time; second step: 2 hours resp. first day: 30 minutes, second day: 30 minutes; third step: 30 minutes without drying time.

Equipment: beaker (400 ml), strainer (mesh size 3-4 mm), magnetic stirrer with heating plate, stirring rod, crystallization dish (0 14 cm), drying oven, balance, mortar with pestle, suction flask (500 ml), porcelain nutsch filter (0 9 cm), filter ring, water pump or diaphragm pump, thermometer, retort stand material, filter paper (0 9 cm).

Reagents and materials: sodium hydroxide solution, w(NaOH) = 2 %, hydrochloric acid, w(HCl) = 7 %, crab shells, demineralized water. *Procedure:*

First step: Coarse purification

Crab shells (150 g) are coarsely cleaned by breaking and stirring with water for some minutes. Then the shells are filtered off. This process is repeated until sand and other soil are removed. The crab shells precleaned are dried overnight in the drying oven at 80°C.
Second step: Protein removal

15 g of the dried shells are grinded in a mortar and transferred to a beaker. Then 250 ml of sodium hydroxide solution are added and the mixture is heated under stirring at 60 - 70 °C for half an hour. The shells are filtered off with a strainer and the process is repeated. The filtrate should be almost clear and colorless. Then the shells are washed neutral with demineralized water. For time-saving the shells may be soaked in sodium hydroxide

solution overnight, after the first sodium hydroxide treatment, then filtered off and washed. *Third step: Calcium carbonate removal*

250 ml of hydrochloric acid are slowly added to the shells and the mixture is stirred at room temperature until no gas escapes. As a check, 10 ml of hydrochloric acid are added. If no generation of gas occurs, the mixture is filtered off and washed neutral with water. The product is dried overnight in the oven at 60 °C.

Result: The chitin isolated is an almost colorless and fluffy substance. 15 g of precleaned crab shells yield 3 g of chitin, corresponding to a yield of 20 %. *Faults:* On reduction of the cleaning steps, the chitin obtained is not colorless. *Waste disposal:* Sodium hydroxide solution and hydrochloric acid are neutralized and poured down the sink.

Experiment 2: Chitosan from chitin by alkaline hydrolysis

Duration: First day: 70 minutes, second day: 30 minutes without drying time. *Equipment:* Round-bottomed three-necked flask (250 ml), connector (cone to hose coupling), reflux condenser, ground-glass thermometer, heating coil, magnetic stirrer, stirring rod, balloon, water pump or diaphragm pump, suction flask, filter ring, porcelain nutsch filter (0 9 cm), filter paper, crystallization dish (0 14 cm), drying oven, balance.

Reagents and materials: sodium hydroxide solution, w(NaOH) = 50 %, chitin, nitrogen bomb.

Procedure: In a round-bottom flask 150 ml sodium hydroxide solution are added to 2 g of chitin. The apparatus is flushed with nitrogen and then it is closed air-tightly with a nitrogen-filled balloon. Now the mixture is heated under stirring to at 125°C for one hour. The mixture is allowed to cool and then 100 ml of water are added. The next day the mixture is filtered off and the residue is washed with water to neutral reaction and dried in the oven at 60°C.

Result: The chitosan obtained is an almost colourless and fluffy substance resembling chitin. The conversion of 2 g of chitin yields 1.5 g of chitosan. *Waste disposal:* Mother liquor and washing water are neutralized and poured down the sink.

<u>Analysis of chitin and chitosan</u>

Like starch chitosan forms with iodine an inclusion complex, which has a purple colour in acidic medium. On the other hand, the chitin is unable to accommodate iodine molecules (experiment 3). In contrast to alkaline hydrolysis the glycosidic bonds of chitin between the sugar units are cleaved by acidic hydrolysis. The amide bond in chitin is preserved. Degradation of chitin leads to N-acetylglucosamine and corresponding oligomers. Hydrolysis of chitosan yields glucosamine and its oligomers (experiments 4 and 5):

The aldehyde groups of the glucosamine and N-acetylglucosamine are oxidized by Fehling's solution to carboxylic acids, whereas the divalent copper is reduced to univalent copper, which precipitates as brick-red coloured copper(I) oxide in alkaline medium. The free aldehyde groups of chitosan are not sufficient for the Fehling's test (experiment 4), and. due to insolubility, the test with chitin is not feasible. The determination of free amino groups in chitosan is performed according to Slyke (Sommerfeld and Bader, 1995).

Experiment 3: Differentiation of chitin and chitosan

Duration: 10 minutes.

Equipment: 2 watch glasses, 2 Pasteur pipettes.

Reagents and materials: Chitin, chitosan, iodine/potassium iodide solution (0.2 g I_2 are added to 100 ml of a potassium iodide solution, w(KI) = 5 %), sulphuric acid, w(H_2S0_4) = 1 %.

Procedure: Some flakes of chitin or chitosan are put onto a watch glass. 2-3 drops of iodine/potassium iodide solution are added and the mixtures are acidified with 2-3 drops of sulphuric acid.

Observation: After addition of iodine/potassium iodide solution the chitosan change color to dark brown and the solution becomes colorless. On addition of sulphuric acid the dark brown colors turns dark purple.

In opposite the chitin remains unchanged on addition of iodine solution, which retains brownish-yellow colour. Also the acidification with sulphuric acid has no consequence.

Precautions: The experiment has to be performed in the hood. *Waste disposal:* Chitin and chitosan treated are added to the waste jar for solids.

Experiment 4: Acidic hydrolysis of chitin and chitosan and analysis of the products of hydrolysis

Duration: 90 minutes.

Equipment: 2 round-bottom flask (250 ml), 2 cork rings, measuring cylinders (100 ml and 10 ml), 2 reflux condenser, 2 heating coils, 2 magnetic stirrer, 2 stirring rods, tubing, retort stand material, filter rack, filter paper, glass filter. *Reagents and materials:* Chitin, chitosan, diluted hydrochloric acid, w(HCl) = 7 %, concentrated hydrochloric acid, w(HCl) = 24 %, acetic acid, w(C2H4O2) = 12 %, Fehling's solution I and II.

Procedure: 1 g of chitin and 1 g of chitosan are added each to a round-bottomed flask filled with 100 ml of diluted hydrochloric acid. 10 ml of concentrated hydrochloric acid are added to each mixture. The flasks are heated to reflux for one hour. The reaction mixtures are allowed to cool down and then filtered off. 2 - 3 ml of each filtrate are mixed with 2 ml of Fehling's solution I and 2 ml of Fehling's solution II and the mixtures are heated for some minutes in a water bath. For comparison some flakes of chitosan are dissolved in acetic acid and mixed also with Fehling's solutions.

Observation: Major parts of chitin and chitosan dissolve on heating with hydrochloric acid. The solutions are freely filterable, i.e. they are not viscous such as the chitosan/acetic acid solution. The Fehling's test proves feasible with the solution, in the case of chitosan it fails.

Faults and precaution: The addition of too much concentrated hydrochloric acid results in a decomposition of chitin and chitosan.

Waste disposal: The filtrates are needed for experiment 5. Filtration residues are added to the waste jar for solids. The samples obtained by the Fehling's test are neutralized and added to the waste jar for heavy-metal solutions.

Experiment 5: Determination of the hydrolyzates of experiment 4 by chromatography

Duration: 40 minutes.

Thin layer chromatography (TLC) on a silica gel plate with mobile solvent made of 10 % of water, 15 % of methanol, 25 % of water-free acetic acid and 50 % of 1,2-dichloroethane produces the result shown in Figure 1. (Spray reagent: 0.5 g of thymol are added to a mixture of 5 ml sulphuric acid (w(H_2S0_4) = 96 %) and 95 ml of ethanol; reference solution: 10 mg of N-acetylglucosamine added to 20 ml of water, 10 mg of glucosamine hydrochloride are added to 20 ml of water, 10 mg of N-acetylglucosamine and 10 mg of glucosamine are added to 20 ml of water).

Observation (cf. Figure 1): The main spot in the chromatogram of the filtrate obtained from the acidic hydrolysis of chitin corresponds to the spot of the N-acetylglucosamine reference on regarding its position and brownish colour. Both chromatograms of the filtrates show below the main spots further spots, which are graded downwards and which are paler in intensity. Those indicate different

oligomers of N-acetylglucosamine and glucosamines consisting of 2 to 4 sugar units.

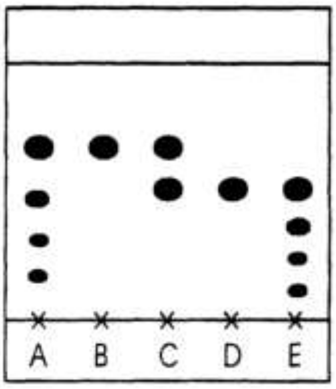
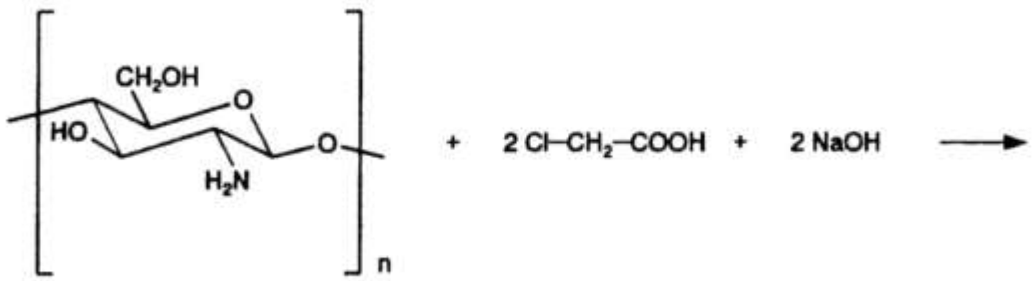


Figure 1. Chromatogram of products obtained in hydrolysis of chitin and chitosan. A: Filtrate of acidic hydrolysis of chitin, B: N-acetylglucosamine reference, C: N-acetylglucosamine/glucosamine reference, D: glucoseamine reference, E: filtrate of acidic hydrolysis of chitosan.

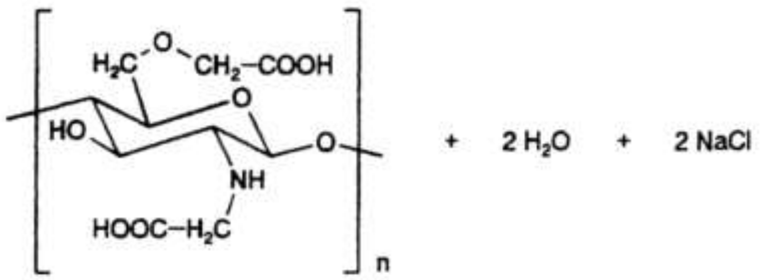
Usings of chitin and chitosan

The macromolecule chitin is used for the preparation of transparent films, because of its film-forming properties, which are caused to intramolecular and intermolecular hydrogen bonds. Therefore it is possible to use tetraethylene glycol as softening agent, which, by hydrogen bond formation, intercalates between the chitosan molecules (experiment 6).

Besides copper many other heavy metal ions like nickel, zinc, cobalt, iron(II), chromium(III) are chelated by chitosan. (Sommerfeld and Bader, 1995). The addition of very small amounts of chitosan to protein-containing waste water causes a agglomeration of the colloidally dissolved protein, as demonstrated in experiment 7. The Polycationic properties of chitosan decrease the electrical charge on the surface of the colloidally dissolved proteins and so allow the flocculation. The solutions treated show a negative biuret test and only a very faint Tyndall effect, indicating very small amounts of proteins. A comparable effect is shown in experiment 8, where clarification of naturally cloudy juices is described. Juices contain naturally occuring polyanionic tannins and other suspended materials. Polycationic chitosan forms with those compounds ionic macromolecular complexes which are centrifuged off.



chitosan



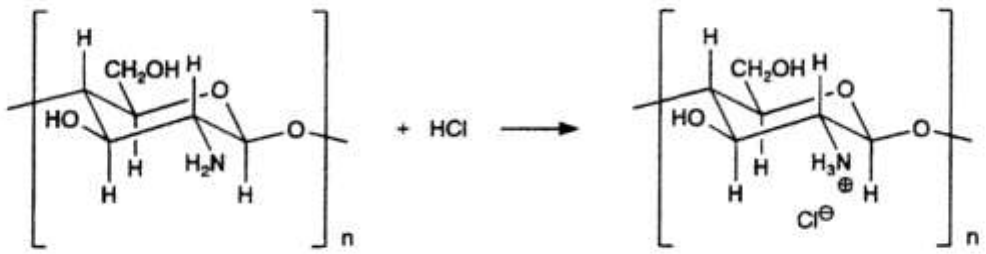
N,O-carboxymethyl chitosan

In alkaline medium chitosan reacts with monochloro acetic acid to N,0-carboxymethyl chitosan, experiment 9:

Like chitosan the carboxymethyl chitosan forms transparent films (experiment 10). Here the film-forming properties are also based on intramolecular and intermolecular hydrogen bond formation.

Experiment 11 shows very impressively, that a film made of N,0-carboxymethyl chitosan protects and conserves fruit. Without problems the coating is removed by washing before consumption. Fruits treated in this way keep well for more than three months when stored cool.

If chitosan is dissolved in hydrochloric acid, water soluble chitosan hydrochloride is formed (experiment 12):



chitosan chitosan hydrochloride

When paper is treated with a solution of this hydrochloride, a film is formed on the surface, which becomes is water-repellent. This is nicely demonstrated with ink as described in experiment 13.

Experiment 6: Preparation of chitosan films

Duration: First day: 30 minutes, second day: 5 minutes.

Equipment: 2 beaker (250 ml), magnetic stirrer with heating plate, stirring rod, Pasteur pipette, small-meshed strainer, 2 plastic plates (30 x 30 cm^2) or rinsing bowl.

Reagents: Chitosan, acetic acid, $w(C_2H_40_2)$ = 12 %, tetraethylene glycol. *Procedure:* Two beakers are filled each with 2 g of chitosan and 100 ml of acetic acid. Under slight heating and stirring the chitosan is dissolved. After cooling one of the solutions is poured through a strainer onto a plastic plate or on the backside of a rinsing bowl. The content of the second beaker is mixed with 0.2 g of tetraethylene glycol and the mixture is stirred for some minutes. Afterwards this solution is poured through a strainer onto a plastic plate or on the backside of a rinsing bowl too. The slightly viscous solutions are not smoothed down. The solvent is allowed to vaporize overnight.

Observation: After the vaporization of the solvent in both experiments a flexible, tear resistant and transparent film remains, which is easily peeled off the plate. The film with additional tetraethylene glycol is softer than the pure chitosan film. *Faults and precautions:* If the solutions are poured directly onto plastic plates without using strainer, it is possible that chitosan particles not dissolved completely cause thickenings and uneven patches. Besides, pouring through strainer prevents the formation of bubbles.

If too much of the softener is added, the two components separate and after some time the softener forms oily drops on the film.

Waste disposal and cleaning: Immediately after use the strainer should be cleaned with running water.

Experiment 7: Use of chitosan for cleaning of protein-containing waste water.

Duration: 20 minutes.

Equipment: 2 beaker (100 ml), 2 test tubes, 2 centrifuge tubes, magnetic stirrer, stirring rod, Pasteur pipette, centrifuge, light source (e.g. laser), pH paper.

Reagents and materials: Fresh egg-white, chitosan solution, $w(C_6H_{11}N0_4)_n$ = 0.5 %, sodium hydroxide solution, w(NaOH) = 5 %, copper sulfate solution, $c(CuS0_4)$ = 1 mol/1, acetic acid, $c(C_2H_4O_2)$ = 0.2 mol/l.

Procedure: Preparation of chitosan solution: Under slight heating 1 g of Chitosan is dissolved in 50 ml of diluted acetic acid (w ~ 1.2 %). The solution is diluted with demineralized water to a volume of 200 ml, resulting in a 0.5-per-cent chitosan solution in 0,3-per-cent acetic acid. This solution shows no Tyndall effect.

50 ml of demineralized water are added to 1 g of fresh egg-white. After short-time stirring 0.5 g of chitosan are added and the mixture is stirred for another 5 minutes. Now the solution is centrifuged for 10 minutes. Then a biuret test for protein is performed and the solution is tested for the Tyndall effect. *Observation:* If water is added to egg-white, then a cloudy unfiltrable solution is formed. After addition of chitosan the precipitate agglomerates. The pH value amounts to 7. The centrifugate is clear. The biuret test proves unsuccessful A very slight Tyndall effect is visible.

Faults and precautions: The heating of the protein solution has an unfavourable effect on results. If more than 60 mg/1 of chitosan are added to the protein solution, the centrifugate remains cloudy. *Waste disposal:* The solutions are poured down the sink.

Experiment 8: Clarification of fruit juices

Duration: 20 minutes.

Equipment: Beaker (100 ml), magnetic stirrer, stirring rod, centrifuge, centrifuge tubes, Pasteur pipette, light source (e.g. laser).

Reagents and materials: Chitosan, naturally cloudy juice (e.g. apple juice). *Procedure:* 50 ml of naturally cloudy apple juice are mixed with 0.1 g of chitosan and the mixture is stirred for 5 minutes. Then the solution is centrifuged for 10 minutes. Equally, 50 ml of naturally cloudy apple juice without additional chitosan are centrifugated as blank test.

Observation: The centrifugate of the apple juice mixed with chitosan is completely clear and no Tyndall effect is visible. In opposite, the centrifugate of the untreated apple juice shows same cloudiness as before. The Tyndall effect is visible.

Faults and precautions: If too much chitosan is added, the centrifugate remains cloudy. *Waste disposal:* The solutions are poured down the sink.

Experiment 9: Preparation of N,0-carboxymethyl chitosan

Duration: 90 minutes (without drying time).

Equipment: 2 beaker (100 ml), magnetic stirrer, stirring rod, filter, filter rack, filter paper, pH paper, crystallization dish (9 cm), desiccator, water pump. *Reagents and materials:* chitosan, monochloroacetic acid, sodium hydroxide solution, w(NaOH) = 50 %, acetic acid, w($C_2H_40_2$) = 98 %, acetic acid, w($C_2H_40_2$) = 12 %, ethanol, silica gel blue.

Procedure: 1 g of chitosan is suspended in 50 ml of diluted sodium hydroxide solution. Then 1 g of monochloroacetic acid is added carefully. Now the mixture

is stirred for 1 hour. Afterwards the pH value is brought to 5 by addition of acetic acid and the precipitate formed is filtered off. The product is washed with ethanol and finally it is dried in the desiccator over silica gel blue. *Observation:* After stirring for 1 hour a high viscous solution is formed. On addition of acetic acid (pH 5) a flocculent, almost colorless precipitate is formed, which is easily filtered off.

Faults and precautions: Because of the vigorous reaction by addition of chloroacetic acid to sodium hydroxide solution, the experiment has to be performed in the hood and protective gloves have to be worn. If stirring time is shortened, possibly not all of the chitosan has reacted with the monochloroacetic acid. In this case in alkaline medium undissolved chitosan remains. *Waste disposal:* The acetic acidic solution is neutralized and poured down the sink.

Experiment 10: Preparation of films made of N,0-carboxymethyl chitosan

Duration: First day: 15 minutes, second day: 5 minutes.

Equipment: Beaker (250 ml), magnetic stirrer with heating plate, stirring rod, Pasteur pipette, small-meshed strainer, plastic plate (30 x 30 cm^2) or rinsing bowl.

Reagents and materials: N,0-carboxymethyl chitosan, demineralized water. *Procedure: 2* g of N,O-carboxymethyl chitosan are dissolved under slight heating and stirring in 100 ml of demineralized water. After cooling the solution is poured through a small-meshed strainer onto a plastic plate or on the backside of a rinsing bowl. The solution is not smoothed down and the water is allowed to vaporize overnight.

Observation: After the vaporization of the solvent a flexible, tear resistant, transparent and very strong film remains, which is easily peeled off the plate. *Faults and precautions:* If the solutions are poured directly onto plastic plates without using strainer, it is possible that

N,0-carboxymethyl chitosan particles not dissolved completely cause thickenings and uneven patches. Besides, pouring through strainer prevents the formation of bubbles.

Waste disposal and cleaning: Immediately after use the strainer should be cleaned with running water.

Experiment 11: Preservation of fruits with N,O-carboxymethyl chitosan

Duration: 20 minutes without waiting period.

Equipment: Beaker (100 ml), magnetic stirrer with heating plate, stirring rod, 2 watch glasses (14 cm), paper cloths, refrigerator.

Reagents and materials: N,0-carboxymethylchitosan, demineralized water, plums.

Procedure: Under slight heating 1 g of N,0-carbonxymehthyl chitosan is dissolved in 50 ml of demineralized water. After cooling the plums are dipped into the solution and then allowed to dry on a paper cloth. Then treated and untreated plums are put each onto a watch glass in the refrigerator and are observed for a longer period.

Observation: The treated plums are covered with a slightly gleaming and transparent film, which does not feel waxy. After one week the fruits untreated show the first changes. With continuing time they look always more wrinkly and after two weeks the first moulding is observable. In opposite the treated fruits do not show any changing.

Faults and precautions: Untreated fruits should be used for the experiment. Without storage in the refrigerator, the preservation time reduces. *Alternatives:* Beside plums other fruits as apples, pears, cherries and peaches may be treated.

Waste disposal: Residues of N,0-carboxymethyl chitosan solution are poured down the sink.

Experiment 12: Preparation of chitosan hydrochloride

Duration: 15 minutes.

Equipment: Beaker (250 ml), magnetic stirrer with heating plate, stirring rod, filter, filter rack, filter paper, desiccator.

Reagents and materials: Chitosan, hydrochloric acid, c(HCl) = 2 mol/l, silica gel blue.

Procedure: 2 g of chitosan are mixed with 100 ml of hydrochloric acid and the mixture is heated to boiling. After cooling the precipitate is filtered off and dried in the desiccator over silica gel blue.

Observation: The chitosan dissolves completely at boiling heat. On cooling the solution a fine, white and crystalline precipitate is formed.

Faults and precautions: Chitosan hydrochloride only dissolves completely at boiling. Already at temperatures just below the boiling point the chitosan is not dissolved or precipitates immediately as chitosan hydrochloride.

Waste disposal: The filtrate is neutralized and poured down the sink.

Experiment 13: Treatment of paper with chitosan hydrochloride

Duration: 30 minutes.

Equipment: 2 crystallization dishes (0 14 cm), 2 pincers, hair-drier, balance.

Reagents and materials: Chitosan hydrochloride, demineralized water, paper (ca. 8x8 cm^2), ink.

Procedure: In a crystallization dish 1 g of chitosan hydrochloride is dissolved in water. Now some pieces of paper are dipped into the solution and then dried in hot air. With different paper samples this process is performed once, twice and three times. Ink drops are put onto untreated and treated paper samples. *Observation:* The often the paper is treated with chitosan hydrochloride, the slower the ink is soaked up.

Faults and precautions: The ink drops have to have the same size for a comparison of the formed spots.

Waste disposal: The treated paper is added to the waste jar for solids. The dipping solutions are poured down the sink."

B. Student worksheets related to the experiments

Experiment A: Chitosan and Fat/ Fatty Acids

Equipment:

6 test tubes
Test tube rack
6 stopper
2 small pipettes
2 10 ml measuring cylinder
spatula
balance

Reagents and materials:

	H-phrases	P-phrases	Danger symbol
Chitosan			
Oleic acid			
Sunflower oil			
Diluted hydrochloric acid, c = 0,1 mol/l			
Diluted sodium hydroxid solution, c = 0,1 mol/l			
Lipase			
Demineralised water			

Procedure:

Do not forget safety glasses and lab coat!

This experiment will help to study the reaction between fats or fatty acids and chitosan in solutions of different pH-values.

1. Fill 5 ml of the above mentioned hydrochloric acid into a test tube and add dropwise 0.2 ml oleic acid. Shake the mixture and watch. After shaking add 0.1 g solid chitosan.
2. In a second test tube prepare a solution of 5 ml water with 5 drops oft he above mentioned sodium hydorxid solution. Add 0.2 ml oleic acid. Shake the mixture and watch After shaking add 0.1 g solid chitosan.
3. Fill 5 ml water into a third test tube and add 0.2 ml oleic acid. Shake the mixture and watch. After shaking add 0.1 g solid chitosan.
4. Repeat the experiments while replacing the oleic acid by sunflower oil.
5. You may also repeat the experiments by changing the pH-values, using other fats

and oils, using a fat soluble dye to make the process better visible.
Disposal of wastes:
The solutions can be poured down the sink.
Quelle:
Gräber, W. & Ledwig, G. (2011/ 2012), current work, IPN Kiel.

Experiment B: Chitin from Crab Shells

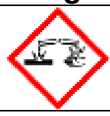
Source:

According to Bader, Birkholz, in: Chitin Handbook, R.A.A. Muzzarelli and M.G. Peter, eds., European Chitin Society. 1997. ISBN 88-86889-01-1

Equipment:

Beaker (400 ml), strainer (mesh size 3-4 mm), magnetic stirrer with heating plate, stirring rod, crystallization dish (Ø 14 cm), drying oven, balance, mortar with pestle, suction flask (500 ml), porcelain nutsch filter (Ø 9 cm)

Reagents and materials:

Reagents and materials	H-Phrases	P-Phrases	Danger symbol
Sodium hydroxide solution (w=2%)	314, 290	280, 301, 303, 305, 309	
Hydrochloric acid (w=7%)			
Crab shells			

Procedure:

Do not forget safety glasses and lab coat!

1st step: coarse purification
150 g of crab shells are coarsely cleaned with water by stirring the broken shells in a 400 ml beaker with water for a few minutes. After this, the shells are filtered off. This process is repeated until sand and other soil are removed. The precleaned crab shells are dried overnight in the drying oven at 80°C.

2nd step: Protein removal
15 g of the dried shells are grinded in a mortar and transferred to a beaker. Then 250 ml of sodium hydroxide solution are added and the mixture is heated under stirring at 60-70°C for half an hour. The shells are filtered off with a strainer and the process is repeated. The filtrate should almost be clear and colorless. Then the shells are washed with demineralized water til neutral reaction. For time-saving the shells may be soaked in sodium hydroxide solution overnight after the first sodium hydroxide treatment, then filtered off and washed.

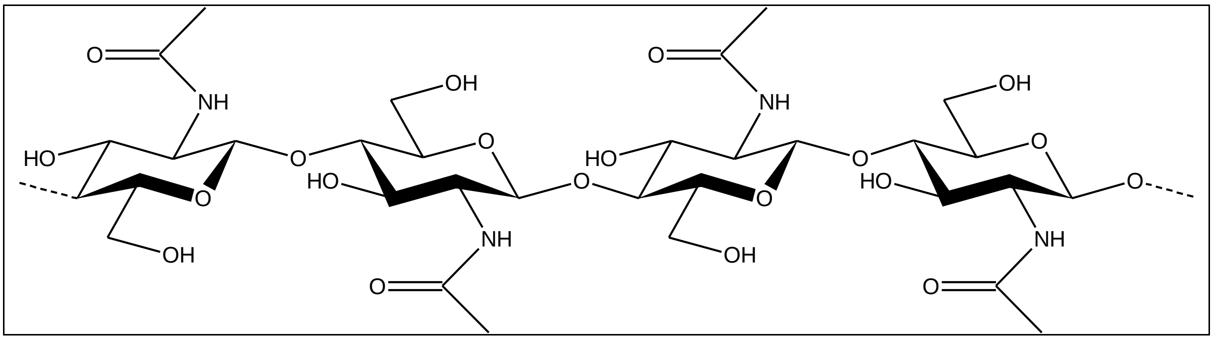
3rd step: Calcium carbonate removal
250 ml of hydrochloric acid are slowly added to the shells and the mixture is stirred at room temperature until no gas escapes anymore. As a check, 10 ml of hydrochloric acid are added. If no further generation of gas occurs, the mixture is filtered off and washed neutral with water. The product is dried overnight in the oven at 60°C.

Sodium hydroxide solution and hydrochloric acid are neutralized and poured down the sink.

Observation:

Anaylsis: (Pictures of the formulas created with Chemdraw)

The obtained Chitin is a dim pink-beige coloured, fluffy substance. 15g of pre-cleaned crab shells yield 3 g of chitin.



Chitin: Poly-β-1,4-N-acetyl-D-glucosamine

Experiment C: Chitosan from Chitin by Alkalyne Hydrolysis

Source:

According to Bader, Birkholz, Chitin Handbook, R.A.A. Muzzarelli and M.G. Peter, eds., European Chitin Society. 1997. ISBN 88-86889-01-1, with additions

Equipment:

Round-bottomed three-necked flask (250 ml, two NS 14, one NS 29), connector (cone to hose coupling), reflux condenser, ground-glass thermometer (NS 14), heating coil, magnetic stirrer, stirring rod, balloon, water pump, suction flask, porcelain nutsch filter (Ø 9 cm), filter paper, crystallization dish (Ø 14 cm), drying oven, balance

Reagents and materials:

Reagents and materials:	H-Phrases	P-Phrases	Danger symbol
Sodium hydroxide solution (w=50%)	314, 290	280, 301, 303, 305, 309	 C
Chitin			

Procedure:

Do not forget safety glasses, safety gloves and lab coat!

In a round-bottomed flask 150 ml sodium hydroxide solution are added to 2 g of chitin. The apparatus closed air-tightly with a balloon (the literature recommends working with a protection gas (Nitrogen). For school purposes, this can be done without). With backflow and under stirring, the mixture is heated at 125°C for one hour. The mixture is allowed to cool down and then 100 ml of water are added. The next day the mixture is filtered off and the residue is washed with water to neutral reaction and dried in the oven at 60°C.

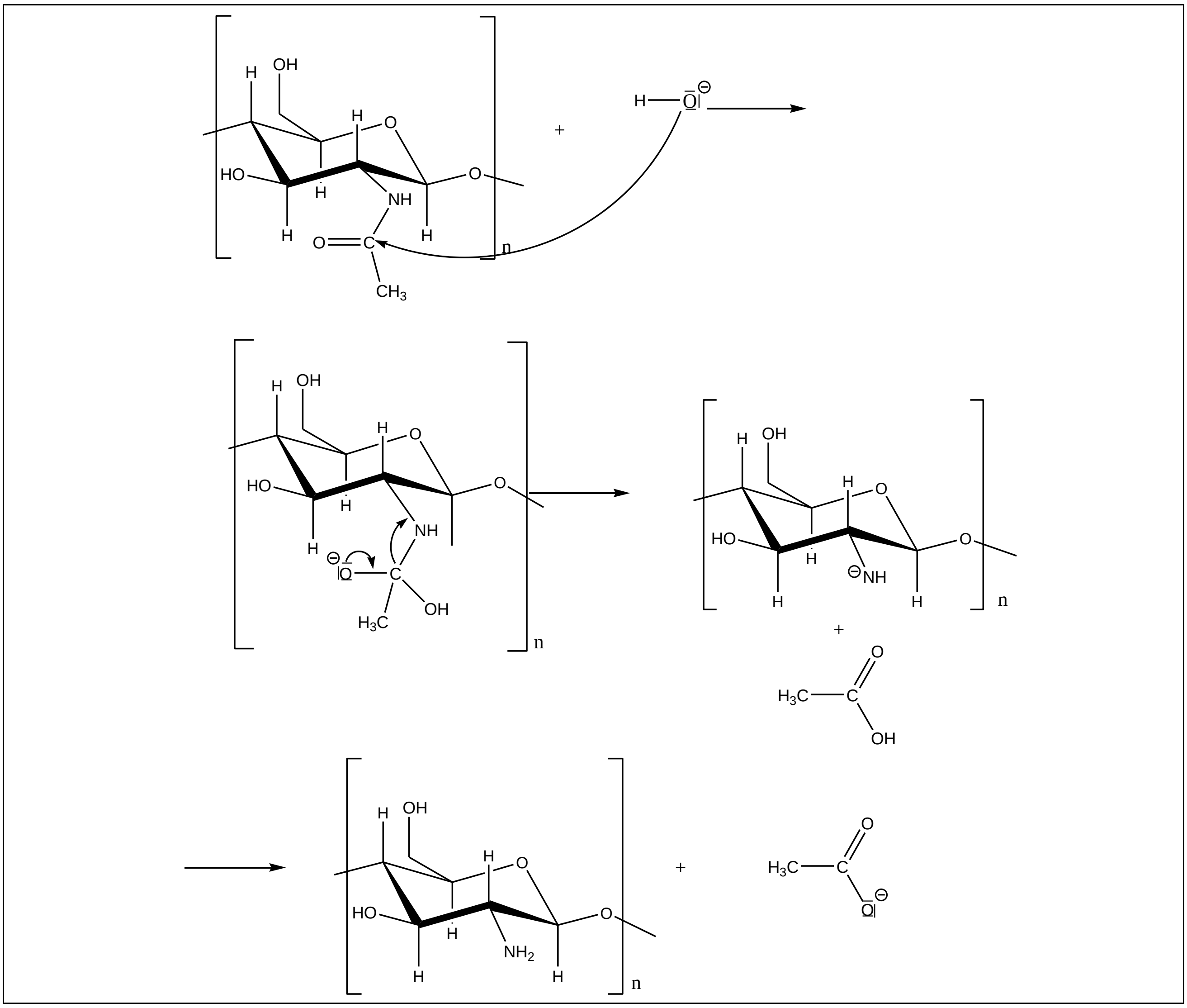
Remark: The ground joint has to be well-greased (possibly using teflon hulls)!

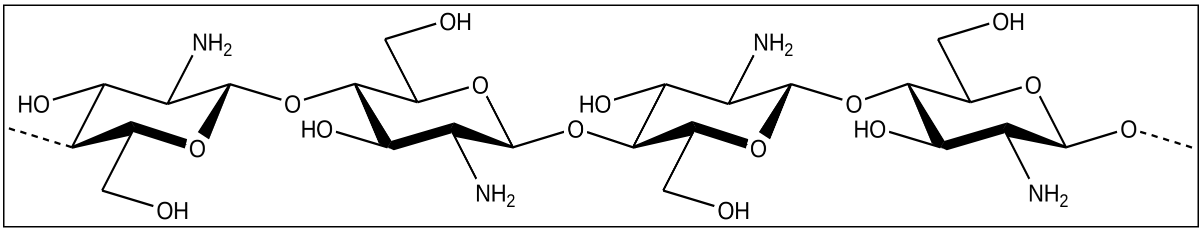
Mother liquor and washing water are neutralized and poured down the sink.

Observation:

Analysis: (Pictures of the formulas created with Chemdraw)

The obtained Chitosan is a dim pink-beige coloured, fluffy substance very similar to Chitin. 2 g of Chitin yield 1,5 g of Chitosan.





Chitosan: Poly-β-1,4-D-glucosamine

Source of errors:

Links:

Experiment D: Differentiation between Chitosan and Chitin

Source:

According to Bader, Birkholz, in: Chitin Handbook, R.A.A. Muzzarelli and M.G. Peter, eds., European Chitin Society. 1997. ISBN 88-86889-01-1

Finger, H.: Chitin und Chitosan – Neue Rohstoffe auf dem Weg zur industriellen Nutzung, WS 1999/2000, Marburg,

Equipment:

2 watch glasses, 2 Pasteur pipettes.

Reagents and materials:

Reagents and materials	H-Phrases	P-Phrases	Danger symbol
Chitin			
Chitosan			
I_2/KI-solution (0.2 g I_2 in 100 ml KI-solution (w = 5%))			
Sulphuric acid (w = 1%)			

Procedure:

Do not forget safety glasses and lab coat! Work at the extractor hood!

Some flakes of chitin or chitosan are put onto a watch glass. 2-3 drops of I_2/KI solution are added and the mixtures are acidified with 2-3 drops of sulphuric acid.

Chitin and chitosan treated are added to the waste jar for solids.

Observation:

After addition of I_2/KI solution, the chitosan changes color to dark brown and the solution becomes colorless. On addition of sulphuric acid, the dark brown color turns dark purple.

On the opposite side, chitin remains unchanged on addition of iodine solution, which retains its brownish-yellow color. Also, the acidification with sulphuric acid has no consequence.

Analysis:

A definite analysis of the experiment does not exist, but a suggestion for an analysis, which shall be presented here: Like the reaction of iodine with starch, chitosan is meant to establish a host-guest complex. To make this clear, the complex is illustrated below. The starch exists in a helix-formed conformation, which creates void spaces, in which the poly-iodine chains are inserted to. This is meant to happen similarly with chitosan. Chitin, on the other hand, is to be sterically inhibited in that regard (residues of acetylamine). However, a helix-formed order of the monomers, which is given with starch by α-1,4-links, is a requirement for this. In chitosan, however, the monomers are β-1,4-linked (according to Finger).

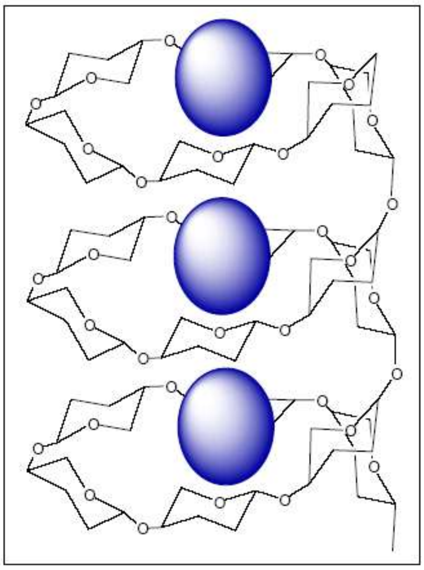


Fig.: Iodine-Starch host-guest complex

Source of errors:

Links:

Experiment E: Preparation of Chitosan Films

Source:

According to Bader, Birkholz, in: Chitin Handbook, R.A.A. Muzzarelli and M.G. Peter, eds., European Chitin Society. 1997. ISBN 88-86889-01-1

Equipment:

2 beaker (250 ml), magnetic stirrer with heating plate, stirring rod, Pasteur pipette, small-meshed strainer, 2 plastic plates (30 cm x 30 cm) or rinsing bowl

Reagents and materials:

Reagents and materials	H-Phrases	P-Phrases	Danger symbol
Chitosan			
Acetic acid (w=12%)	226, 314	210, 260, 280, 303, 304, 305, 310	
Tetraethylene glycol			

Procedure:

Do not forget safety glasses, safety gloves and lab coat! Work at the extractor hood!

Two beakers are filled each with 2 g of chitosan and 100 ml of acetic acid. Under slight heating and stirring the chitosan is dissolved. After cooling one of the solutions is poured through a strainer onto a plastic plate or on the backside of a rinsing bowl. The content of the second beaker is mixed with 0.2 g of tetraethylene glycol; the mixture is stirred for some minutes. Afterwards this solution is poured through a strainer onto a plastic plate or on the backside of a rinsing bowl too. The slightly viscous solutions are not smoothed down. The solvent is allowed to vaporize under the extractor hood overnight.

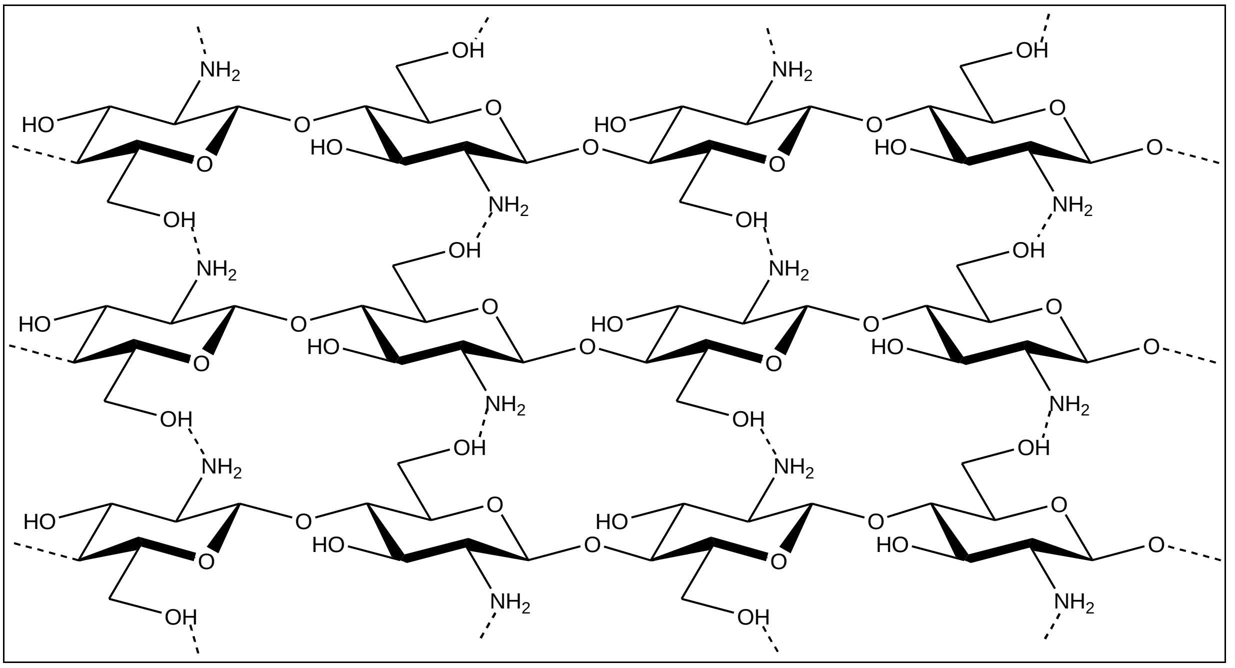
Immediately after use, the strainer should be cleaned with running water.

Observation:

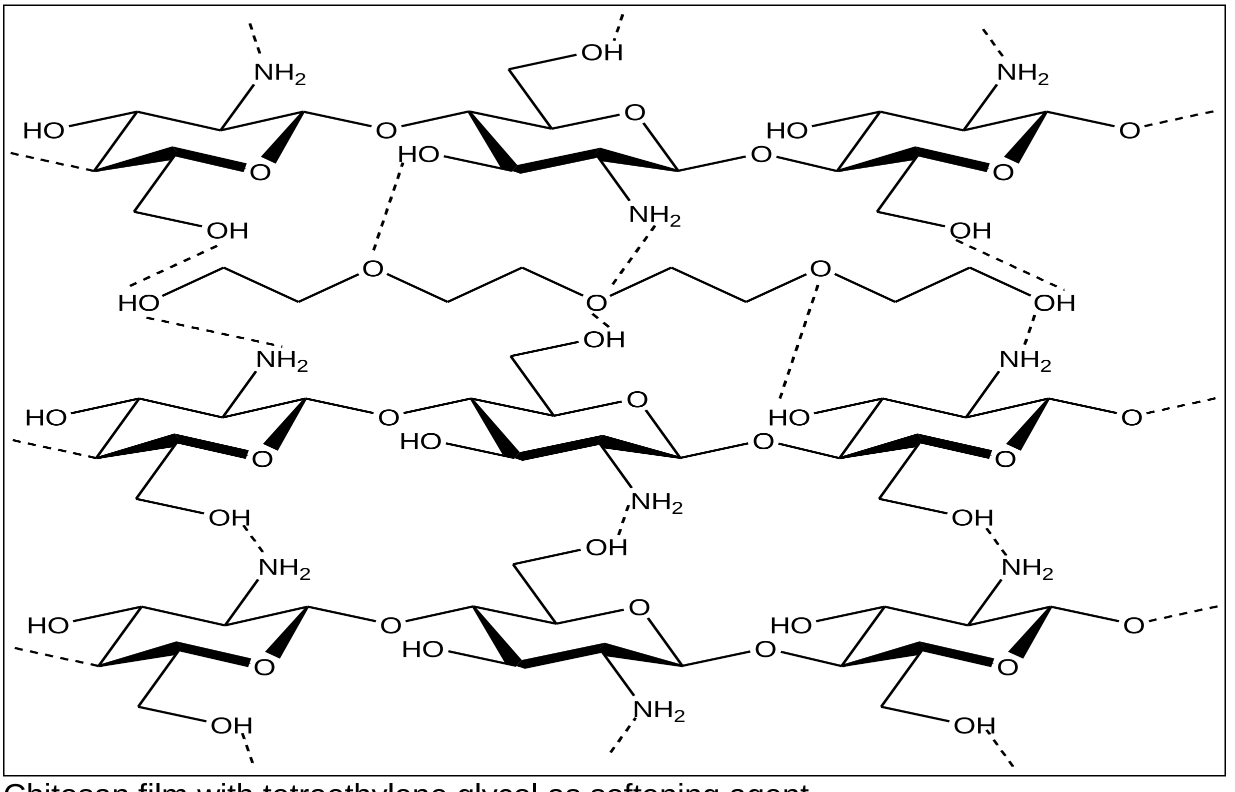
After the vaporization of the solvent in both experiments a flexible, tear resistant and transparent film remains, which is easily peeled off the plate. The film with additional tetraethylene glycol is softer than the pure chitosan film

Analysis: (Pictures of the formulas created with Chemdraw)

For the creation of transparent films, the film-creating characteristics of the macro molecule chitosan are used, which are caused by intra- and inter-molecular hydrogen bonds. Tetraethylene glycol can serve as a softening agent in this case, as it inserts itself into the chitosan molecules under the creation of hydrogen bonds.



Chitosan film without softening agent



Chitosan film with tetraethylene glycol as softening agent

Source of errors:

If the solutions are poured directly onto plastic plates without using strainer, it is possible that chitosan particles not dissolved, completely cause thickenings and uneven patches. Besides, pouring through strainer prevents the formation of bubbles.

If too much of the softener is added, the two components separate and after some time the softener forms oily drops on the film.

Links:

Experiment F: Clarification of Fruit Juices

Source:

According to Bader, Birkholz, in: Chitin Handbook, R.A.A. Muzzarelli and M.G. Peter, eds., European Chitin Society. 1997. ISBN 88-86889-01-1

Equipment:

Beaker (100 ml), magnetic stirrer, stirring rod, centrifuge, centrifuge tubes, Pasteur pipette, light source (e.g. laser).

Reagents and materials:

Reagents and materials	H-Phrases	P-Phrases	Danger symbol
Chitosan			
Naturally cloudy juice (e.g. apple juice)			

Procedure:

Do not forget safety glasses and lab coat!

50 ml of naturally cloudy apple juice are mixed with 0,1 g of chitosan and the mixture is stirred for 5 minutes. Then the solution is centrifuged for 10 minutes. Parallel, 50 ml of naturally cloudy apple juice without additional chitosan are centrifugated as blank test.

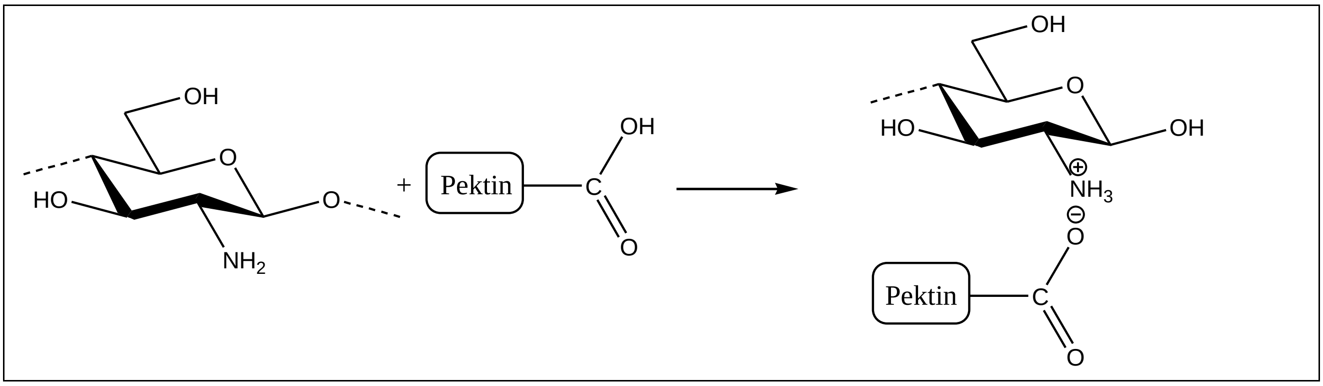
The solutions are poured down the sink.

Observation:

The centrifugate of the apple juice mixed with chitosan is completely clear and no Tyndall effect is visible. In opposite, the centrifugate of the untreated apple juice shows same cloudiness as before. The Tyndall effect is visible.

Analysis: (Pictures of the formulas created with Chemdraw)

Fruit juice without addition of chitosan does not show any clarification when filtrated and centrifugated as it is a suspension, in which natural poly-anionic tannins and other matter exist colloidally suspended. Fruit juice does not show a Tyndall effect after adding chitosan and centrifugating it. This is due to the poly-cationic characteristics of chitosan. As a poly-cation, chitosan builds ionic macromolecular complexes with these compounds which can be centrifugated off.



Source of errors:

If too much chitosan is added, the centrifugate remains cloudy. Use original fruit juice without any conservation agents or solubilizer.

Links:

Tyndall effect: An effect of light scattering by colloidal particles or particles in suspension. It is named after the 19th century Irish scientist John Tyndall. It is similar to Rayleigh scattering, in that the intensity of the scattered light depends on the fourth power of the frequency, so blue light is scattered more strongly than red light. An example in everyday life is the blue colour sometimes seen in the smoke emitted by motor bikes. The phenomenon is best explained as the particle size is much greater than the wavelength of light.. *Source:* http://en.wikipedia.org/wiki/Tyndall_effect

C. Some articles giving more background information about chitosan as slimming agent (found in the internet):

Article 1

http://www.quackwatch.org/04ConsumerEducation/QA/chitosan.html

Is Chitosan a "Fat Magnet"?

Stephen Barrett, M.D.

Question

Ads for chitosan claim it can lower cholesterol and produce rapid weight loss by blocking the absorption of fat. Is this true?

Answer

Chitosan is derived from chitin, a polysaccharide found in the exoskeleton of shellfish such as shrimp, lobster, and or crabs. Many sellers claim that chitosan causes weight loss by binding fats in the stomach and preventing them from being digested and absorbed. Some refer to it as a "fat magnet." It is even marketed as a weight-control product for dogs.

Although chitosan can decrease fat absorption, the amount contained in the capsules is too small to have much of an effect on cholesterol levels. Moreover, with better, more predictable cholesterol-lowering products available, it doesn't make much sense to use chitosan for that purpose. There is no evidence that chitosan is effective for weight control.

The British Advertising Standards Authority has upheld complaints about chitosan products advertised by eight companies. In the case where "Fat Magnets" capsules were described as "the much acclaimed fat absorbing food supplement," the Authority concluded:

The advertisers said the product was sold not on a slimming platform but on the grounds that, by absorbing fat, it prevented weight gain. They argued that the advertisement was for a food supplement, not a slimming aid, and was therefore not subject to Clause 51. [This clause states: Any claims made for the effectiveness or action of a slimming method or product should be backed where appropriate by rigorous practical trials on people; testimonials that are not supported by trials do not constitute substantiation.] The advertisers provided a technical report of the product's contents (which included Chitosan) and copies of nearly 30 trials carried out on animals, in vitro, and on humans. They provided the results of a telephone survey of 201 people. The Authority noted that respondents to the survey did not see the name in context and considered that readers would infer from the advertisement, partly because of the product's name, that the tablets would aid weight loss. Some of the trials showed a relationship between the consumption of Chitosan and weight loss over a four-week period for, in aggregate, a large number of people. The Authority took expert advice and concluded that there were many problems with, and incompatibilities between, the trials. It noted that the human trials that showed weight loss had appeared in a toxicology journal that was not known internationally for its expertise in weight-related matters. The Authority acknowledged the volume of material amassed by the advertisers but concluded that, because of the shortcomings in the reports of the trials, the ability of Chitosan to prevent the absorption of enough dietary fat to affect energy balance in humans had not been substantiated. Because of this and the product's name, the Authority asked the advertisers both to make clear in future that the product had not been proven to aid slimming or prevent weight gain and to consult the Copy Advice team before advertising the product again. [1]

Three studies have found no significant differences in weight or serum cholesterol levels between subjects who took chitosan and those who received a placebo. One study involved 30 overweight volunteers who received four capsules of either chitosan or a placebo for 28 consecutive days and were told to eat their normal diet. The chitosan and placebo groups showed no differences in weight or serum cholesterol levels [2]. The second study involved 51 healthy obese women followed for 8 weeks. The chitosan group had slightly (but not significantly) greater cholesterol reduction than the placebo group, but no difference in weight occurred between the two groups [3]. The other study, which involved 68 obese men and women, found no improvement in weight, body composition, blood pressure, or lipid profile [4].

Another study has found that the amount of fat actually removed by chitosan is insignificant. The study involved 15 men who consumed five meals per day for 12 days with a daily total of about 25 grams of fat. The amount of fat excreted during four days when they took chitosan supplements was then compared to the amount excreted without chirosan. Taking 10 capsules of chitosan per day increased fecal fat excretion by only about 1 gram (9 calories), which would have no significant effect on a person's weight [5].

U.S. Government Actions

On August 31, 1999, the FDA warned the president of TRY-Lean, Inc., to stop making claims that taking his company's chitosan-containing products would reduce the risk of obesity, high blood pressure, heart attack, and cancer [6].

In 2000, the marketers of "The Enforma System" agreed to settle FTC charges of deceptively advertising that the user could "eat what you want and never, ever, ever have to diet again." The FTC complaint named Enforma Natural Products, Inc., its president and chief executive officer, Andrew Grey, and Fred Zinos, a former vice president of sales and marketing. The system consists of "Fat Trapper," a chitosan-based product purported to prevent the absorption of dietary fat; and "Exercise In A Bottle," a pyruvate product that supposedly increases the body's capacity to burn fat. The system was promoted chiefly through televised 30-minute infomercials, featuring former baseball player Steve Garvey, as well as through the company's Web site. The settlement prohibits the marketers from making unsubstantiated claims that any product, service, or program: provides weight control without dieting or exercise; prevents fat absorption; increases metabolism; burns fat; or allows weight loss even if users eat high-fat foods. The company must also pay $10 million to be used for refunds or distributed to the U.S. Treasury [7].

References

1. British Advertising Standards Association. Adjudication: Marshtech International Ltd t/a Fat Magnets International Ltd. December, 1997.
2. Pitler MH and others. Randomized, double-blind trial of chitosan for body weight reduction. European Journal of Clinical Nutrition 53:379-381, 1999.
3. Wuolijoki E and others. Decrease in serum LDL cholesterol with microcrystalline chitosan. Methods and Findings in Experimental and Clinical Pharmacology 21(5):357-361, 1999.
4. Ho SC and others. In the absence of dietary surveillance, chitosan does not reduce plasma lipids or obesity in hypercholesterolaemic obese Asian subjects. Singapore Medical Journal 42:6-10 , 2001.
5. Gades M, Stern JS. Chitosan supplementation and fecal fat excretion in men. Obesity Research 11:683-688, 2003.

6. Bingham, CA. Warning letter to Larry C. Ormson, president, TRY-Lean, Inc., Elroy, Wisconsin, Aug 31, 1999. [PDF document]
7. Marketers of "The Enforma System" settle FTC charges of deceptive advertising for their weight loss products. FTC news release, April 26, 2000.

This article was revised on May 13, 2003.

Article 2

http://www.ncbi.nlm.nih.gov/pubmed/10369493

Eur J Clin Nutr. 1999 May;53(5):379-81.

Randomized, double-blind trial of chitosan for body weight reduction.

Pittler MH, **Abbot NC**, **Harkness EF**, **Ernst E**.

Department of Complementary Medicine, School of Postgraduate Medicine and Health Sciences, University of Exeter, United Kingdom.

BACKGROUND: Overweight and obesity is a prevalent and costly threat to public health. Compelling evidence links overweight and obesity with serious disorders such as cardiovascular diseases and diabetes. Dietary regimen are notoriously burdened with poor compliance. Chitosan is promoted in the US and other countries as an oral remedy to reduce fat absorption and has now been incorporated as a major constituent into several over-the-counter remedies. The primary aim of this study is to investigate the clinical effectiveness of oral chitosan for body weight reduction. METHODS: Thirty-four overweight volunteers were included in a randomized placebo-controlled double-blind trial. Subjects were assigned to receive either four capsules of chitosan or indistinguishable placebo twice daily for 28 consecutive days. Measurements were taken at baseline, after 14 and 28d of treatment. Subjects maintained their normal diet and documented the type and amount of food consumed. Adverse effects were assessed and compliance monitored. RESULTS: Data from 30 subjects were entered into an intention-to-treat analysis. After four weeks of treatment, body mass index, serum cholesterol, triglycerides, vitamin A, D, E and beta-carotene were not significantly different in subjects receiving chitosan compared to those receiving placebo. Vitamin K was significantly increased after four weeks in the chitosan group compared with placebo ($P<0.05$). Compliance was 91.5% and 96.0% for chitosan and placebo groups respectively. CONCLUSION: The above data suggest that chitosan in the administered dosage, without dietary alterations, does not reduce body weight in overweight subjects. No serious adverse effects were reported.

PMID: 10369493 [PubMed - indexed for MEDLINE]

Article 3

http://www.ncbi.nlm.nih.gov/pubmed/10420392

Methods Find Exp Clin Pharmacol. 1999 Jun;21(5):357-61.

Decrease in serum LDL cholesterol with microcrystalline chitosan.

Wuolijoki E, **Hirvelä T**, **Ylitalo P**.

Finn-Medi Research Ltd., Department of Pharmacological Sciences, University of Tampere, Finland.

Peroral microcrystalline chitosan (MCCh; 3 capsules, each 400 mg b.i.d.) or placebo was given for 8 weeks in a double-blind manner to 51 healthy obese women just before routine hospital and home meals. Weight records, serum lipids (total, LDL and HDL cholesterol, triglycerides) and safety laboratory parameters were monitored before the trial and at 4, 6 and 8 weeks of treatment. In a subgroup of subjects with a body mass index > or = 30 who had not changed their eating habits, serum LDL cholesterol decreased 0.57 +/- 0.72 mmol/l (n = ll) at 4 weeks in the MCCh group and 0.10 +/- 0.60 mmol/l (n = 14) in the placebo group (p < 0.05). At 8 weeks, LDL cholesterol reduction was 0.48 +/- 0.91 mmol/l in the MCCh group and 0.26 +/- 0.57 mmol/l in the placebo group (p > 0.1). In all subjects, the reduction in LDL cholesterol at 4 weeks was 0.48 +/- 0.72 mmol/l (n = 24) in MCCh subjects and 0.18 +/- 0.58 mmol/l (n = 27) in placebo subjects (p = 0.057), and 0.52 +/- 0.69 mmol/l and 0.31 +/- 0.63 mmol/l, respectively, at 8 weeks (p > 0.1). MCCh did not significantly alter serum total and HDL cholesterol (p > 0.1), but slightly increased serum triglycerides compared to placebo (p = 0.015-0.06). No reductions in weight were observed in any treatment group. Chitosan was well tolerated and no serious adverse events or changes in safety laboratory parameters were noted including serum fat-soluble vitamins A and E, and serum Fe++ and transferrin.

PMID: 10420392 [PubMed - indexed for MEDLINE]

Article 4

http://www.sma.org.sg/smj/4201/4201a1.pdf

Singapore Med J. 2001 Jan;42(1):6-10. Comment in: Singapore Med J. 2001 May;42(5):230-1.

In the absence of dietary surveillance, chitosan does not reduce plasma lipids or obesity in hypercholesterolaemic obese Asian subjects.

Ho SC, **Tai ES**, **Eng PH**, **Tan CE**, **Fok AC**.

Department of Endocrinology, Singapore General Hospital, Singapore.

OBJECTIVE: To investigate the effects of Absorbitol on body weight, anthropometry, body composition, blood pressures and lipid profiles in obese, hypercholesterolaemic subjects without dietary restriction. DESIGN: A randomised, double blind. Placebo-controlled study. SUBJECTS: Normal volunteers with no history of chronic illnesses (n=88) who were obese (body fat percentage > 20% in males and > 30% in females) and hypercholesterolaemic (total cholesterol > 5.20 mmol/L). Sixty-eight (72.3%) subjects completed the study. INTERVENTION: After a 4 week run in phase, 4 placebo/Absorbitol (250 mg) capsules were prescribed 3 times a day before meals. Subjects received written information on healthy lifestyle but there was no dietary restriction or monitoring. MAIN OUTCOME MEASURES: Weight, body mass index, lean body mass, waist, hip, blood pressure, fasting lipids and insulin levels were taken at baseline, 4th and 16th week of the study. STATISTICAL ANALYSIS PERFORMED: Analyses were on an intention-to-treat basis. Comparisons between groups were made using Student's t and Mann-Whitney tests for parametric and non-parametric data respectively. RESULTS: There was no significant change in the measured parameters in Absorbitol treated subjects compared to those on placebo, with exception of HDL-cholesterol which increased in the absorbitol group and decreased in the placebo group (p=0.048). The side effects of Absorbitol were also comparable to that of placebo. CONCLUSIONS: In the absence of dietary surveillance, Absorbitol does not bring about improvement in weight, anthropometry, body composition, blood pressure or lipid profile.

PMID: 11361230 [PubMed - indexed for MEDLINE]

Artikel 5

http://www.ncbi.nlm.nih.gov/pubmed/12740459

Obesity Research 11:683-688 (2003)

Original Research

Chitosan Supplementation and Fecal Fat Excretion in Men

Matthew D. Gades[*] and Judith S. Stern[*,†]

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Address correspondence to Dr. Judith S. Stern, Department of Nutrition, University of California at Davis, One Shields Avenue, Davis, CA 95616. E-mail: jsstern@ucdavis.edu

Objective: Few weight loss supplements are clinically tested for efficacy, yet their proliferation continues. Chitosan-based supplements are sold as fat trappers and fat magnets. They purportedly block fat absorption and cause weight loss without food restriction. We quantified the in vivo effect of a chitosan product on fat absorption.

Research Methods and Procedures: Participants (n = 15) consumed five meals per day for 12 days. Energy intake was not restricted. Participants consumed no supplements during a 4-day control period and two capsules five times per day (4.5 g chitosan/d), 30 minutes before each meal, during a 4-day supplement period. All feces were collected from days 2 to 12. Oral charcoal markers permitted division of the feces into two periods. The two fecal pools were analyzed for fat content.

Results: Participants were male, 26.3 ± 5.9 years old, BMI of 25.6 ± 2.3 kg/m^2. Subjects consumed 133 ± 23 g of fat/d and 12.91 ± 1.79 MJ/d (3084 ± 427 kcal/d). Individual meals averaged 26.3 ± 9.3 g of fat. With chitosan supplementation at 10 capsules/day, fecal fat excretion increased by 1.1 ± 1.8 g/d (p = 0.02), from 6.1 ± 1.2 to 7.2 ± 1.8 g/d.

Discussion: The effect of chitosan on fat absorption is clinically negligible. Far from being a fat trapper, at 0.11 ± 0.18 g of fat trapped per 0.45-g capsule or 1.1 g (9.9 kcal) fat trapped per day, this product would have no significant effect on energy balance. The fat trapping claims associated with chitosan are unsubstantiated.

Key Words: supplements • obesity • dietary fiber • chitosan • fat absorption

Artikel 6

http://www.ftc.gov/opa/2000/04/enforma.shtm

Federal Trade Commission
600 Pennsylvania Avenue, NW
Washington, DC 20580

For Release: April 26, 2000

Marketers of "The Enforma System" Settle FTC Charges of Deceptive Advertising For Their Weight Loss Products

Settlement requires payment of $10 million

"With Enforma, you can eat what you want and never, ever, ever have to diet again."

These and other weight loss claims for "The Enforma System" are touted in television and Internet ads. But, according to a Federal Trade Commission complaint filed in federal court, the company's claims are false and unsubstantiated. Under a settlement filed with the court, the company will no longer make deceptive weight loss claims and will pay the FTC $10 million to be returned to purchasers of the product or, if that is not practical, paid to the U.S. Treasury.
The marketers of "Fat Trapper" and "Exercise In A Bottle" have settled FTC charges that they made false and unsubstantiated weight loss claims in their advertising of "The Enforma System." The FTC complaint names Enforma Natural Products, Inc., its president and Chief Executive Officer, Andrew Grey, and Fred Zinos, a former Vice President of Sales and Marketing. Enforma Natural Products advertises and sells "The Enforma System" to consumers nationwide. The product has been promoted chiefly via televised 30 minute infomercials, featuring former baseball player Steve Garvey, as well as through the company's Web site. "The Enforma System" consists of two dietary supplements with ingredients that are becoming increasingly popular weight loss remedies: a chitosan-based product called "Fat Trapper" that purports to prevent the absorption of dietary fat; and a pyruvate product named "Exercise In A Bottle" that supposedly increases the body's capacity to burn fat.

"Lose weight without dieting? Not a chance!" said Jodie Bernstein, Director of the FTC's Bureau of Consumer Protection. "Miracle weight loss claims prey on people who are overweight or obese. When marketers promise effortless weight loss, it's bad business. The fact is there's only one sure way to lose weight and keep it off: eat less and exercise more."

According to the FTC, the Enforma infomercials have included such statements as:

- The Enforma System "helps your body to burn more calories while you're just standing or sitting around doing nothing - even while you're sleeping."
- With the Enforma System, "you can enjoy all these delicious foods like fried chicken, pizza, cheeseburgers, even butter and sour cream, and stop worrying about the weight."
- Fat Trapper "permanently" blocks fat "so that it can never be absorbed by your body - never."

- "Exercise In A Bottle works on a cellular level, forcing every cell in your body to work, whether you're exercising or not. And when your cells are working, you are burning calories or losing fat."

The FTC's complaint charges that through these and other statements Enforma Natural Products, Grey and Zinos have represented, without adequate substantiation, that "the Enforma System" allows users to lose substantial weight, and keep it off, without dieting or exercise; and works even if users eat substantial amounts of high fat foods like fried chicken, pizza or cheeseburgers. The complaint also challenges as unsubstantiated the claims that Fat Trapper prevents absorption of all or substantially all of the fat users consume, and that Exercise In A Bottle increases metabolism, burns sugar and carbohydrates before they turn to fat, and burns off fat already in the body. Finally, the complaint alleges that the defendants falsely claimed that they had scientific testing proving their weight loss, fat absorption, and fat burning claims.

The FTC has filed two Stipulated Final Orders (one with Enforma Natural Products and Grey and the other with Zinos) in settlement of the charges. Both orders:

- prohibit the defendants from making unsubstantiated claims that any product, service or program causes or maintains weight loss or avoids weight gain without dieting or exercise, prevents fat absorption, increases metabolism, burns fat, or allows weight loss even if users eat high fat foods;
- require that future weight loss claims be accompanied by a clear and prominent disclosure that reducing calorie intake and/or exercising more is necessary to lose weight;
- require that the defendants have scientific substantiation for any claims about the health or weight loss benefits, performance, safety or efficacy of any product, service or program; and
- prohibit false claims about the existence or results of any tests, studies, or research.

The Stipulated Order with Enforma Natural Products and Grey also requires that they pay to the FTC $10 million as consumer redress. The first payment of $5 million must be made within five days after the order is entered, with the remaining $5 million paid over six months. The defendants must execute a promissory note for the unpaid $5 million, and give a security interest to the FTC in all of the company's assets to ensure payment of the judgment. The $10 million will be used by the FTC to provide refunds to consumers who bought "the Enforma System"directly from the defendants prior to March 31, 2000. But, if the FTC decides that refunds are not practical, it may choose to distribute the money to the U.S. Treasury.
The Stipulated Final Order with Fred Zinos does not require him to make any monetary payment to the FTC. The order states the Commission's agreement is premised on the accuracy of sworn financial statements provided by Zinos, and that should these statements contain any material misrepresentation or omission, the Commission may ask that the order be reopened to allow the Commission to modify Zinos' monetary liability.

The Commission vote to authorize staff to file the complaint against Enforma Natural Products, Andrew Grey, and Fred Zinos, and the stipulated final orders, was 5-0. The case was filed in the U.S. District Court, Central District of California, in Los Angeles, on April 25, 2000.

NOTE: These stipulated final orders are for settlement purposes only and do not constitute an admission by the defendants of a law violation. Final orders have the force of law when signed by the judge.

Copies of the complaint and stipulated final orders will be available shortly from the FTC's Consumer Response Center, Room 130, 600 Pennsylvania Avenue, N.W., Washington, D.C. 20580; 877-FTC-HELP (877-382-4357); TDD for the hearing impaired 202-326-2502. Copies of news releases pertaining to other dietary supplement cases are also available from the FTC's web site at *http://www.ftc.gov* To find out the latest news as it is announced, call the FTC NewsPhone recording at 202-326-2710.

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(FTC File No. 992 3160)
(Civil Action No.: 04376JSL(CWx))

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Article 7

http://www.raysahelian.com/chitosan.html

Chitosan supplement, safety, side effect, does it reduce absorption of fats? by Ray Sahelian, M.D.
Does it work for weight loss or cholesterol reduction?

Chitosan is extracted from the shells of crustaceans, such as shrimp and crab. This substance is not digestible but may have beneficial effects on the gastrointestinal tract. Chitosan appears to reduce the absorption of bile acids or cholesterol; either of these effects may cause a lowering of blood cholesterol, however studies regarding its ability to lower cholesterol have been mixed. A study published in Finland did not show it to have much of an effect on cholesterol levels, whereas another study conducted in Argentina showed diabetics who ate bread containing chitosan had lower cholesterol levels. It's frustrating when researchers come to opposite conclusions.

Buy Chitosan supplement 500 mg each pill

Chitosan, a fiber derived from chitin in shell-fish, is a nondigestible aminopolysaccharide synthesized by removing acetyl groups from chitin, through a process called deacetylation. This process enhances its activity by improving its solubility in the acidic environment of the stomach.

Supplement Facts: Chitosan (minimum 90% deacetylated chitin) 500 mg per pill

Suggested Use: Two chitosan capsules before lunch and two capsules before dinner. Drink at least 4 glasses of fluid daily.

Click here to buy Chitosan supplement

Review of research study

There is mixed evidence whether chitosan is more effective than placebo in the short-term treatment of overweight and obesity. Many trials to date have been of poor quality and results have been variable. Results obtained from high quality trials indicate that the effect of chitosan on body weight is minimal, if any. A nutrient that can limit appetite is 5-HTP which converts into serotonin. Acetylcarnitine may also be helpful in some users.

Studies evaluating the role of chitosan in weight loss and cholesterol reduction have produced inconsistent results. I'm not ready to endorse the use of chitosan by itself for weight loss or cholesterol reduction at this time. Perhaps chitosan may be a useful addition to cholesterol reduction when used along with other supplements. Time will tell. If you wish to reduce body weight or maintain healthy cholesterol levels, see other options provided on these web pages: weight loss information and cholesterol.

Allergy

Can you tell me if it is safe to take chitosan if a person is allergic to shell fish, such as shrimp?

Chitin is a polysaccharide derived from sources like crab, lobster and shrimp shells, and marine coral, that are not eaten as foods. Chitin is used to make various other substances, including chitosan, which is derived from chitin by heating it with a chemical solution. See below for an article on this topic.

Chitins and chitosans as immunoadjuvants and non-allergenic drug carriers.
Mar Drugs. 2010. University of Ancona, Ancona, Italy.
Due to the fact that some individuals are allergic to crustaceans, the presumed relationship between allergy and the presence of chitin in crustaceans has been investigated. There is quite a large body of knowledge today on the use of chitosans as biomaterials, and more specifically as drug carriers for a variety of applications: the delivery routes being the same as those adopted for the immunological studies. Said articles, that devote attention to the safety and biocompatibility aspects, never reported intolerance or allergy in individuals and animals, even when the quantities of chitosan used in single experiments were quite large. Therefore, it is concluded that crab, shrimp, prawn and lobster chitins, as well as chitosans of all grades, once purified, should not be considered as "crustacean derivatives", because the isolation procedures have removed proteins, fats and other contaminants to such an extent as to allow them to be classified as chemicals regardless of their origin.

Cholesterol reduction
Improvement of HDL- and LDL-cholesterol levels in diabetic subjects by feeding bread containing chitosan.
J Med Food. 2003.
In this work we evaluated the efficacy and safety of a bread formulation containing chitosan in dyslipidemic type 2 diabetic subjects. For this purpose a total of 18 patients were allowed to incorporate to their habitual diets 120 g/day of bread containing 2% (wt/wt) chitosan or standard bread. Before the study and after 12 weeks on the modified diet, the following parameters were evaluated: body weight, plasma cholesterol, high-density lipoprotein (HDL)-cholesterol, low-density lipoprotein (LDL)-cholesterol, triglyceride, and hemoglobin A(1c) (HbA(1c)). Compared with the control group, the patients receiving chitosan-containing bread decreased their mean levels of LDL-cholesterol and significantly increased their mean levels of HDL-cholesterol at the end of the study. There were no significant differences in the body weight, serum triglyceride, and HbA(1c).

The effect of long-term microcrystalline chitosan therapy on plasma lipids and glucose concentrations in subjects with increased plasma total cholesterol: a randomised placebo-controlled double-blind crossover trial in healthy men and women.
Tampere University Hospital, Tampere, Finland.
A total of 130 middle-aged men and women without severe disease and with a total cholesterol of 4.8-6.8 mmol/l and triglycerides below 3.0 mmol/l were randomised into two treatment groups. At the beginning of the 10-month trial, all participants received placebo twice daily during a 1-month run-in period. Subsequently, group 1 first received placebo twice daily for 3 months and then 1.2 g chitosan twice daily for 3 months. Correspondingly, group 2 received 1.2 g chitosan twice daily during the first and placebo twice daily during the second 3-month period. Treatment with chitosan had no effect on the concentrations of plasma lipids or glucose in healthy middle-aged men and women with moderately increased plasma cholesterol concentrations.

Fat excretion
Efficacy of a novel chitosan formulation on fecal fat excretion: a double-blind, crossover, placebo-controlled study.
J Med. 2002.
The ability of a novel chitosan formulation to influence gastrointestinal fat absorption in vivo was examined in a double-blind, placebo-controlled, crossover study by determining the content of total fat in feces in two groups of subjects. During the placebo and the test periods, the subjects were administered six capsules three times daily 10 minutes before meals for three days and for the two days of the stool collection. A daily serving of six

tablets of the test compound contained 2100 mg chitosan and 300 mg psyllium husk seeds. The average daily increase in fecal fat of 3-4 grams over control could account for a decrease in calorie consumption of 30-40 kcal per day. A total of 19 subjects completed both parts of the study.

Weight Loss
Evaluating efficacy of a chitosan product using a double-blinded, placebo-controlled protocol.
J Am Coll Nutr. 2006. Health and Medical Research Center, 4940 Broadway, Suite 201, San Antonio, TX
To examine the safety and efficacy of a chitosan dietary supplement on body composition under free-living conditions. In a randomized, double-blinded, placebo-controlled dietary intervention protocol, subjects were assigned to a chitosan treatment group, a placebo group (PLA) and a control group (CTL). A total of 150 overweight adults enrolled; 134 (89%) completed the study; 111 (82%) were women who were similarly distributed in the three groups. The chitosan treatment group took six 500 mg chitosan capsules per day and both chitosan treatment and PLA groups wore pedometers during their waking hours and recorded daily step totals. The CTL group followed weight loss programs of their choice, and took the same baseline and ending tests. Outcome measures were Dual Energy X-ray Absorptiometry tests, fasting blood chemistries, and self-reported daily activity levels and caloric intakes. Compared to the control group, the chitosan treatment group lost more weight and fat mass. Compared to PLA, the chitosan treatment group lost more weight, % fat, fat mass. These data provide evidence for the efficacy of a chitosan compound to facilitate the depletion of excess body fat under free-living conditions with minimal loss of fat-free or lean body mass.

The effect of the dietary supplement, Chitosan, on body weight: a randomised controlled trial in 250 overweight and obese adults.
Int J Obes Relat Metab Disord. 2004.
Chitosan, a deacetylated chitin, is a widely available dietary supplement purported to decrease body weight and serum lipids through gastrointestinal fat binding. Although evaluated in a number of trials, its efficacy remains in dispute. To evaluate the efficacy of chitosan for weight loss in overweight and obese adults, a 24-week randomised, double-blind, placebo-controlled trial was conducted at the University of Auckland. A total of 250 participants were randomly assigned to receive 3 g chitosan/day (n=125) or placebo (n=125). All participants received standardised dietary and lifestyle advice for weight loss. Adherence was monitored by capsule counts. In an intention-to-treat analysis with the last observation carried forward, the chitosan group lost more body weight than the placebo group during the 24-week intervention, but effects were small. Similar small changes occurred in circulating total and LDL cholesterol, and glucose. There were no significant differences between groups for any of the other measured outcomes. In this 24-week trial, chitosan treatment did not result in a clinically significant loss of body weight compared with placebo.

Effect of chitosan in complex management of obesity
Zahorska-Markiewicz B. Katedra Patofizjologii Sl. AM w Katowicach.
The aim of the present study was to verify the effect of chitosan as a possible adjuvant in the complex management of obesity. Fifty obese women (22-59 years, BMI > 30) participated in the study. A six months program consisted of 2-hour meetings with a physician, psychologist and dietitian, in a group of about 20 persons, every two weeks. Low calorie diet (1000 kcal/day), physical activity and behaviour modification were recommended. Supplementation with chitosan was evaluated in a randomized, placebo-

controlled, double-blind study. In the chitosan group, participants received ChitininN (Primex Ingredients ASA, Avaldsnes, Norway) i.e. 750 mg pure chitosan per tablet, two tablets three times daily before each main meal. Significantly higher body weight loss was noted in the chitosan-supplemented group (15.9 kg) than in the placebo group (10.9 kg) Also a greater decrease of systolic and diastolic blood pressure was observed in the chitosan group. There was no difference between the groups in the decrease of LDL and total cholesterol.

Randomized, double-blind trial of chitosan for body weight reduction.
Pittler MH. University of Exeter, United Kingdom. Eur J Clin Nutr 1999
Overweight and obesity is a prevalent and costly threat to public health. Compelling evidence links overweight and obesity with serious disorders such as cardiovascular diseases and diabetes. Dietary regimen are notoriously burdened with poor compliance. Chitosan is promoted in the US and other countries as an oral remedy to reduce fat absorption and has now been incorporated as a major constituent into several over-the-counter remedies. The primary aim of this study is to investigate the clinical effectiveness of oral chitosan for body weight reduction. Thirty-four overweight volunteers were included in a randomized placebo-controlled double-blind trial. Subjects were assigned to receive either four capsules of chitosan or indistinguishable placebo twice daily for 28 consecutive days. Measurements were taken at baseline, after 14 and 28d of treatment. Subjects maintained their normal diet and documented the type and amount of food consumed. Adverse effects were assessed and compliance monitored. Data from 30 subjects were entered into an intention-to-treat analysis. After four weeks of treatment, body mass index, serum cholesterol, triglycerides, vitamin A, D, E and beta-carotene were not significantly different in subjects receiving chitosan compared to those receiving placebo. Vitamin K was significantly increased after four weeks in the chitosan group compared with placebo. Compliance was 91% and 96% for chitosan and placebo groups respectively. The above data suggest that chitosan in the administered dosage, without dietary alterations, does not reduce body weight in overweight subjects. No serious adverse effects were reported.

Chitosan side effects, safety, toxicity
I am not aware of any significant side effects with chitosan supplement intake.

Safety aspects and cholesterol-lowering efficacy of chitosan tablets.
J Am Coll Nutr. 2008; Tapola NS, Lyyra ML, Kolehmainen RM, Sarkkinen ES, Schauss AG. Oy Foodfiles Ltd, Neulaniementie, Finland.
The purpose of this study was to determine the effect of two different doses of chitosan on serum fat-soluble vitamin concentrations, cholesterol concentrations, and other safety parameters. A total of 65 men and women consumed 0, 4.5, 6.75 g per day of chitosan or 6.75 g per day glucomannan for eight weeks in a parallel, placebo-controlled, single-blind study. Altogether, 56 participants completed the study. No differences were detected among the treatments in serum vitamins (vitamin A, vitamin E, 25-hydroxyvitamin D), carotenes (alpha- and beta-carotene), clinical chemistry or hematology measurements. The changes in the total and LDL-cholesterol concentrations among the study groups were not statistically significant. In the present study, the consumption of chitosan tablets was found to be safe, but there was no significant effect on cholesterol concentration.

Delivery and absorption
The absorption enhancing effects of chitosan and its derivatives have been intensively studied in recent years. It has been shown that these compounds are potent absorption enhancers. Chitosan is only soluble in acidic environments and is therefore incapable of enhancing absorption in the small intestine, the main absorption area in the

gastrointestinal tract.

Chitosan has great potential for pharmaceutical applications due to its biocompatibility, high charge density, non-toxicity and mucoadhesion. It has been shown that it improves the dissolution of poorly soluble drugs. Gel formation can be obtained by interactions of chitosans with low molecular counterions such as polyphosphates, sulphates and crosslinking with glutaraldehyde. This gelling property allows a wide range of applications such as coating of pharmaceuticals and food products, gel entrapment of biochemicals, plant embryo, whole cells, microorganism and algae.

Besides its low toxicity and good ocular tolerance, chitosan exhibits favourable biological behaviour, such as bioadhesion- and permeability-enhancing properties, and also interesting physico-chemical characteristics, which make it a unique material for the design of ocular drug delivery vehicles.

The Varied uses

Chitosan is a partially deacetylated polymer obtained from the alkaline deacetylation of chitin. Chitosan exhibits a variety of physicochemical and biological properties resulting in numerous applications in fields such as waste and water treatment, agriculture, fabric and textiles, cosmetics, nutritional enhancement, and food processing. In addition to its lack of toxicity and allergenicity, and its biocompatibility, biodegradability and bioactivity make it a very attractive substance for diverse applications as a biomaterial in pharmaceutical and medical fields, where it has been used for systemic and local delivery of drugs and vaccines. Research indicates that chitosan can increase crop yields, and clean and clear up pools. Chitosan has been known to aid plants' immune systems while they are growing. When placed on a seed, it induces protective measured within the growing plant.

Questions

Is a chitosan pill necessary if a person is taking a weight loss reducing supplement?

There are many such products over the counter, it is difficult to make generalizations, but I don't see much harm in taking this supplement in reasonable dosages.

Source Naturals - Diet Chitosan 500 mg, 240 Capsules

Chitosan, a fiber derived from chitin in shell-fish, is a nondigestible aminopolysaccharide. Chitosan is synthesized by removing acetyl groups from chitin, through a process called deacetylation. This process enhances the activity of chitosan by improving its solubility in the acidic environment of the stomach.

WP3 | Direct Current Electricity

European Science and Technology in Action Building Links with Industry, Schools and Home

Work Package 3
Direct current electricity
A – Teacher Information

European Science and Technology in Action:
Building Links with Industry, Schools and Home

Lead authors: **Zuzana Jeskova et al. (UPJS)**

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A. Teacher Information

I. Unit description

In the unit Direct circuit electricity students study electric current and the basics of direct electric circuits. They learn about the simple electric circuit, conductivity of different materials, how to measure current and voltage. They learn that a potential difference across a conductor causes a current through that conductor. They investigate the behaviour of different electric elements in direct electric circuits. They are introduced the concept of electric resistance and investigate its temperature dependence. They learn about the model of electric conductivity and are introduced the serial and parallel connection of resistors. They learn about the effect of electric current on human body. They get known about the electric energy and power delivered to the circuit. They also explore simple electrochemical sources followed by the investigation of the behaviour of real emf device and its parameters. They learn about the properties of the batteries.
The goal of this unit is not to cover all the topics but to provide inquiry-based activities to support teaching and learning the topic of Direct electric circuit in an inquiry way.

The unit is enriched with many ICT activities (ready-made) in which a voltage and a current sensor as well as a temperature sensor together with an interface and software are used to measure the physical quantities and to analyse the results.

Student level: students aged 12-19
Discipline(s) involved: Physics
Estimated duration: approx. 13 class periods (each lasting 45 minutes)

II. IBSE Character

The activities designed within the unit were all selected with regard to IBSE, strongly emphasizing the IBSE approach. The activities are aimed at learning the basics of simple electric circuits and its properties. They are designed for upper secondary level of students (15-19). But several of them can be used for lower secondary level as well (aged 12-15). In the following table we introduce the types of IBSE skills developed within the activities.

Activity	***Inquiry Type***	***IBSE skills***
1. Electric current, battery and bulb		
1.1. How torch works	guided discovery/guided inquiry	Observe, formulate questions
1.2. Construct a simple electric device	bounded inquiry	Design simple investigation, perform experiment, formulate and test hypotheses
2. What material conducts electric current?	guided inquiry	Observe, design simple investigation, perform experiment
3. How is it connected inside the black box?	guided discovery/inquiry	Design investigation, formulate and test hypothesis
4. Measuring current and voltage	guided inquiry	Perform experiment, gather data by using ICT tools (or standard measuring devices), measure using standardized units of measure
5. Electric element in a dc circuit 5.1. Resistor 5.2. Bulb 5.3. Other elements in a dc circuit (diode)	guided discovery	Design simple investigation, formulate and test hypothesis Perform experiment, gather, analyze and describe data by using ICT tools, communicate results through diagrams
5.4. What element is hidden in the black box?	bounded inquiry	Design simple investigation, formulate and test hypothesis Perform experiment, gather, analyze and describe data by using ICT tools, use evidence to make inferences, communicate results through diagrams
6. Resistance and temperature (build your own thermometer) 6.1. Metal conductor 6.2. Thermistor	guided inquiry guided inquiry	Design simple investigation, formulate and test hypothesis Perform experiment, gather, analyze and describe data by using ICT tools, communicate results through diagrams
7. Model of electric conductivity	Interactive	Identify questions, construct a

(why is it more or less resistive)	discussion/demonstration	model
8. Does human body obey Ohm's Law?	bounded inquiry	Apply scientific knowledge in a new situation, search information
9. Intriguing behaviour of bulbs 9.1. Two identical bulbs in series 9.2. Two different bulbs in series 9.3. Switch on the circuit 9.4. Two identically labelled bulbs	 guided inquiry guided/bounded inquiry bounded inquiry bounded inquiry	Design simple investigation, formulate and test hypothesis Perform experiment, gather, analyze and describe data by using ICT tools, use evidence to make inferences, communicate results through diagrams
10. Build your own battery 10.1. Coins in solution 10.2. Fruit cell 10.3. Lead storage battery	 guided inquiry guided inquiry interactive demonstration	Observe, design simple investigation, perform experiment
11. Battery and its basic parameters 11.1. Terminal voltage 11.2. Power transfer to the load 11.3. Power transfer efficiency 11.4. Build up a model of battery behaviour	 guided discovery guided inquiry guided inquiry bounded inquiry	Design simple investigation, formulate and test hypothesis Perform experiment, gather, analyze and describe data by using ICT tools, communicate results through diagrams Construct a model
12. Batteries in series and in parallel	bounded inquiry	Design simple investigation, formulate and test hypothesis Perform experiment, gather, analyze and describe data by using ICT tools, communicate results through diagrams
13. How electric eel kills its prey	bounded inquiry	Apply scientific knowledge in a new situation, search information
14. How much energy is stored in a battery?	guided inquiry	Design simple investigation, formulate and test hypothesis Perform experiment, gather, analyze and describe data by using ICT tools, communicate results through diagrams
15. Batteries and their reasonable use	open inquiry	Search information, communicate knowledge gained from

		investigation
16. Other alternative electrical sources		
16.1. Fuel cell	Bounded inquiry	Search information, communicate knowledge gained from investigation
16.2. Photovoltaic cell	Bounded inquiry	

III. Science Content Knowledge

Before starting the activities of Direct circuit electricity unit students are supposed to have prior knowledge of:

- *Some electrostatics: the matter consists of two kinds of electric charge and that at least some negative charge can be moved from one object to another leaving the first positively charged and the second negatively charged. Once the charges stopped moving we explore the electrostatic forces between them (Coulomb´s law), the concept of potential difference (voltage).*
- *Phenomenon of electric current, the physical quantity of electric current.*
- *The schematic symbols for basic circuit elements. A circuit sketch.*
- *The set of designed activities do not cover all the topics concerning direct electric circuit. The activities presented here were selected and designed with regard to their potential towards IBSE and they do not to cover the entire topic of direct electric current. Nevertheless, there are some concepts that are needed within the activities (like power, energy delivered to the circuit, electromotive force) and hence they should be introduced before the activity starts within a theoretical lesson.*

In the unit students are introduced to the following scientific concepts and ideas:

- *In order to have stable electric current we need a closed electric circuit with certain elements.*
- *There are materials that conduct electric current. They can differ according to their ability to conduct electric current.*
- *The amount of electric current can be measured by ammeter, voltage can be measured by a voltmeter, how to connect ammeter and voltmeter into the circuit. We can use ICT tools (current and voltage) sensors for measurement. Electric current is the same at all places of the simple circuit.*
- *The concept of resistance and Ohm´s law. There are many elements that can be a part of the circuit. They can behave differently when connected in a direct electric circuit.*
- *The resistance depends on temperature. This relationship can be increasing (metal conductors) and decreasing (semiconductors). This relationship can be used for designing a thermometer.*
- *Theoretical model of electric circuit based on the concept of surface charges. Resistors in series and parallel.*
- *Electricity and human body. Ohm´s Law for a human body.*
- *The concept of power and energy delivered to the circuit. These concepts basic introduction is not a part of the activities. Their introduction must be done within a lesson before the activity 9 (Intriguing behaviour of bulbs). Electric current delivers energy (power) to the circuit (e.g. to the bulb). The energy delivered determines the bulb brightness.*
- *The concept of electrochemical cell (primary and secondary) and a battery made of a connection of several cells.*
- *The concept of terminal voltage (compared to the electromotive force) and its dependence on the current flowing through the circuit. The concept of internal resistance.*
- *Power transferred from the battery to the load. Power transfer efficiency. Theoretical model of the battery behaviour.*
- *Batteries connected in series and parallel. Emf and internal resistance of these batteries.*

- *The properties of battery. Battery capacity. Energy supplied by the battery. Other important parameters.*
- *Everyday use of batteries. Environmental aspects of battery disposal.*
- *Alternative electric sources (fuel cell, photovoltaic cell)*

The detailed explanation of the model of electric circuit can be found in the articles:
Haertl, H.: The electric Circuit as a System: A New Approach, Eur.J.Sci.Educ., 1982, vol.4, No.1, 45-55
Sherwood, B., A., Chabay, R., W. A unified treatment of electrostatics and circuits, available at <http://matterandinteractions.org/Content/Articles/circuit.pdf>

IV. Pedagogical Content Knowledge

The unit contains activities, majority of which is aimed at students´ independent investigation. They were selected and designed with regard to their potential towards IBSE with strong emphasize on the students´ inquiry. Hence the activities do not cover all the range of topics concerning direct electric circuit. The goal of this unit is not to cover the entire topic but to provide inquiry-based activities to support teaching and learning the topic of Direct electric circuit in an inquiry way. As a result there are some concepts that are not the central part of any activity but they are used within the activities (like power, energy delivered to the circuit, electromotive force). These concepts are supposed to be introduced within theoretical lesson before the activity starts.

Electricity is one of the basic areas of physics that are very important at all levels of physics teaching. At the primary level young children gain experience with simple electric circuits. At the secondary level electricity is taught more systematically. In this sense the activities can be used at different levels. For lower secondary level students (aged 12-15), depending on the national curriculum, it is recommended to carry out activities 1, 2, 3, 4, 5.1, 5.2, 8, and 10.

Electricity is one of the most difficult concepts for students to grasp. It is around us but at the same time it is invisible. Current and voltage are difficult to understand because they cannot be observed directly. As a result, there are many misconceptions concerning electricity identified by physics education research[1]*. The most common misconceptions concerning electric circuits involve:*

- *Current is used up in a bulb. It is consumed while running through the resistor so that less current is flowing back to the battery.*
- *There is no potential difference across an open switch because V=IR and there is no I.*
- *Ohm´s Law applies to all circuit elements (not just resistors).*
- *Electrons move quickly (near the speed of light) through a circuit. That's why when we connect the bulb to the battery, it lights up immediately.*
- *Charges slow down as they go through the resistor.*
- *A conductor has no resistance.*
- *The resistance of a parallel combination is larger than the largest resistance.*
- *Battery is a source of electric current. Battery either outputs zero current (if nothing is attached to it) or outputs a standard amount of current, independent of what is attached to the battery. Emf and potential difference are synonymous.*
- *There is no current between the terminals of a battery.*
- *Charges that flow in circuit are from battery.*
- *Current and voltage are the same.*

Taking into account the physics education research results on students misconceptions the activities are designed to confront these common misconceptions. To reveal them the teacher should ask questions so that the student can confront his pre-knowledge with the results gained in the experiment. The activity Model of the electric circuit (why is it more or less resistive) presents an approach to teaching electric circuit concepts described by

[1] Sherwood, B., A., Chabay, R., W. A unified treatment of electrostatics and circuits, available at <http://matterandinteractions.org/Content/Articles/circuit.pdf>
Helping Students Learn Physics Better, Preconceptions and Misconceptions, available at http://phys.udallas.edu/C3P/Preconceptions.pdf
Haertl, H.: The electric Circuit as a System: A New Approach, Eur.J.Sci.Educ., 1982, vol.4, No.1, 45-55

Herman Haertl[2] that addresses successfully some of the standard students´ misconceptions.

The activities are designed for the certain level of inquiry. But it is up to the teacher and the level of his students to change the activity to more open investigation or vice versa.

V. Industrial Content Knowledge

This topic can involve a lot of industrial and everyday applications. We use electric devices in everyday life.
It should be stressed that to make the electric devices work the closed electric circuit is needed.
The electric circuit elements are parts of electric devices. Changing the electric resistance of resistors can change the current in the circuit and hence we can change the lamp brightness, the speed of a race car, etc. Electric resistance is used in archaeology for electrical resistance survey of the potential excavation sites.
Light-dependent resistors are used to switch the light on at night.
Diodes gave basis for the wide development of electronics. Light-emmiting diodes are widely used instead of bulbs.
Teaching about different elements in electric circuit gives opportunity to visit a place where electronic devices are dismantled into electronic components and separated. The excursion can lead to discussion about possible environmental problems connected with electronic waste.
The temperature dependence of metal or semiconductor (thermistor) resistance leads to the application of this in thermometer design.
To engage students in technological design they can design and build their own thermometer.
The applications of Ohm´s Law can involve also the effect of electric current on human body and the ways how to increase safety to prevent from being electrically shocked.
The concept of power and energy delivered to the load can be illustrated by the examples of electric devices and their corresponding power input and comparing different electric devices comparing their energy consumption. The incandescent bulbs compared to other types of electric lights can be a good example of the different power input towards more energy-efficient lighting.
The wide industrial application is connected with the concept of battery. Students can build their own simple battery.
The analysis of different batteries from the point of view of their emf, internal resistance, and energy supplied to the circuit and other important properties can give students a picture about the battery properties and their reasonable use in everyday life.
The application in animal world (electric eel) can be a good example to illustrate the purpose of batteries in parallel and series. The environmental aspects of batteries disposal can be discussed and students can find where the nearest battery recycling place is and how and where we can get rid of the used batteries. This is also a good opportunity to find out information about the battery electric vehicle.
Connected to the batteries as sources of energy students could look for other electrochemical sources, such like fuel cells or photovoltaic cells (used in solar panels).

[2] Haertl, H.: The electric Circuit as a System: A New Approach, Eur.J.Sci.Educ., 1982, vol.4, No.1, 45-55

VI. Learning Path(s)

The unit of Direct circuit electricity involves 16 activities altogether, some of them consists of several parts. They offer a wide range of IBSE activities on different inquiry level. The teacher can choose the activity that is appropriate for his own curriculum. Here is the possible arrangement of the activities with respect to the e-learning cycle.

Activity	*Inquiry Type*	*E-emphasis*
1. Electric current, battery and bulb		
1.1. How torch works	guided discovery/guided inquiry	Engage/explore
1.2. Construct a simple electric device	bounded inquiry	Engage/explore
2. What material conducts electric current?	guided inquiry	Explore/Explain
3. How is it connected inside the black box?	guided discovery/inquiry	Explore/Explain
4. Measuring current and voltage	guided inquiry	Exploration
5. Electric element in a dc circuit 5.1. Resistor 5.2. Bulb 5.3. Other elements in a dc circuit (diode)	guided discovery	Explore/Explain
5.4. What element is hidden in the black box?	bounded inquiry	Extend/elaborate
6. Resistance and temperature (build your own thermometer)		
6.1. Metal conductor	Guided inquiry	Explore/Explain
6.2. Thermistor	Guided inquiry	Explore/Explain
7. Model of the electric circuit (why is it more or less resistive)	Interactive discussion/demonstration	Explain
8. Does human body obey Ohm's Law?	bounded inquiry	Extend (elaborate)
9. Intriguing behaviour of bulbs		
9.1. Two identical bulbs in series	guided inquiry	Extend (elaborate)

9.2. Two different bulbs in series	guided/bounded inquiry	Extend (elaborate)
9.3. Switch on the circuit	bounded inquiry	Extend (elaborate)
9.4. Two identically labelled bulbs	bounded inquiry	Extend (elaborate)
10. Build your own battery		
10.1. Coins in solution	guided inquiry	Engage/explore
10.2. Fruit cell	guided inquiry	Engage/explore
10.3. Lead storage battery	interactive demonstration	Engage/explore
11. Battery and its basic parameters		
11.1. Terminal voltage	guided discovery	Explore/explain
11.2. Power transfer to the load	guided inquiry	Explore/explain
11.3. Power transfer efficiency	guided inquiry	Explore/explain
11.4. Build up a model of battery behaviour	bounded inquiry	Extend (elaborate)
12. Batteries in series and in parallel	bounded inquiry	Extend (elaborate)
13. How electric eel kills its prey	bounded inquiry	Extend (elaborate)
14. How much energy is stored in a battery?	guided inquiry	Explore/explain
15. Batteries and their reasonable use	open inquiry	Elaborate/evaluate
16. Other alternative electrical sources		
16.1. Fuel cell	bounded inquiry	Extend (elaborate)
16.2. Photovoltaic cell	bounded inquiry	Extend (elaborate)

VII. Assessment

The activities 1, 2,3,4,5 are aimed at basic knowledge about simple electric circuit. The assessment can include practical assignments on constructing a simple circuit and measuring voltage and current.

The activities 5,6,7,8 involve V-A characteristics (Ohm´s Law), the temperature dependence of resistance and resistors in series and parallel. The assessment of the conceptual understanding of these concepts can include theoretical test and as well as a presentation based on searching information on the effect of electricity on human body.

The activity 9 is aimed at the conceptual understanding of the concept of power delivered to the circuit. The theoretical test can be appropriate to check the understanding.

The activities 10-16 aimed at the understanding the concept of battery and its parameters can be assessed by a theoretical test. Presentation or written report on the results of open inquiry based on searching information about batteries (activity 15) can be assessed when presenting results in front of the class.

In all the activities where students realize guided/ bounded inquiry to carry out investigation on a specific topic and they gain and analyze data to draw conclusions consequently, the written report on the labworks can be a part of the assessment, as well.

VIII. Student Learning Activities

1. Activity Electric current, battery and bulb

Learning aims:

- *To understand how a potential difference can cause an electric current through a conductor*
- *To learn to design and construct simple electric circuits using batteries, bulbs, wires and switches*
- *To learn to draw circuit diagrams using symbols*

Materials:

- *A few cheap torches that can be taken apart,*
- *Three bulbs (e.g. 4,5V/0,3A), Zinc-carbon battery (4,5V), leads, one-way switch, two-way switch*

Suggestions for use:

*Divide the class into small groups of 2-4 students and hand out the worksheet: Electric current, battery and bulb. The students working in groups go step by step from **simple observation** to **guided discovery** up to **bounded inquiry**.*

Let students play in groups with a torch and dismantle and examine its components. Students should identify three basic components: a switch, a bulb and a battery that are connected in series. They learn that for current to flow the closed circuit is needed. The torch case can be a part of the circuit.

After this first simple investigation they learn to build their own simple electric circuit from a battery, a bulb, leads and a switch.

Once the students know to light up a single bulb, they can design and build some simple electric devices using extra switches, wires and bulbs. They are asked to invent and construct more complicated circuits with series or parallel connection of bulbs using switches. Even if the students do not know what goes on in electric circuit in details, this task can motivate them to think and investigate in order to find out the appropriate solution. Students are engaged in design of a model of electric devices that are commonly used in real life.

*Students should work on their own realizing **bounded inquiry**. Once they have completed the investigation they summarize the results and present them to the other groups. In case we do not have all materials for each group or we are lack of time, each group can construct one of the suggested electric circuits.*

Possible questions:

- *What are the torch basic components?*
- *What makes the bulb light up?*
- *What components can a simple electric circuit be made of?*
- *What influences the bulb brightness?*
- *How is the current direction set?*
- *How do different switches work?*

2. Activity What material conducts electric current?

Learning aims:

- *To learn to design and construct simple electric circuits using batteries, bulbs, wires and switches*
- *To understand that there are different types of materials conducing or not conducting electric current*

Materials:

- Zinc-carbon battery (4,5V), leads, wires of similar size and different materials, pencil lead, match, piece of plastic, distilled water, tap (salty, sweet) water, glass, porcelain, china plate with metal strip, etc.

Suggestions for use:

*Divide the class into small groups of 2-3 and hand out Classroom Material**:** What material conducts electric current.*

*Once the students can construct simple electric circuits, they can be asked to plan and design their own experiment to examine different materials and their conductivity. They should use a bulb as an indicator of current. Students should work within the group on their own realizing **guided inquiry**. Once they have completed the investigation they summarize the results and present them to the other groups. In case we do not have all materials for each group or we are lack of time, each group can investigate several of them. Finally we can do a contest on the longest electric circuit that makes the bulb light up.*

Possible questions:

- *What physical quantity does the bulb brightness indicate?*
- *How do different materials connected into the circuit influence the brightness of the bulb?*
- *Compare the current flowing through the circuit in each case.*
- *Which materials are good conductors and which are not?*
- *Why is it important to know if the material conducts electricity?*

3. Activity How is it connected inside the black box?

Learning aims:

- *To deepen and widen students' knowledge about the simple electric circuit.*

Materials:

- *Black boxes with four connectors (that are mutually interconnected in different ways inside each box using wires or resistors), bulbs, batteries (or some other convenient source of DC voltage), leads.*

Suggestions for use:

*We divide the class into groups of three. Each group has all the necessary equipment ready on their table. We hand them out the Black box's secret worksheet and let the students perform their own experiments in a **guided discovery/inquiry** way. At the beginning they should answer introductory questions that should update their knowledge necessary for independent investigation. In accordance with the principles of inquiry based* *learning students first draw possible ways of interconnection, then they propose a procedure for investigation and, finally, they perform an experiment to reveal the internal structure of the boxes. They use a power source, wires and a bulb to indicate the current (yes or not, strong or less strong) through a selected path. During the independent investigation the teacher observes and by asking questions moderates the individual work of the students. (In case of a less advanced class, the questions are answered one by one and the correctness of the answers of different groups is checked in the form of a class-wide discussion). After the experiments are finished, the contents of the black boxes are revealed – the students check the correctness of their investigations and in case they have made a mistake they try to analyze the cause of the mistake.*

Possible questions:

- *What internal connection corresponds to the situation when the bulb lights up?*
- *What internal connection corresponds to the situation when the bulb lights up but it shines dimmer than in the previous case?*
- *When is the brightness of a bulb connected in an electric circuit lower and when higher?*
- *What internal connection corresponds to the situation when the bulb does not shine at all?*
- *What is understood by the term "black box"?*
- *Where can we find black boxes in everyday life?*

4. Activity Measuring current and voltage

Learning aims:

- *to understand the measurement of two basic physical quantities that describes the operation of electric circuits: current and voltage using current and voltage sensor (ammeter and voltmeter, eventually)*
- *to understand that current is the same at all points in simple circuits*
- *to understand how voltage is distributed across different parts of a simple electric circuit.*

Materials:

- *Battery (e.g.zinc-carbon or fresh alkaline, 4,5V), two bulbs (e.g. 4,5V/0,3A), leads, computer, interface and software (e.g. COACH 6), current sensor, voltage sensor (ammeter and voltmeter eventually)*

Suggestions for use:

Divide the class into small groups of 2-3 and hand out Classroom Material: Measuring current and voltage. This is a simple activity aimed at developing basic skills concerning measurement of current and voltage in a simple electric circuit with the help of sensors and understanding about current and voltage in the simple circuit. That's why it is very important to work in small groups so each student has a chance to manipulate with the circuit components. Students learn that to measure the voltage across an element in a circuit the voltage sensor has to be connected in parallel and to measure the current flowing through it the current sensor has to be connected In series with it. They learn that the current is the same at different points of a simple electric circuit and that it is not used up by the circuit element. They learn how the voltage is distributed across different parts of *the electric circuits. Students working in groups of 2-3 are engaged in a **guided inquiry** answering the questions and predicting the behaviour of the circuit following gradually the instructions in the worksheet. In case the sensors are not available, the activity can be carried out with the help of ammeter and voltmeter. Industrial content can be emphasized mentioning that the sensors aimed at measuring not only current and voltage are widely used nowadays.*

Possible questions:

- *Is the current the same at different points of a simple electric circuit? Explain.*
- *Is the voltage the same across the battery and the bulb in a simple electric circuit? Explain.*
- *Is there a circuit element with zero voltage across it?*
- *What is the voltage expected to be at the two ends of the same wire?*
- *How is the voltage across a battery influenced by the number of bulbs connected in series?*
- *How is the current through a circuit influenced by the number of bulbs connected in series?*
- *Is the battery a source of a constant current or a constant voltage?*

5. Activity Electric element in a dc circuit

Learning aims:

- *Understanding that the potential difference across the conductor causes a current through it*
- *Exploring the relationship between the current flowing through a conductor and a potential difference across it.*
- *Interpreting the current – voltage diagram of a conductor*
- *Understanding the concept of resistance*
- *Investigating the behaviour of different electric elements in a direct electric circuit*
- *Interpreting the current – voltage diagram of different electric elements*

Materials:

Variable power source (up to 10V), leads, resistors of different values of resistance (e.g. 20Ω or higher), bulb (e.g. 6V/0,05A), other electric elements (e.g. semiconducting diode) limiting resistor to be used in a circuit with diode, computer, interface and software (e.g. CMA Coach6), current sensor, voltage sensor (if computer with interface is not available, ammeter and voltmeter can be used)

Suggestions for use:

Divide the class into small groups of 2-3 and hand out Classroom Material: Electric element in a dc circuit. In this activity students carry out an experiment in order to investigate the relationship between the current flowing through a resistor and the voltage across it and to understand the concept of resistance. We expect students to be confident enough in measuring current and voltage with the help of sensors.

Firstly, they are introduced the concepts of resistor and resistance – as a physical quantity *defined as $R = \frac{U}{I}$. During the investigation students discover that this relationship is linear and they learn to understand the current-voltage diagram and the concept of resistance.*

The important point of this investigation is to connect the real experiment with its graphical representation and to develop the ability to grasp the required information from the graph. Students learn to understand the physical meaning of diagram features (linear, non-linear, slope of the line) and so that to interpret the diagram correctly.

In the next step they investigate the behaviour of other electric components in the direct electric circuit, such like bulbs and diodes and compare it with the behaviour of a resistor.

In the activity students follow the instructions in the worksheet in a guided- discovery way.

In order to enhance conceptual understanding of Ohm's law, the activity can be followed up by the additional activity carried out in the inverse sequence. The components are hidden in a "black box" and on the basis of their current-voltage relationship measurement students reveal the black box content. This activity is carried out as a bounded inquiry when students having the problem to solve and materials available design the experiment in order to find the problem solution. The black boxes can contain a resistor, a bulb, a diode and a thermistor so that the students decide about the component that behaves differently than the other ones.

Let them plan the measuring procedure without significant help.

In this activity there are wide opportunities to connect this knowledge with Industry.

This can involve the application of resistors and other electric elements and electronic components, here are several examples:

- *Standard applications of resistors in electric circuits in various devices. When using variable resistor, with the changing current the brightness of the lamp can be changed. In some electric model race car sets squeezing the trigger the variable resistor changes its value and hence the current through the car motor can increase so the car speeds up.*
- *The use of electric resistance in a wider context, e.g. in archaeology for electrical resistance survey, when metal probes are inserted into the ground to obtain a reading of the local electric resistance. Soil resistivity testing is used to find potential excavation sites. Scientists use meters to find and map out man-made areas beneath the surface. Roads and building foundations tend to be dry and compacted, producing high soil resistivity. Covered ditches and trenches have high moisture content and readily conduct electricity.*
- *Light-dependent resistors decrease in resistance with more light. They are widely used in light-night to switch the light on at night. Thermistors decrease in resistance when their temperature rises.*
- *Diodes gave basis for the wide development of electronics. Light-emitting diodes (LED) give out light when a current passes through. LEDs hardly ever fail, and are used instead of bulbs.*

Teaching this topic gives a good opportunity to visit a place where electronic devices (such like TVsets, radios, computers, mobile phones, etc.) are dismantled into electronic components and separated according to their possible reuse. When dealing with *electronic waste a question of their influence on the environment should be taken into account and may be discussed.*

Possible questions:

- *What does the voltage applied across a circuit element cause to happen?*
- *Do different elements (resistor, bulb, diode) behave the same way in a dc circuit?*
- *How is the current flowing through an element influenced by the voltage applied across it? Does the current increase, decrease or stay constant when applying increasing voltage? What is the mathematical relationship between current and voltage (I-U relationship) for a circuit element?*
- *How could you distinguish between several elements knowing their I-U diagram?*

6. Activity Resistance and temperature (build your own thermometer)

Learning aims:

- *Understanding that the resistance of the electric element can depend on its temperature*
- *Understanding that different elements react on increasing temperature differently*
- *Exploring the relationship between the resistance of a metal conductor and its temperature*
- *Exploring the relationship between the resistance of other elements like thermistor and its temperature*
- *Interpreting the resistance – temperature diagram of a metal conductor and that of a thermistor*
- *Understanding the use of resistance thermometer for measuring temperature*

Materials:

Variable power source (up to 10V), leads, computer, interface and software (e.g. CMA Coach6), current sensor, voltage sensor, temperature sensor (if computer with interface is not available, ammeter and voltmeter and thermometer can be used), metal conductor (e.g. a long thin copper wire), thermistor

Suggestions for use:

Divide the class into small groups of 2-3 and hand out Classroom Material: Resistance and temperature. In this activity students carry out an experiment in order to investigate the relationship between the resistance of a resistor (thermistor) and its temperature. The resistance is measured via measuring current flowing through the element and voltage across it calculating the corresponding resistance. At this stage students should be confident enough in measuring current and voltage as well as the temperature with the help of sensors.

The main idea is to find out the main difference between the metals and semiconductors in terms of the temperature dependence of their resistance and understand that based on this dependence the element can be used as a device for measuring temperature.

Since the temperature coefficient of resistance for metals is rather small (α is typically from $3.10^{-3}K^{-1}$ to $6.10^{-3}K^{-1}$) we need a long thin wire to have the initial resistance big enough to see the difference when heated. In case we do not have an appropriate wire available, students can use the results measured already in COACH 6 that they can analyse. (the file Resistance and temperature_metal.cmr.)

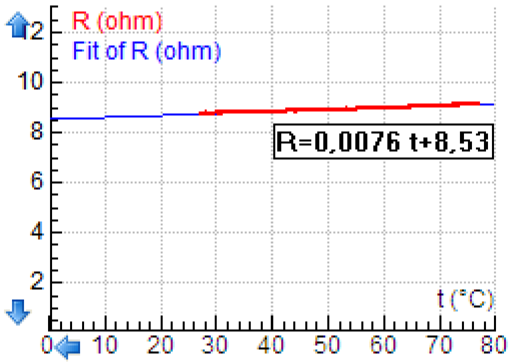


Fig. Experimental results for metal

The resistance temperature dependence for a thermistor is much more significant with negative temperature coefficient of resistance. The result can be seen in the file temperature_metal.cmr.

*In both cases students carry out measurement and the following analysis in a **guided inquiry** mode. The ready-made result can be used in case of lack of time but real measurement is preferable. In both cases the analysis should lead to the data fit that is linear for the metal but much more complicated for thermistor. We introduce the idea of the temperature calibration. For students who are already familiar with the exponential function the thermistor calibration can be done. So, at the end, students get the thermistor calibrated for temperature measurement. They can compare their thermometer with data from the temperature sensor.*

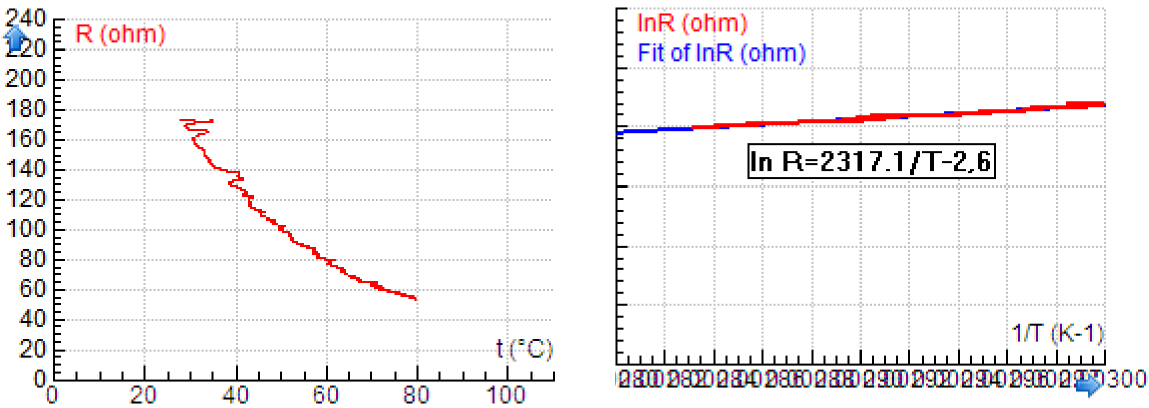


Fig. Example of thermistor calibration result

The important point is to get the idea about the principle of resistance thermometer and its calibration. The connection with industry can involve information about resistance thermometers and thermistors and their applications (thermistors in automotive industry for monitoring the coolant and oil temperature in the engine, temperature of the incubator, etc.).

Possible questions:

- *How does the resistance of a metal conductor change with temperature?*
- *How does the resistance of a thermistor change with temperature?*
- *How can the resistance-temperature dependence be used for measuring temperature?*
- *How can we calibrate a metal or a thermistor for measuring temperature?*

7. Activity Model of the electric circuit (why is it more or less resistive)

Learning aims:

- *Understanding the conduction mechanism in metals in terms of the electrons´ motion*
- *Understanding the concept of surface charges on conductors*
- *Understanding the role of resistor in a current carrying circuit*
- *Understanding that the current is divided at the junction*
- *Understanding what is the final resistance of two resistors connected in series (parallel)*

Materials:

- *Animations available at http://www.astrophysik.uni-kiel.de/~hhaertel/CLOC_doc/CLOC_doc_uk/index.htm*

Suggestions for use:

This activity is aimed at conceptual understanding of electric circuit through the concept of surface charges. The explanation can be found in
Haertl, H.: The electric Circuit as a System: A New Approach, Eur.J.Sci.Educ., 1982, vol.4, No.1, 45-55
Haertl, H.:Conceptual learning of Circuit, available at http://www.astrophysik.uni-kiel.de/~hhaertel/CLOC_doc/CLOC_doc_uk/index.htm
Sherwood, B., A., Chabay, R., W. A unified treatment of electrostatics and circuits, available at <http://matterandinteractions.org/Content/Articles/circuit.pdf>
The activity should be guided by the teacher who carries out an interactive discussion in order to explain the basic mechanism of electric current in a circuit and the related concepts. Within the interactive discussion teacher ask questions and students try to formulate answers. The important point is not to give the answer but try to make students think to come to the answer by themselves. Therefore the questions are formulated to revise the already known facts towards new situations and coherence.
Here is a possible scenario how to carry out the activity with the questions and corresponding answers. The first set of questions is aimed at the revision of the already known facts.

1. ***When is the object electric?***

Describe your idea about the internal structure of a matter.
Every material object shows a grainy structure, where the basic elements of this structure - the atoms or molecules - consist of charge carriers of opposite polarity - the protons inside of the core and the electrons at the outer shells.
What is the reason of interaction between electrons and protons?
The existence of charge with opposite polarity has to be accepted as given by nature. The same holds for the fact that charge of equal polarity repel while charge of opposite polarity attract each other. Protons and electrons carry the same elementary charge with opposite polarity. For historical reasons the charge of electrons is called negative, the charge of the protons as positive.
How does a group of equal number of positive and negative charges behave?
Every macroscopic amount of charge is always an integer multiple of the elementary charge.
The unit of charge has been defined (again for historical reasons) as consisting of $6{,}2.10^{18}$ elementary charges. The unit is called 1 Coulomb, in honour of the French physicist Charles Augustin de Coulomb (1736-1806).
An equal amount of protons and electrons are seen from outside as neutral.
What happens when we add a single electron (or proton) to the group of charges that are in equilibrium?
Charge cannot be created or annihilated. Within an electric device electrons can only be displaced.
If electrons pile up at some place it is certain that positive charge carriers will pile at some other place which has been neutral before. Repelling forces will show up between charge carriers with equal polarity and attracting forces between charge carriers of opposite polarity - the so-called Coulomb forces. These

Coulomb forces are counteracting the original separation and prevent any further displacement of electrons. The area with extra negative (positive) charge is called electrically negative (positive).

2. What is an electric power source?

How could you describe the operation of electric power source?

An electric power source consists in principle of a conductive device which is connected to the outside by two metallic contacts. A power source can apply a force on the internal electrons to move them from one external contact towards the other. The kind of force is different for different kinds of power sources. Within a battery chemical forces are active, within a generator electromagnetic forces can be applied.

The action of these forces is always the same: At one of the external contacts an excess of electrons will occur. These electrons are missing at the other contact and will show up there as a positive charge (Fig. 1).

Fig. 1. Power source with surface charges at the metallic contacts

How is the excess charge (electrons) distributed on the metal electrode of the power source?

A basic law comes into play here: Additional electrons can never exist inside of a metallic conductor but only at its surface. It is sufficient to accept as an experimentally proven fact that additional electrons can exist at the surface of a metallic conductor and only at its surface.

The larger the density of the additional negative charges at the surface of the metallic contacts, the more these charge carries repel each other. A certain limit will be reached, which is characteristic for the actual power source, where these repelling Coulomb forces will prevent any further accumulation of electrons.

A state of equilibrium will be established between the internal force of the power source and the back driving Coulomb forces from electrons in metallic contact surface.

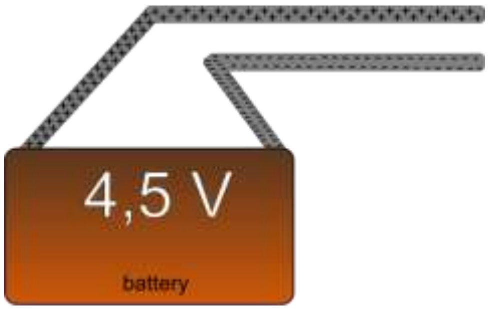


Fig. 2. Power source with connected conductors and surface charges

What happens with the electrons when we attach leads to the power source electrodes? The leads are not mutually connected, the circuit is open.

Connecting the contacts of a power source with metallic conductors is in principle nothing different than increasing the surface of these contacts.

Caused by their mutual repulsion, these charge carriers will redistribute on this enlarged surface and therefore reduce their density. For a short moment this implies non-equilibrium between the internal force of the power source and the Coulomb forces. Some additional electrons will be pushed on to these enlarged surfaces until the original density and equilibrium between the involved forces is re-established.

3. How does electric current flow through a conductor?

Now the leads that come from the power source electrodes are connected by a piece of metal. We created a closed electric circuit. What will the electrons do in a circuit?

All conductors possess a certain internal resistivity. If the power source is strong enough to replace the electrons drifting through the resistor, a circular current will result, where all electrons inside of the conductors will take part.

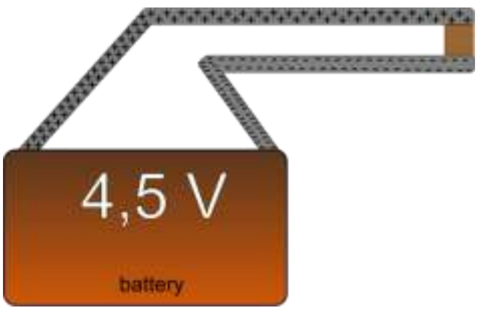


Fig. 3: A closed circuit and surface charges

As long as the driving force of the power source remains constant the charges on the surfaces of the conductors will remain, however, will start drifting along together with the bulk of internal charges. To maintain an electric current through such a conductor it therefore needs an internal driving force to overcome the opposing effect of this resistivity.

For the simplest case of a rectilinear homogeneous conductor, carrying a constant current, it can be calculated that it needs a linear change in the distribution of surface charges to produce an internal constant force oriented parallel to the conductor.

Within the copper wire, the electrons experience a very small resistive force; and it is possible to think of a mechanism of conduction where the single electrons are accelerated under the influence of the interaction with the surface charges and collide with some atoms within the lattice. The number of collisions per second is high (about 10^{14}/s), and the mean free path between two collisions is about 10 diameters of a copper atom.

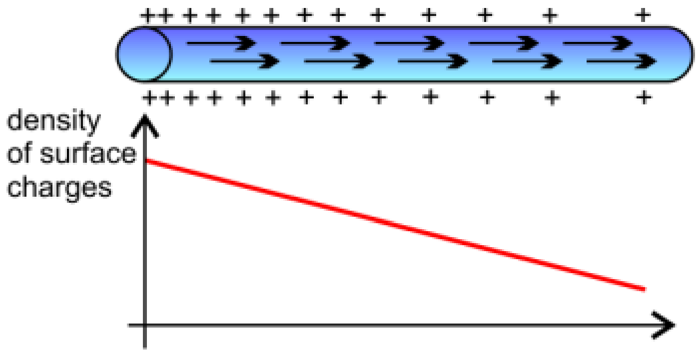


Fig. 4: Linear density distribution of surface charges on a rectilinear conductor

4. How does electric current flow through a resistor?

Now the leads that come from the power source electrodes are connected by a resistor. We created a closed electric circuit. ***What will the electrons do in a circuit?***

If a conductor is electrically connected with a resistor a layer is formed separating the area with high conductivity from the resistive part with low conductivity. Depending on the type of resistor these layers have a different thickness. These layers at both ends of a resistor do not remain neutral when electrons are pushed through.

Within the layer in front of the resistor a few electrons will pile up because ahead of them lies an area of low conductivity. This layer will carry a charge with negative polarity.

From the layer behind the resistor some electrons will escape because an area with high conductive lies ahead of them. Some charged atom ions with positive polarity are left behind. This layer will carry a charge with positive polarity.

Differently distributed charges on the surfaces as well as the charged layers at both ends of the resistor will produce attracting and repelling forces to drive the electrons through the resistor.

If the force of the battery is increased, the gradient of the charge density and the charge within the separating layers will be increased. As a result the force on the mobile electrons will be increased, resulting in a larger current, i.e. a larger number of electrons passing a cross section per time period.

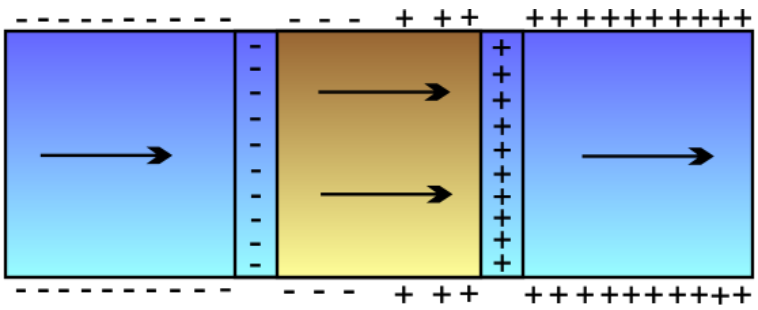


Fig. 5: Charged layers between conductors and resistors

5. Why is the voltage on the current–carrying resistor ?

When we connect a voltmeter across the resistor we can measure the voltage. ***How does the resistor create a different value of charge in order to create potential difference (voltage)?***

A voltage or potential difference between two points within an electric circuit is present whenever charges are separated, either in form of surfaces with a certain density of charges with opposite polarity or with a difference in surface charge density.

Such a separation of charges call some Coulomb forces into existence which try to re-install neutrality and these forces are the actual cause for voltage or potential difference.

The work is done by surface charge forces or in other words the energy transformation which results from a certain current driven by a certain voltage.

This offers the possibility to relate voltage or potential difference between two points A and B to the amount of energy which is transformed when a certain amount of charge is moved from A to B. Numerically voltage is equal to the amount of energy which is transformed if a unit of 1 Coulomb is moved from A to B.

6. Model of the electric circuit

To illustrate the process within an electric circuit it is helpful to compare such a circuit with a stiff ring driven by a motor at one place and restricted in its motion by a brake at another place. The stiff ring is used as a device to transmit a force. It can be concluded that ring consists of two parts. The part before the brake is under the push and the part behind the brake is under the pull. The pushed part will become slightly compressed, the pulled part will become slightly stretched. This difference in deformation will be sustained by the motor and will produce the necessary force at *the brake to keep the ring moving.*

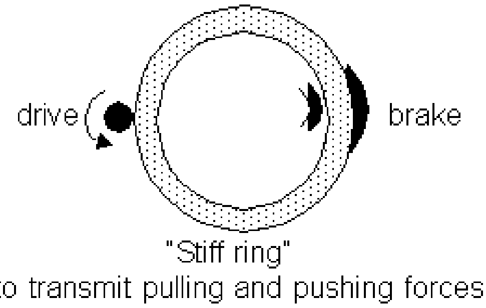


Fig. 6 The stiff ring model of the electric circuit

The similarities between the electric circuit and a stiff ring with a drive and brake can be summarized as follows:

Stiff ring	***Electric circuit***
The stiff ring serves to transmit a force	*The electric circuit transmit a force*
Matter moves in a circle	*Electrons move in a circle*
Matter is not consumed	*Electrons are not consumed*
The stiff ring is pushed by the motor on one side and pulled on the other side	*Electron gas is pushed at one side and pulled on the other side by the power source*
The stiff ring is compressed or stretched by the motor.	*The density of the charges at the surface is changed.*

Restricted models for the electric current

In comparison with the stiff ring, the bicycle chain, the drive belt, blood circuit or circular systems like hot water system can be used as model for the electric circuit in a much more restricted manner. These systems do not transmit a force but mainly energy-rich matter. The transmission of energy is therefore couple to the motion of the transmitting medium. Within an electric circuit the electrons are drifting with a rather low velocity while the energy is spread out with nearly the speed of light.

As problematic model for the electric circuit could be also models, where the single components can be driven individually (e.g. trucks on the highway). In contrast to such a system electron do not have an own drive but are driven by an external power source.

7. Simulation of current and voltage in a circuit

Students can construct simple electric circuits with the help of interactive applet in order to understand the surface charges distribution.

The current is visualised graphically at selected locations in the form of triangles.

The voltage along the components is related to the density of surface charges (display perpendicular to the circuit).

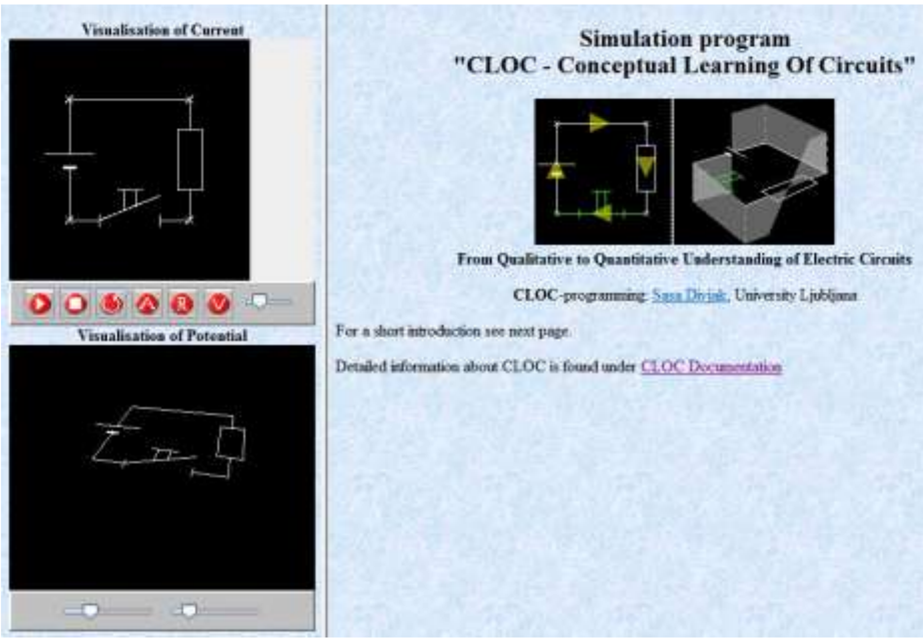


Fig. 7 Simulation of current and voltage as interactive applet

8. ***When do electrons pull together (resistors in series)***

The resistance of the circuit element describes its ability to act against the current flowing through it. If we connect the resistors in series then the current must act against the resistance of all the connected resistors. What is the final resistance of all the resistors connected in series?

In each of the resistors there is a surface charge at the area between the resistor and the lead. The total difference between the surface charges before and after the resistor equals the sum of the charges at each of the resistors.

Hence the total resistance of resistors connected in series is a sum of the resistance of each of the connected resistors.

Students use interactive simulation for visualization of the current and voltage in the series circuits.

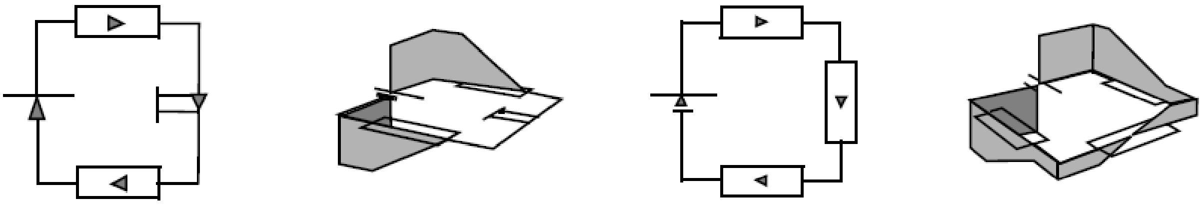


Fig. 8 Series circuit with resistors

9. ***How is the current divided in a junction?***

In an electric circuit with a branching point, the current is split up at the branching point according to the resistors within the different parallel branches.

How can you explain the mechanism to divide the current in a junction?

Shortly after closing the circuit with parallel branches the same current flows through each of the branches. At the points where the resistors are connected in a junction the surface charges start to pile up. Their density is influenced by the value of resistance in the branch. The larger the resistor in such a branch, the smaller the current through this branch.

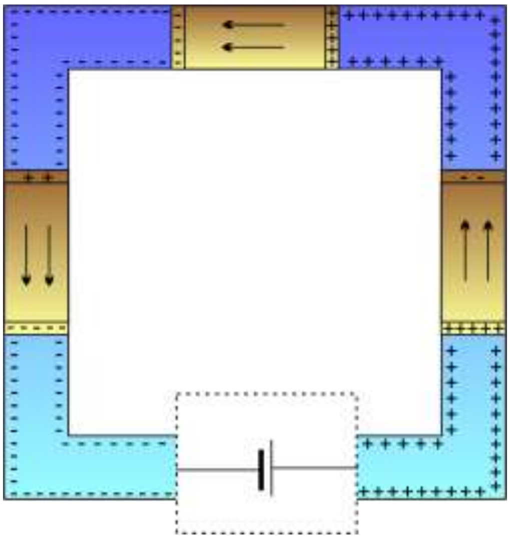


Fig. 9 Surface charge distribution in a series circuit

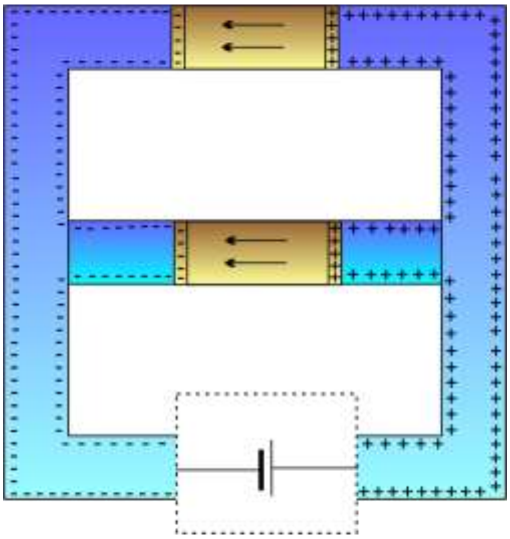


Fig. 10 Surface charge distribution in a parallel circuit

Students use interactive simulation for visualization of the current and voltage in the parallel circuits.

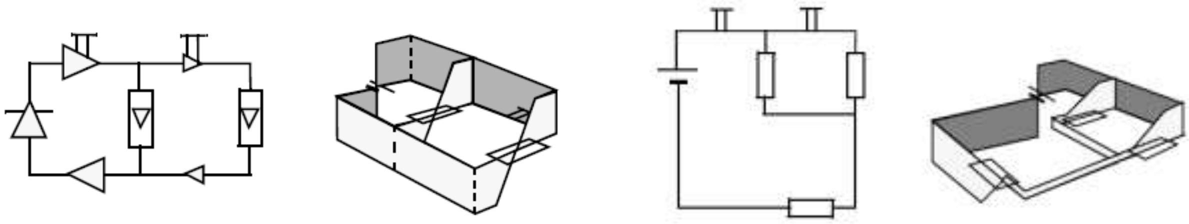


Fig. 11 Parallel circuit with resistors

Possible questions:

- *When is the object electric?*
- *What is an electric power source?*
- *How does electric current flow through a conductor?*
- *How does electric current flow through a resistor?*
- *Why is the voltage on the current-carrying resistor?*
- *When do electrons pull together (resistors in series)?*
- *How is the current divided in a junction?*
- *What is the resistance of two resistors connected in series (parallel)?*

8. Activity Does human body obeys Ohm's Law?

Learning aims:

- *Understanding that the human body acts like a resistor obeying Ohm´s law*
- *Understanding what determines the danger of electricity*
- *Understanding the effects of electricity on human body*
- *Introducing the applications of electric current through a human body (e.g. in medicine)*

Materials:

Text about the effects of electricity on human body

Internet resources on the effects of electricity on human body and about other applications of electricity in human body

Suggestions for use:

In this activity students study the text about the effect of electricity on human body or they can use internet or other resources to study the topic. On the basis of it they can prepare a short presentation on the effects of electric current on human body. A group of students can do this activity on their own, looking up information in different sources, then preparing a presentation on the topic and share it with their peers. The interdisciplinary physics-biology approach can be enhanced by searching information about the physiological effects of electricity (burning, muscle contraction, heart fibrillation).

There are also good examples of the deliberate uses of the application of Ohm's law for a human body, e.g. medical uses or bioelectrical impedance analysis for estimating body composition. Another group of students can study these applications and prepare a presentation to be discussed in the class.

Possible questions:

- *Is the human body a good conductor of electricity?*
- *What will happen if electricity travels through you?*
- *Is it a voltage or a current that causes electric shock?*
- *Why are people good conductors of electricity?*
- *Why should you never touch anything electrical while you have wet hands or while standing in water?*
- *How can you increase your safety to prevent yourself from being electrically shocked?*
- *What are the medical uses of electric current in your body?*

9. Activity Intriguing behaviour of bulbs

Learning aims:

- *conceptual understanding the concept of electric energy and power delivered to a resistor by investigating the behaviour of bulbs in dc circuit*

Materials:

Two identical bulbs (e.g. 6V/0,3A, 6V/0,1A), two identical bulbs (e.g. 6V/0,05A), power source (6V), leads, computer, interface and software (e.g. CMA Coach6), current sensor, voltage sensor differential (if computer with interface is not available, ammeter and voltmeter can be used)

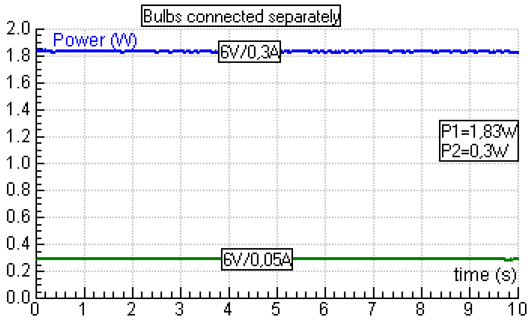
Suggestions for use:

*Before starting this activity students are already introduced the series connection of resistors and the concept of energy and power dissipated in the resistor. In this activity students can solve two problems to investigate on the behaviour of bulbs in a dc circuit. Both of them can be solved as **guided (or bounded) inquiry** activities depending on the students´ level. In both cases students work in groups of 2-3. Supposing we have two different bulbs and a power source with voltage standard to light each separate bulb we can light the bulbs separately as well as connecting them in series. From understanding these simple experiments new problems can emerge.*

Problem 1, activity 1,2:

If we put two identical bulbs in the holders they shine equally brightly. If we put two identical bulbs (different from the first ones) they also shine equally brightly. When we put two different ones in the holders than one lights up but the other does not (or very faintly)

*If we let students do **guided inquiry** they carry out experiments according to the instructions in their worksheets. They investigate what physical quantity is responsible for the bulb brightness in order to find out that energy (or power) dissipated is crucial. They do measurement with the help of sensors on the current through the bulb and voltage across it to determine the power dissipated in each of the bulb. If two bulbs are connected in series, the power dissipated in each of them drops. In steady state, the one that draws power closer to its normal condition will shine; the other one will barely glow at all.*



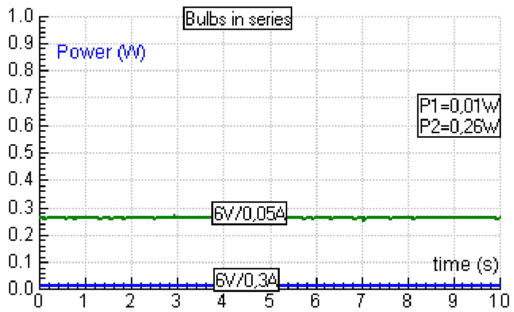


Fig. Example of measurement results for two bulbs connected to 6V power source

*In case of **bounded inquiry** students get the problem and materials available and they design their own experiment to reason the intriguing behaviour of bulbs.*

Problem 2, activity 3, 4:

If we put two different bulbs in the holders one of them will light up later then the other. There is a noticeable delay between the two bulbs.

*If they did the previous investigation, they could do this activity as a **bounded inquiry** to design their own experiment and decide about measurement and analysis of the relevant quantities.*

Analysing the current, voltage, resistance and power diagrams students can draw conclusions. When connected in series, bulbs are heated gradually, so their resistances change after some time and hence the voltage and power is redistributed. As a result, one bulb gradually lights up (power rises) while the other bulb fades a little (power decreases).

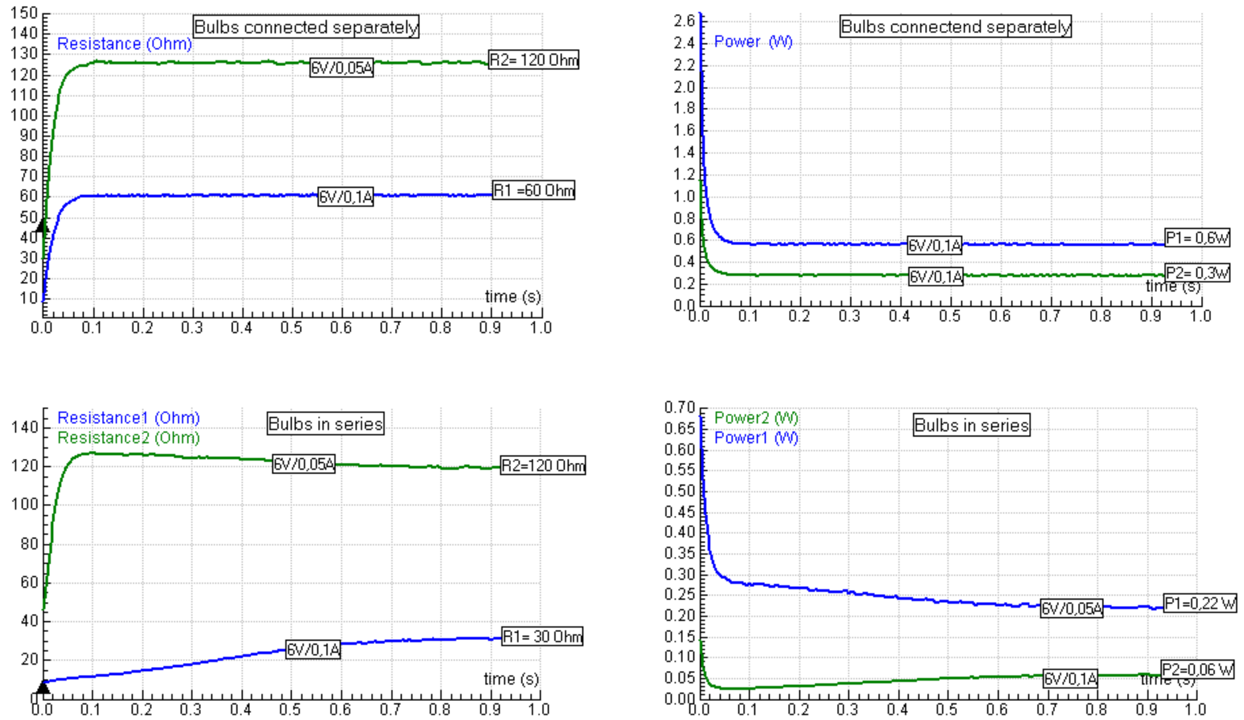


Fig. Example of measurement results for two bulbs in series connected to 6V power source

The investigation can be extended to exploration of identically labelled bulbs from different sources or even from the same producer but different batches. It can be pointed out that even if the label presents identical parameters, the reality can be different in some cases.

The industrial content can be illustrated by examples of bulbs with different energy consumption. The incandescent bulbs are gradually replaced by other types of electric lights towards more energy-efficient lighting. Students can look up some other electric devices and compare the same kind of device made by different producers in terms of the power input.

Possible questions:

- *What determines the bulb brightness?*
- *How is the bulb brightness influenced if we connect two identical bulbs in series compared to if they are connected individually to the same power source? Describe and explain in terms of current, voltage, power and resistance.*
- *How is the bulb brightness influenced if we connect two different bulbs in series compared to if they are connected individually to the same power source? Describe and explain in terms of current, voltage, power and resistance.*
- *What happens just after the switch is closed if we connect two different bulbs in series? Describe and explain in terms of current, voltage, power and resistance.*
- *How do identically labelled bulbs from different sources or even from the same producer but different batches behave in a dc circuit?*
- *Compare different bulbs you find in a shop considering their power input.*
- *Compare some other electric devices in terms of their power input.*

10. Activity Build your own battery

Learning aims:
• *Understanding the basic principles of electrochemical cell as a voltage source* • *Discovering which combination of materials produce a voltage* • *Distinguishing between the chargeable and non-chargeable batteries and main differences between these two types of batteries.*
Materials:
Coins of different metal, salt solution (acid, alkaline solution eventually), paper tissue, lemon, alligator clips, scalpel, graphite pencil (C), iron nail (Fe), magnesium strip (Mg), zinc strip (Zn), led strips, beaker for electrolysis, sulphuric acid solution (10%), power supply (6V), two-way switch, interface and software (e.g. CMA Coach6), voltage sensor (if computer with interface is not available, voltmeter can be used)
Suggestions for use:
Divide the class into small groups of 2-3 and hand out Classroom Material: Build your own battery. *The first two activities aimed at construction of primary cells made from simple materials can be carried out in groups as* ***guided inquiry*** *activities. If we are lack of time or materials, each group studies different combination of materials and then all the findings are put together and conclusions are drawn within a class discussion.* *The third activity on building the secondary cell can be carried out as an interactive experiment presented by the teacher who carries out voltage measurement during charging and discharging with the help of voltage sensor connected to the computer (or voltmeter). Nevertheless, students can use their worksheets to record the findings. While doing the experiment, teacher interacts with students to discuss and answer the questions in the worksheet.* *These activities are good examples to point the industrial content. Batteries are devices that students often use so this is a good starting point to attract their attention and continue investigation and inquiry. The environmental aspects can be also mentioned about the batteries disposal and their recycling.*
Possible questions:
• *How is the electrical energy produced in an electrochemical cell?* • *What is the difference between the primary and the secondary cell?* • *What is the basic physical principle of the primary cell?* • *What is the basic physical principle of the secondary cell?* • *What are the applications of batteries in everyday life?* • *What are the environmental aspects of the use of batteries?*

11. Activity Battery and its basic parameters

Learning aims:
• *Understanding the differences between ideal emf device and real emf device* • *Understanding the concept of internal resistance of emf device and its influence on the*

current-carrying capability

- Understanding the relationship between the voltage across the battery and the current flowing through the circuit and interpreting the diagram
- Understanding the power transfer to the load and the power transfer efficiency in relation to the load resistance.

Materials:

Battery (e.g. 4,5V zinc-carbon, older one with high internal resistance recommended), leads, resistor with adjustable resistance (e.g. 100Ω), computer, interface and software (e.g. CMA Coach6), current sensor, voltage sensor (if computer with interface is not available, ammeter and voltmeter can be used)

Suggestions for use:

In this activity students learn about the battery and its properties that influence its use.

***Before starting this activity** students are already introduced Ohm's Law, the concept of energy and power dissipated in the resistor. They understand the concept of electromotive force (in terms of work or energy) and internal resistance of the emf device. Firstly they are introduced that the energy produced by the emf device is transferred via resistive dissipation in the external part (load with the total resistance R) and internal part of the circuit (with internal resistance R_i):*

$$U_e Q = UQ + U_i Q$$

$$U_e I^2 t = RI^2 t + R_i I^2 t$$

Hence the voltage across the external part of the circuit (i.e. the terminal voltage) can be expressed as $U = U_e - R_i I$.

The theoretical background introduction is followed up by four small activities. To carry them out, divide the class into small groups of 2-3 and hand out Classroom Material: Battery and its properties. Each group of students can investigate the behaviour of different battery and finally the results can be compared and discussed within a class discussion.

In order to gain expected results the battery used in the experiment should have quite a large internal resistance (significantly larger than that of the current probe and the connections) so the minimum external resistance can be set to lower value than the battery internal resistance itself. The old already used zinc-carbon 4,5V battery works well since as a result of aging its internal resistance increases significantly with still satisfying value of emf.

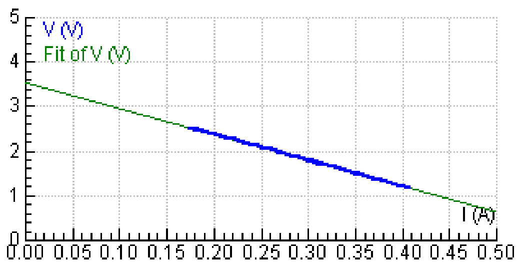


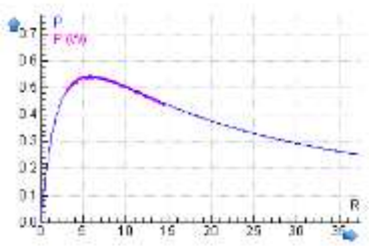
Fig. Experimental results of U related to I

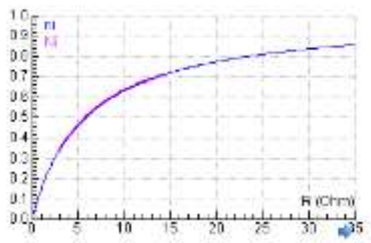
***In the first activity** students explore the behaviour of real battery in a dc circuit measuring the voltage between its terminals in relation to the current through the circuit. Using current and voltage sensor they record the voltage-current relationship and they interpret the diagram. Students learn that the terminal voltage of real emf device is always less than the emf because there is an internal resistance r. Ideal emf device has a zero internal resistance. They understand that the internal resistance of the power source influences its current-carrying capability. The activity is carried out in a guided discovery mode.*

***In the following two activities** they investigate the power transfer from the battery to the load and its efficiency in relation to the load resistance. They carry out **guided inquiry** in* order to discover the condition for the maximum power transfer and maximum efficiency.

The connection with the industry can be stressed by giving examples in which situations the maximum power transfer or maximum power transfer efficiency is used. The efficiency of power transfer from the source to the load increases as the load resistance increases. However, the maximum power transfer is achieved when the load resistance matches the internal resistance of the source, while the efficiency of power transfer is only 50%. The problem of a desire for both high efficiency and maximum power transfer is resolved by a compromise between maximum power transfer and high efficiency. Where the amounts of power involved are large and the efficiency is important, the load resistance is made large relative to the source resistance so that the losses are kept small and high efficiency is achieved in this case (batteries, power supplies, power plants). Where the problem of matching a source to a load is important, as in communications circuits (amplifiers, radio receivers or transmitters), a strong signal may by more important than a high percentage of efficiency. The efficiency in this case is only 50%, however the power transfer would be the maximum which the source is capable to supply.

***In the last activity** designed as a **bounded inquiry** in addition to the results gained by measuring students can create simple models on the phenomena investigated experimentally in the previous activities. Based on theoretical knowledge about the processes the students build the models of terminal voltage related to current flowing through the circuit, power transfer and power transfer efficiency related to the load resistance. Hence they compare the model with the experimental data looking for the data that best fit the experimental results.*






```
R=R+dR                  R=0
P=R*(Ue/(R+Ri))^2       dR=0.1
ni=R/(R+Ri)             Ue=3.54
                        Ri=5.8
```

Fig. Model vs. experimental data for a battery (U_e=3,54V, R_i=5,8Ω)

Possible questions:

- *Is the voltage across the power source terminals constant? Does it change with different load (current)?*
- *How is the voltage across the power source terminals influenced by the current flowing through the circuit?*
- *What is the main reason the voltage across the power source terminals is not constant?*
- *Is there any difference between e.g. zinc-carbon battery and an alkaline battery of the same emf?*
- *What is the power transfer to the load influenced by?*
- *Under what condition is the maximum power transfer to the load?*
- *What is the power transfer efficiency under the condition of maximum power transfer?*
- *Under what condition is the maximum power transfer efficiency reached?*
- *What is the main goal: to achieve the maximum power transfer or maximum power transfer efficiency?*

12. Activity Batteries in series and in parallel

Learning aims:

- *Understanding what is the purpose of batteries in series and how the series connection of batteries influences its characteristics*
- *Understanding what is the purpose of batteries in parallel and how the parallel connection of batteries influences its characteristics*

Materials:

Two (or more) batteries (e.g. 4,5V zinc-carbon battery), leads, resistor with adjustable resistance (e.g. 100Ω), computer, interface and software (e.g. CMA Coach6), current sensor, voltage sensor (if computer with interface is not available, ammeter and voltmeter can be used)

Suggestions for use:

In this activity students investigate the behaviour of batteries connected in series and in parallel in order to find out the purpose of these connections. They should be already familiar with the battery characteristics in terms of emf and internal resistance as well as with the series and parallel connection of resistors.

Divide the class into small groups of 2-3 and hand out Classroom Material: Battery in series and in parallel. The activity can be carried out in a ***bounded inquiry*** *mode. They can investigate the connection of identical or different batteries. Students plan the experimental procedure on their own and draw conclusions about the emf and internal resistance of a battery that is equivalent to series or parallel connections. They can investigate the power supplied to the load.*

Linear fits to terminal voltage vs. current allow students to extract values for emf and internal resistance and compare the calculated maximum power and the load resistance at which it occurs with the experimental data.

Possible questions:

- *How does the emf and internal resistance change if batteries are connected in series (parallel)?*
- *Discuss the connection of two identical and two different batteries.*
- *How to connect two batteries for maximum power transfer to the load?*

13. Activity How electric eel kills its prey

Learning aims:

- *Applying the knowledge about the properties of batteries connected in series/parallel in a real life situation*
- *Understanding the effects of electricity on a living organism*

Materials:

Text about the electric eel

Internet resources on how the electric eel creates electricity

Suggestions for use:

In this activity students should apply the previously gained knowledge in a real life situation of the animal world. Students study the text or use other internet resources about the electric eel. On the basis of it they can prepare a short presentation analyzing and explaining the fact that the electric eel can manage to produce a current in order to kill its prey without shocking itself. The interdisciplinary physics-biology approach can be enhanced by looking up information about the anatomy and physiology of electric eel (electric ray, electric catfish, etc.) and its organs producing electricity.

The activity can be carried out in a ***bounded inquiry*** *mode, e.g. as a home assignment. Students in groups or individually search information in order to present and discuss it in front of the class.*

Possible questions:

- *How can the electric eel manage to produce a current that large without shocking itself?*
- *What are the emf devices of the electric eel? How are they connected? Draw a sketch of its emf devices.*
- *What is the typical voltage produced by the electric eel?*
- *Explain why the eel kills its prey and does not hurt itself.*
- *What other animals prey the same way?*

14. Activity How much energy supplies a battery?

Learning aims:

- *Understanding that battery stores energy that is consumed by load*
- *Understanding how much charge and energy is supplied by a battery measuring current and voltage in a circuit.*
- *Understanding the properties of good battery in terms of life and economy*
- *Understanding what parameters producers take into account in order to build a battery appropriate for its application.*

Materials:

- *Batteries of the same size (e.g., AAA, AA, C, D) and different producers, connecting leads, computer, interface and software (e.g. CMA Coach6), voltage sensor (not necessarily), current sensor (if current sensor is not available, the resistor of known value R_A is recommended, e.g. $R_A=1\Omega$, in order to measure current)*

Suggestions for use:

The activity is aimed at understanding the battery properties in terms of energy it can supply to the circuit and what battery is considered to be good. During one lesson students set several measuring spots depending on how many batteries are going to be measured. They can use the same emf value batteries from different producers (non chargeable and chargeable, eventually). With the help of computer and sensors they measure current and voltage across the external load during battery discharging. Since the measurement can last up to 24 hours, it is recommended to start the measurement during one lesson and the next day to save the results. Then, students working in groups of 2-3 analyze the results.

Each group analyzes one of the measured batteries. Firstly, they determine battery capacity from the area under current-time graph. Then they analyze the power delivered to the external part of the circuit and hence they count the energy amount delivered to the circuit by determining the area under power vs. time graph. Finally, the groups compare their results for batteries of different producers in term of energy delivered to the load and they draw conclusions.

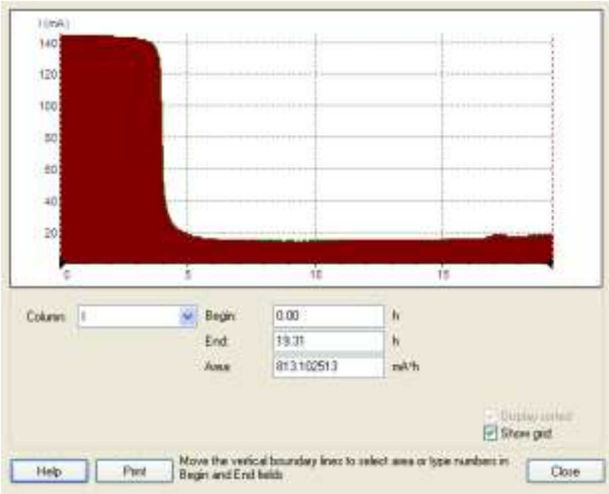


Fig. Battery capacity as an area under the current-time diagram.

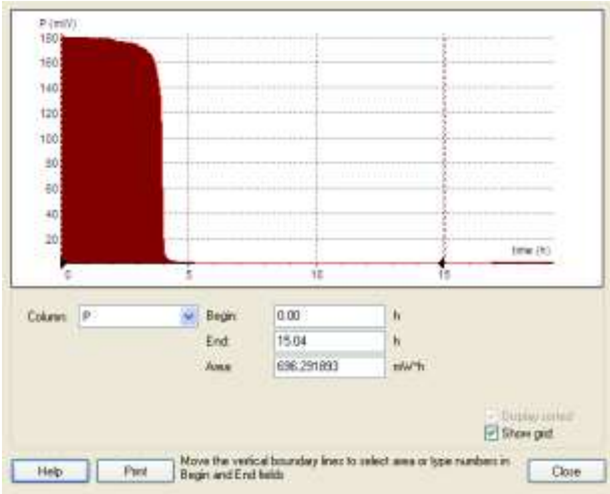


Fig. Energy stored in battery as an area under the power-time diagram.

*Measurement is done in a **guided inquiry** mode according to the instructions in the worksheet. Considering the students level of understanding, teacher can decide about the **bounded inquiry** mode.*

This activity offers a lot of industrial applications. They include the knowledge about other properties of the battery that are important for the consumer (chargeable, non-chargeable, voltage, current, energy supply, life, economy, price, weight, self-discharging of batteries, memory effects of chargeable batteries).

*The activity can be followed by an **open inquiry** assignment aimed at formulating some other research questions considering the properties of batteries, e.g. the self discharge, the effect of temperature on the battery performance, the memory effect, battery performance when the operation is interrupted several times (the effect on the terminal voltage and current), etc. Students design an experiment in order to answer the research question.*

Possible questions and research questions:

- *What energy is stored in a battery?*
- *How much charge is stored in a battery?*
- *What is the energy delivered into the circuit during the battery discharging?*
- *What parameters should be taken into account when you buy a battery for a certain purpose?*

Research questions can include:

- *What do we mean by self discharge, memory effect?*
- *What is the influence of temperature on the battery performance?*
- *How does the battery work when its operation is interrupted several times?*

15. Activity Batteries and their reasonable use

Learning aims:

- *Understanding the industrial and environmental aspects of batteries.*
- *Understanding the basic principles and properties of batteries to learn about the applications of batteries in everyday life regarding their purpose of use.*
- *Understanding the environmental aspects of batteries (disposal and recycling).*

Materials:

- *Internet resources, available printed resources*

Suggestions for use:

When understanding the principles and properties of batteries, students can work on the industrial applications and environmental and ecological aspects of batteries. This activity is aimed at small home assignments meant as project work to search for information on a selected problem and prepare a short presentation for the class. The activity can be carried out as an ***open inquiry*** *assignment. Student working in groups can formulate their own problem to solve. They use internet resource and other available printed resources to search relevant information.*

Possible research questions:

Possible assignments to carry out an ***open inquiry*** *on industrial and environmental aspects of batteries can include:*

- *Look for information about non-rechargeable batteries that are available in stores. Find out what materials they consist of, what are the voltages produced and energy supplied and what they are mainly used for.*
- *Look for information about chargeable batteries, e.g. a car battery. Describe its properties and name the possible problems the user can come across with.*
- *Look for information about chargeable batteries that are available in stores. Find out what materials they consist of, what are the voltages produced and energy supplied and what they are mainly used for.*
- *Compare batteries of the same size and emf from different producers.*
- *Battery electric vehicle and its future perspective.*
- *What rules should people follow in regard to batteries disposal and recycling (where is a battery recycling place close to your school?).*
- *What are the environmental hazards of batteries?*

16. **Activity Other alternative electrical sources**
Learning aims:
• *Introduce other electrochemical sources, such like a fuel cell* • *Introduce a photovoltaic cell*
Materials:
Internet sources, other sources about the fuel cell and a photovoltaic cell
Suggestions for use:
*This activity can be carried out as a **bounded inquiry**. Students are given a task to prepare a presentation on the alternative electrical sources, like fuel cell and photovoltaic cell. They are expected to prepare a presentation for their peers. Some of the resources can include:* http://en.wikipedia.org/wiki/Photovoltaics#Solar_cells http://en.wikipedia.org/wiki/Fuel_cell
Possible questions:
• *How does photovoltaic cell work?* • *What is the photovoltaic cell used for?* • *How does the fuel cell work?* • *What are the applications of the cells?*

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WP3 | Direct Current Electricity Unit

European Science and Technology in Action Building Links with Industry, Schools and Home

Work Package 3
Direct current electricity
B – Classroom Materials

Lead authors: **Zuzana Jeskova et al. (UPJS)**

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Total Number of Pages: 55

1. Worksheet: Electric current, battery and bulb

Activity 1-1 How torch works

The torch is a very simple electric circuit. Try to find out how it works, build up your own electric circuit and try to design a simple electric device.

1. Dismantle the torch and examine its components. What are they?

2. Draw a circuit diagram for the torch. Mark the current direction.

3. Label each torch component and describe its function.

4. Check the material of the torch case. What is it made of? Is it a part of the circuit?

5. Put the torch back to its initial shape.

6. Build your own simple electric circuit that makes the bulb light up. Check the bulb parameters first. Sketch the circuit diagram.

Activity 1-2 Construct a simple electric device

Now you know how to construct a simple electric circuit that lights up a bulb. Now try to design a simple electric device. You can use extra switches, wires and bulbs. You can use these materials:

- Three bulbs (e.g. 4,5V/0,3A), zinc-carbon battery (4,5V), leads, one-way (single-pole-single-throw) switch, two-way (single-pole-double-throw) switch, double-pole-double-throw switch

Invent and construct the electric circuits according to the description. In order to understand how the more complicated switches work, look up the information at http://en.wikipedia.org/wiki/Switch

1. Christmas tree lights: You want to light up your Christmas tree with three bulbs. What happens if one of the bulbs fails? Connect them the way that if one of the bulbs fails, the other two are still lit. Sketch the circuit diagram.

2. Lighting a tunnel: A person walking through the tunnel turns a lamp in the first half of it and then he turns a second lamp for the second half of the tunnel and the first one is turned off. Connect the two bulbs the way it works according to the description. Sketch the circuit diagram.

3. Entry and exit light switches: There is a lamp in a tunnel. Light switches are at both tunnel entrances. Either switch turns the light in the tunnel on and off. Connect the circuit the way it works according to the description. Sketch the circuit diagram.

2. Worksheet: What material conducts electric current?

In this activity you have to design and carry out an experiment to examine different materials (wires of different materials, pencil lead, match, piece of plastic, distilled water, tap (salty, sweet) water, glass, porcelain, china plate with metal strip, etc.) and their conductivity. Use a bulb as an indicator of current.

1. Draw a circuit diagram in order to investigate the ability of different materials to conduct electric current.

2. Fill in the table according to your observation. Tick into the appropriate box.

Material	**Bulb brightness** **bright** → **dim**				

3. Which material is the best conductor?

4. Which material is the worst conductor?

5. Now connect whatever material you have to make a circuit to light up the bulb. Try to make the longest circuit!

3. Worksheet: How is it connected inside the black box?

1. Using the materials on the table construct a simple electric circuit. Write down which elements you choose.

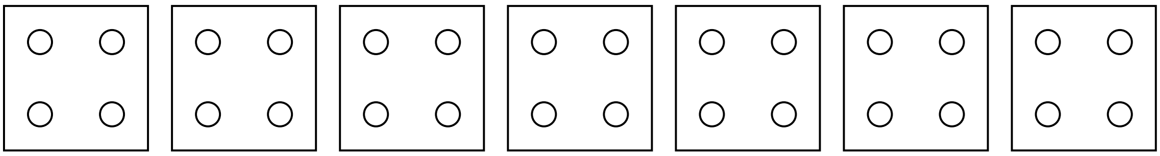
2. Draw the symbols of the selected circuit elements.

3. Draw a circuit diagram of your designed electric circuit.

INVESTIGATION

In front of you there are several black boxes – each of them with four outputs. Try to investigate and find out how these outputs are connected inside the box. They can be mutually interconnected by a lead or a resistor. Determine the type of connection in each case. You can use materials that are on the table in front of you.

- How can the outputs be interconnected inside the box? Predict the possible connections that are different from each other.

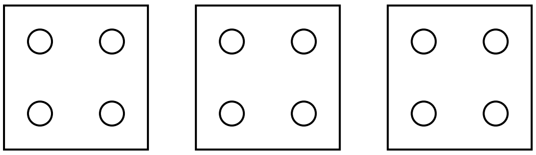


- Think about an experimental procedure in order to find out the black box content. Write it down step by step.

- Draw the electric circuit diagram which you use to reveal the box's content.

- In what case the bulb connected in the circuit with black box shines or does not shine?

- Connect the circuit that you designed to be investigated and carry out the experiment.
  Draw the box's internal connection into the pictures below.
  .



- After finishing experimentation and drawing the corresponding internal structure check your answers with your teacher.
  How many black boxes were revealed correctly? What was the reason of the wrong answer?

4. Worksheet: Measuring current and voltage

In this activity you are going to learn how to measure current and voltage in simple electric circuit. Firstly, set up the simple electric circuit and connect the current and the voltage sensor as in the figure.

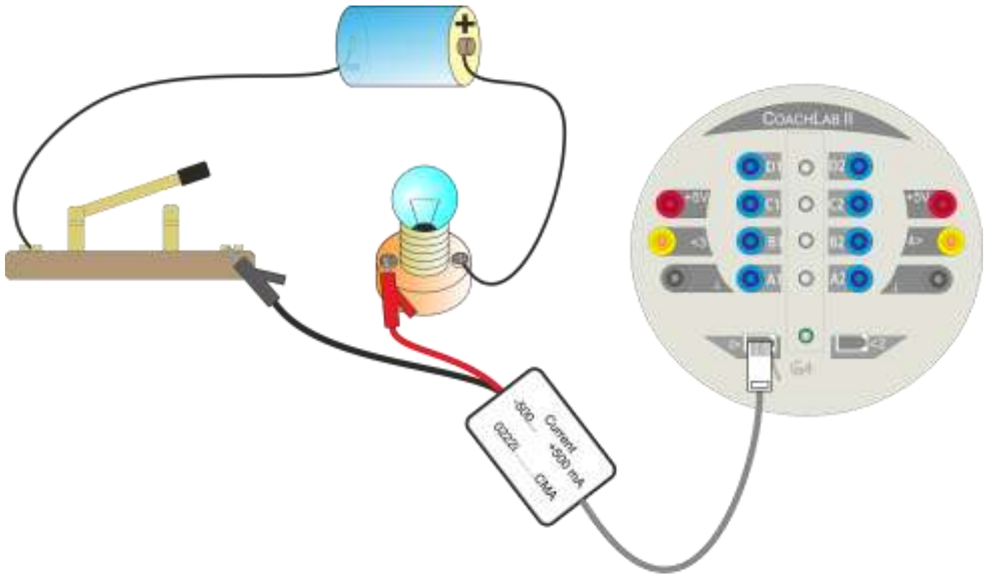


Fig. Simple electric circuit – battery, bulb, leads, switch, current sensor

1. Open the file "*Measuring current and voltage*". The amount of current is displayed digitally. Write down the current flowing through the circuit.

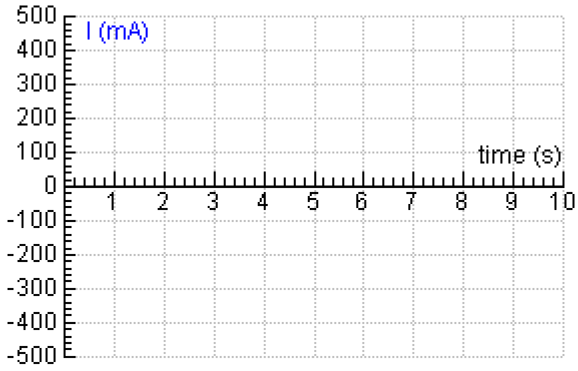
I_1 =

2. Now connect the current sensor from the other side of the bulb. Read its value and compare it with the previous reading.

I_2 =

3. What happens with the current value when you exchange the current sensor leads?

4. Connect the current sensor so that it displays positive values. Display the current vs. time diagram. Start measuring and try closing the switch for a few seconds and then opening it for a several seconds. Sketch your result.



5. Now disconnect the current sensor and set the circuit as in the figure but do not connect the voltage sensor yet.

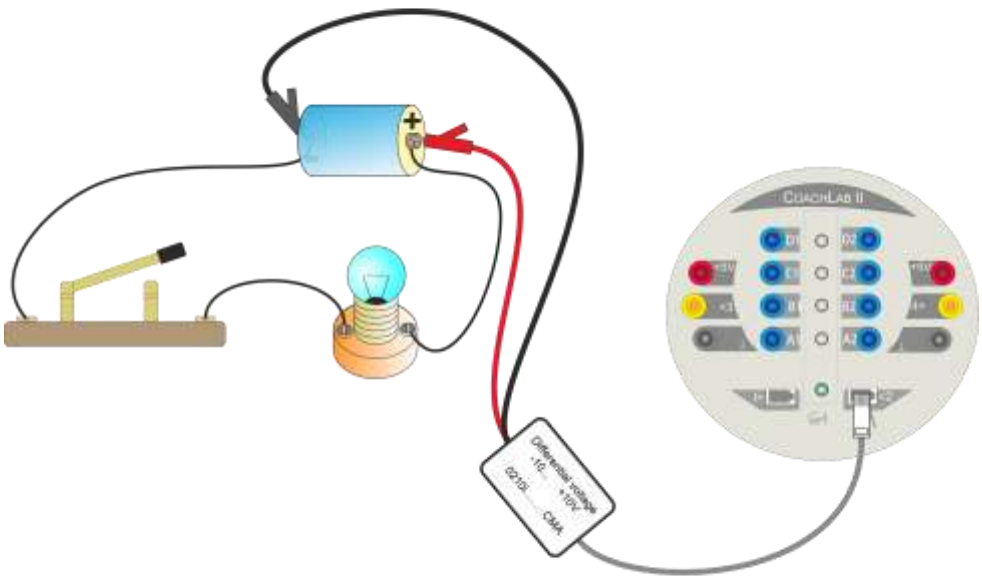


Fig. Simple electric circuit – battery, bulb, leads, switch, voltage sensor across the battery

6. Firstly, connect both clips of one voltage sensor together. Observe the reading. Next connect both clips to the same point in the circuit. Close the switch. Then connect both clips at the two ends of the same wire. Close the switch. Finally connect the voltage sensor clips to the battery as in the figure. Close the switch. Test your predictions.

	Prediction	***Result***
	U (V)	U (V)
Clips together		
Clips at the same point		
Clips at the two ends of the same wire		
Clips at the battery		

7. In the same circuit, how would you expect the voltage across the battery to compare to the voltage across the bulb with the switch open and closed? Test your predictions.

	Prediction		***Result***	
	$U_{battery}$ (V)	U_{bulb} (V)	$U_{battery}$ (V)	U_{bulb} (V)
Switch open	$U =$	$U =$	$U =$	$U =$
Switch closed	$U =$	$U =$	$U =$	$U =$

8. Explain the results. What is going on as the switch is closed and opened?

9. Now connect a voltage and a current sensor as in the figure so that you are measuring the voltage across the battery and current through the battery at the same time. Display current vs. time diagram and voltage vs. time diagram.

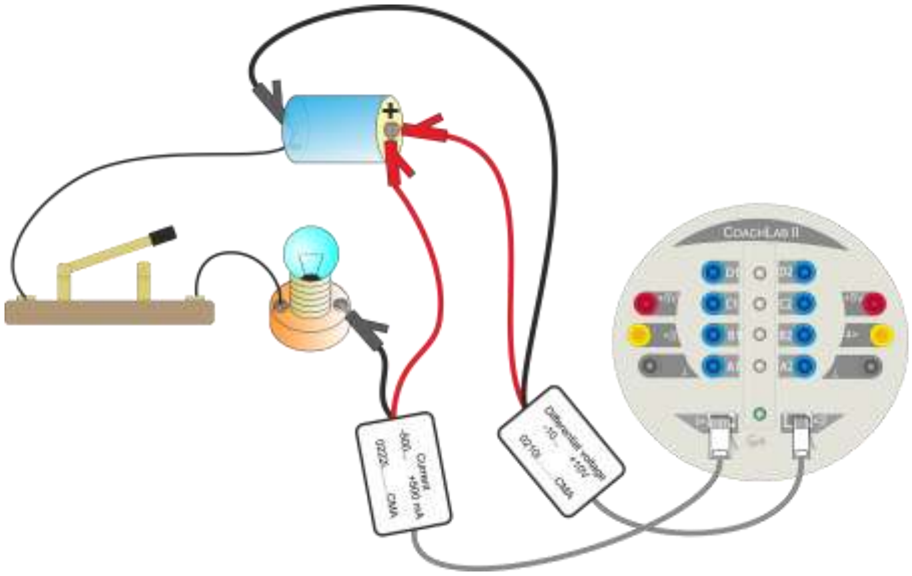
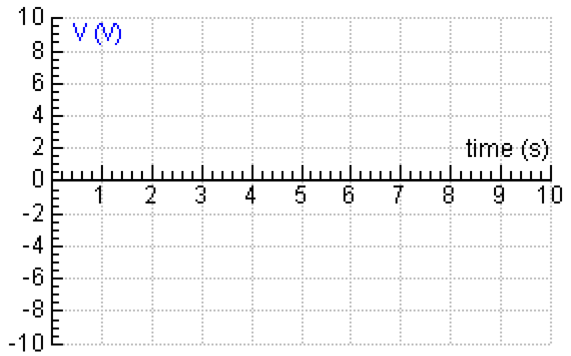
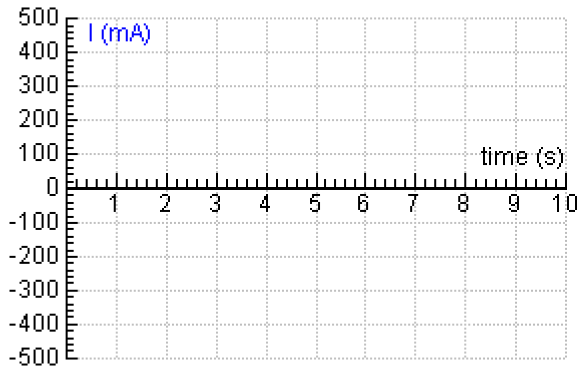


Fig. Simple electric circuit – battery, bulb, leads, switch, voltage sensor across the battery, current sensor next to the battery

10. Start measuring and open and close the switch several times. Sketch your graphs and write down the results.





	U_{battery} (V)	I (A)
Switch open		
Switch closed		

11. Explain your results. What happens to the current through the battery and the voltage across it when the switch is closed and open?

12. Now suppose you connect a second bulb in the circuit as shown in the figure. How do the readings change? Predict.

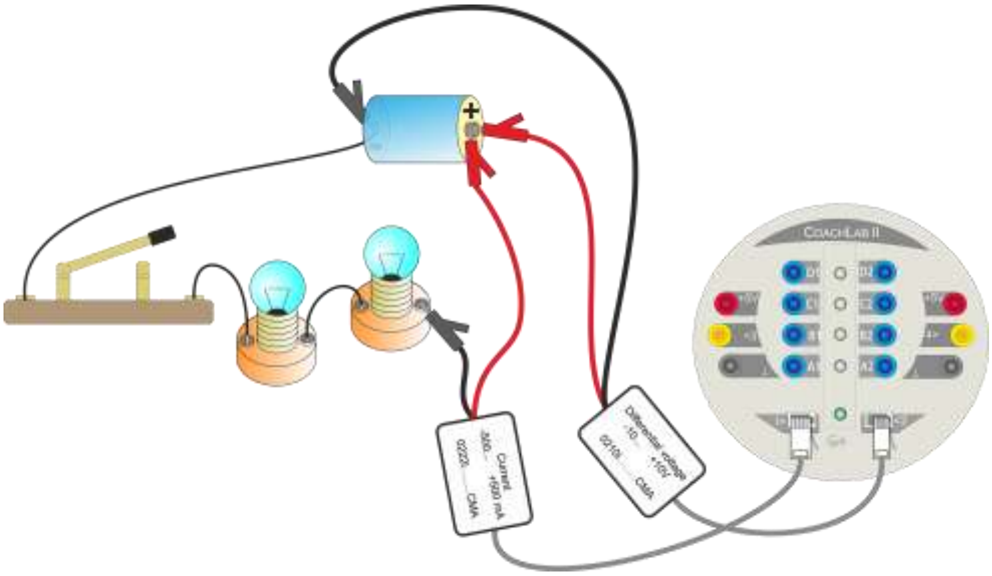


Fig. Simple electric circuit – battery, two bulbs, leads, switch, voltage sensor across the battery, current sensor next to the battery

13. Connect the circuit with two bulbs and test your prediction.

	Prediction		***Result***	
	U_{battery} (V)	I (A)	U_{battery} (V)	I (A)
Single bulb in a circuit				
Two bulbs in series				

14. Explain the results. Does the battery appear to be a source of constant current, constant voltage, or neither when different elements are added to a circuit?

5. Worksheet: Electric element in a dc circuit

Activity 5-1 Resistor and Ohm's law

In this activity you are going to use common electric component called resistor that is usually connected to a circuit to make current more difficult to flow. This property to resist the current is described by the physical quantity of ***resistance,*** marked *R*. Now you are going to investigate how the voltage across a resistor influences the current flowing through it and what role is played by its resistance.

1. Open the file "*Current-voltage relationship*". Set up a simple electric circuit with a resistor and connect the current and the voltage sensor as in the figure. In the experiment you will use a variable power supply in order to change the voltage across the resistor while watching the corresponding current through it.

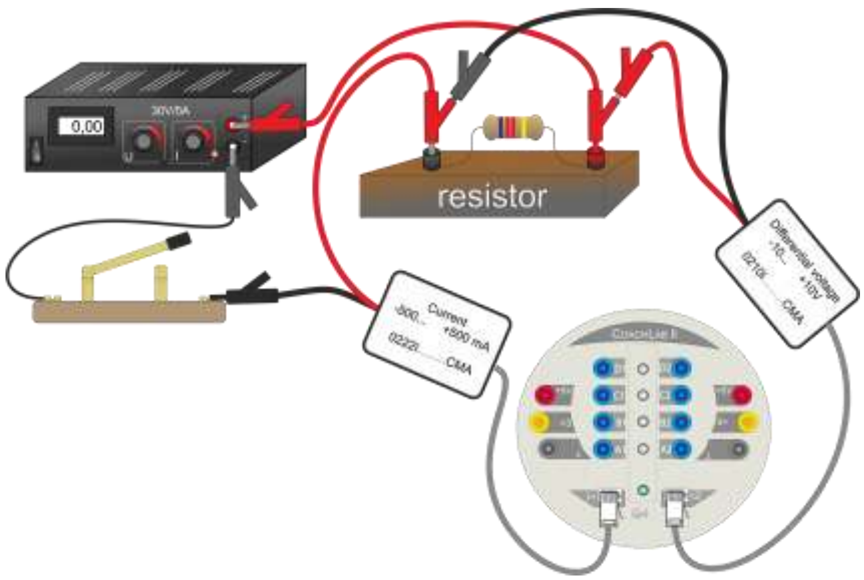
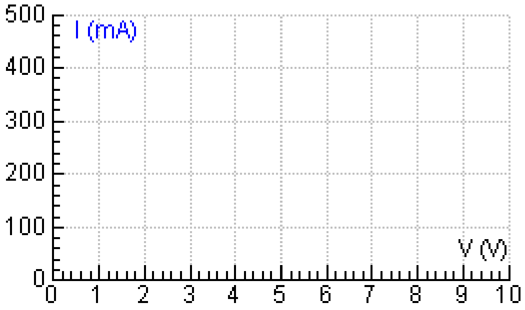
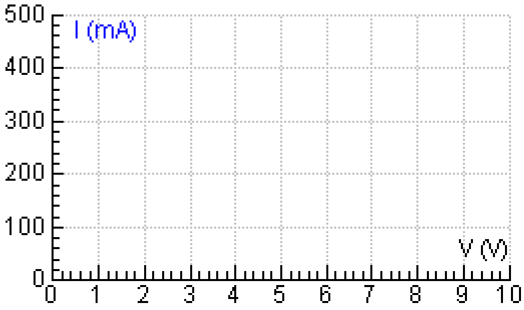


Fig. Simple electric circuit – power supply variable, resistor, current sensor and voltage sensor across the resistor

2. Do not start measuring yet. Imagine you turn the dial on the power supply and hence increase the voltage across the resistor. What happens with the current? Draw your prediction into the graph below.

Prediction ***Result***





3. Start measuring current and voltage. Turn the dial on the power supply slowly from 0V up to 10V within 10 seconds. Do not exceed the recommended maximum voltage. Compare your result with the prediction. Does it agree?

4. Fill in the table below for at least three voltage values. For each reading check the ratio between the voltage across the resistor and current.

	U (V)	*I(A)*	$\frac{U}{I}$ (V/A)
1.			
2.			
3.			
4.			

What is this ratio between the voltage and the current in each case?

5. Describe the result of your measurement. What is the mathematical relationship between the current flowing through the resistor and the voltage across it?

6. Try to fit the graph with the appropriate function. Use the fit routine in the software. Write down the function type and the value of its parameters.

f(x)= *a*=

7. Identify the physical meaning of the variables *x, y* in the function *y=f(x)*.

x = *y* =

8. The relationship that you have observed is known as ***Ohm's law***. In order to put the law into its normal form we have to define another physical quantity known as ***conductivity*** marked ***G***. The unit of the conductivity is the ***Siemens***, marked ***S***. Conductivity is defined as the slope of the graph (parameter *a*). Its inverted value is known as ***resistance*** marked ***R***. The unit of the resistance is the ***ohm***, marked ***Ω***, Try to define conductivity and resistance in terms of *U* and *I.*

   $G =$ $R =$

9. State the mathematical relationship between the current flowing through the resistor and the voltage across it using the quantities of *U, I and R (G, eventually)*.

   $I =$

   This formula is known as Ohm´s law. Circuit **elements** that **obey Ohm´s law** are said to be **ohmic**.

10. Based on your measurement, is the value of resistance constant or does it change as the current through the resistor changes?

11. What is the value of the resistance of your resistor? Use the appropriate parameter of the function used to fit your measurement. How does it agree with the value written on the label?

    $R_{\text{measured}} =$ $R_{\text{written}} =$

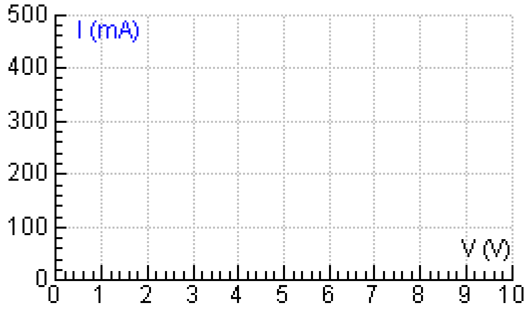
12. Note that resistors are manufactured such that their actual value is within a tolerance. For most resistors, the tolerance is 5% or 10%. Determine the tolerance of the measured resistor and calculate the range of values for it. Is the measured value within the tolerance?

    Tolerance in % = Range of values: $R_{\text{measured}} =$

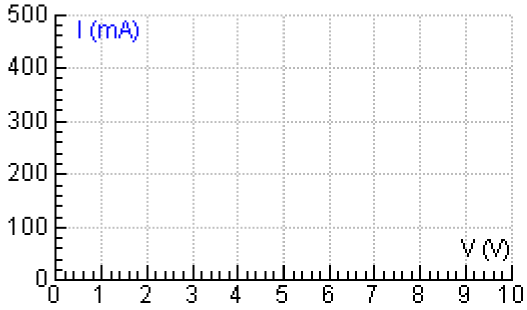
13. Repeat the measuring procedure for a resistor with higher resistance. Draw your prediction of current-voltage diagram first.

    First resistor *Second resistor with higher resistance*

Result from the previous measurement



Prediction



14. Describe the difference between *I-U* diagrams of two resistors with different resistance.

Activity 5-2 Light bulb and Ohm's law

In the activity 5-1 you have discovered that for a resistor the relationship between the current through the resistor and the voltage across it is proportional. In the following activity you are going to explore the same relationship for a bulb.

1. Open the file "*Current-voltage relationship*". Replace the resistor by the bulb as in figure.

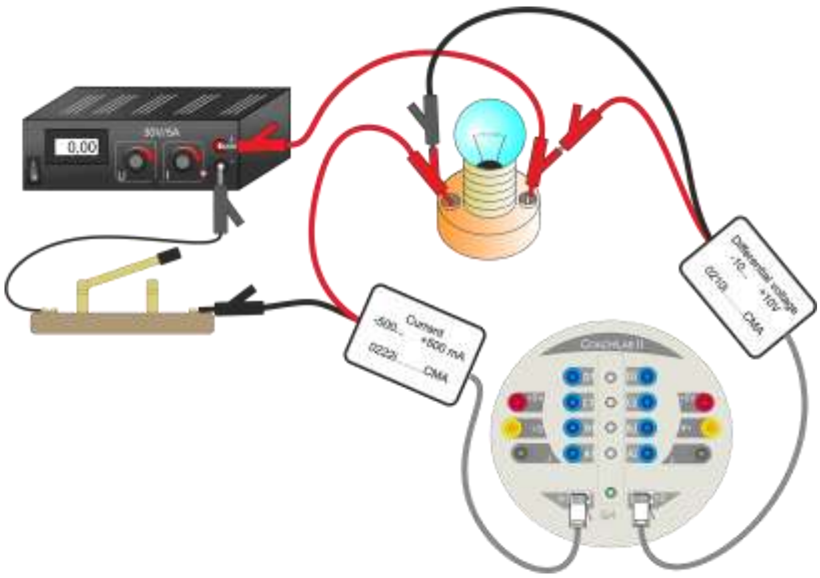
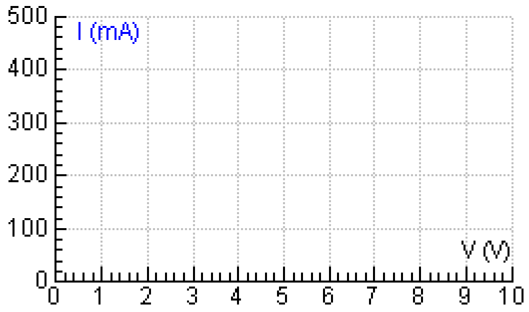


Fig. Simple electric circuit – power supply variable, bulb, current sensor and voltage sensor across the bulb

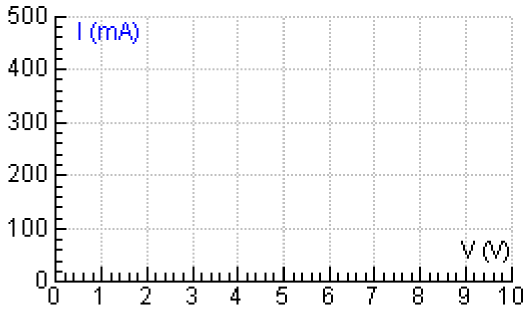
2. Do not start measuring yet. Imagine you turn the dial on the power supply and hence increase the voltage across the bulb. What happens to the brightness of the bulb?

3. What happens with the current? Draw your prediction of the *I-U* relationship into the graph below.

Prediction



Result



4. Start measuring current and voltage. Check your bulb parameters. Turn the dial on the power supply slowly from 0V up to the maximum voltage within 10 seconds. Do not exceed the recommended maximum voltage since it can burn out the bulb. Compare your result with the prediction. Does it agree?

5. Compare the result for the bulb to that for the resistor. Describe the differences.

6. Based on your measurement, is the value of resistance constant or does it change as the current through the bulb changes?

7. Find out the resistance of the bulb for at least three values of current flowing through it ($I_1 < I_2 < I_3$).

	I(A)	*U (V)*	$R=\frac{U}{I}$ (Ω)
1.			
2.			
3.			
4.			

8. How does the resistance change with increasing current?

9. Does your bulb follow Ohm's law? Is a bulb an ohmic circuit element? Explain.

Activity 5-3 Other electric elements in a dc circuit

You have already investigated the behaviour of a resistor and a bulb in a dc circuit. There are many other electric elements that can be parts of an electric circuit. Now you can extent your investigation exploring the behaviour of devices such as diodes.

1. Open the file "*Current-voltage relationship*". Replace the resistor by the diode but do not forget to place a limiting resistor in series to protect the diode from burning by high current (see fig.).

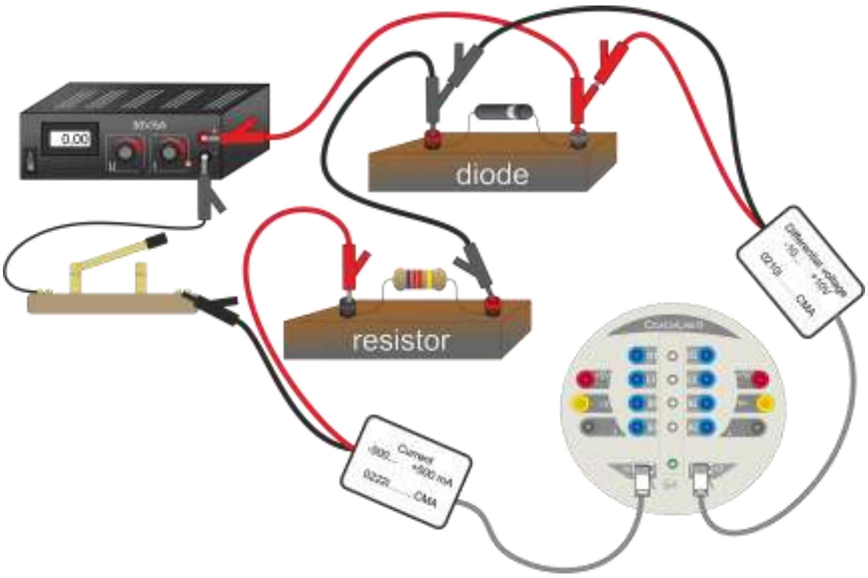
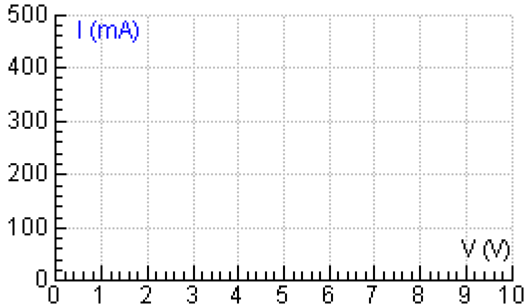
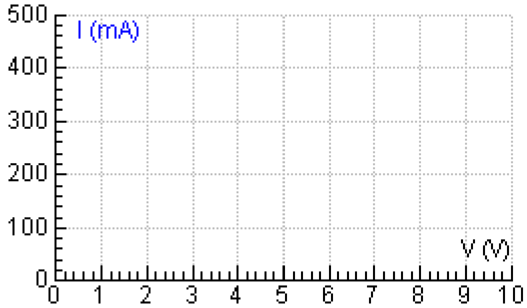


Fig. Simple electric circuit – power supply variable, diode, limiting resistor to protect the diode, current sensor and voltage sensor across the diode

2. Do not start measuring yet. Imagine you turn the dial on the power supply and hence increase the voltage across the diode. What happens with the current? Draw your prediction of the *I-U* relationship into the graph below.

Prediction ***Result***





3. Start measuring current and voltage. Check your diode parameters first. Turn the dial on the power supply slowly from 0V up to the maximum voltage within 10 seconds. Do not exceed the recommended maximum voltage since it can burn the diode. Now turn the dial back, reverse the leads of the diode and try again. What do you observe?

4. You have observed that diode behaves differently in response to different direction of current having a preferred current direction. Does a resistor or a bulb behave the same way?

5. Now place the diode into the position the current flows through the circuit. Start measuring current and voltage again. Compare your result with your prediction. Does it agree?

6. Compare the result for the diode to that for the resistor. Describe the differences.

7. Based on your measurement, is the value of resistance constant or does it change as the current through the diode changes?

8. Find out the resistance of the diode for at least three values of current flowing through it ($I_1 < I_2 < I_3$).

	I(A)	*U (V)*	$R=\frac{U}{I}$ (Ω)

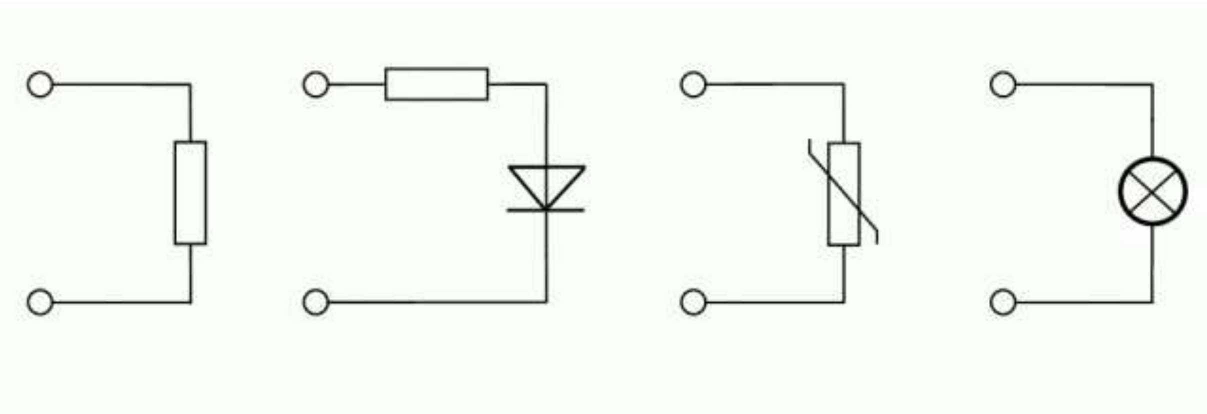
1.			
2.			
3.			
4.			

9. What can you conclude about the resistance of the diode?

10. Does your diode follow Ohm’s law? Is a diode an ohmic circuit element? Explain.

Activity 5-4 What electric element is hidden in the black box?

You have already investigated the behaviour of three elements – resistor, bulb and diode often used in electric circuits. Now you have four boxes available, three of them containing the already investigated elements (resistor, bulb and diode) and one of them has a new element inside. You are going to reveal the black box content using variable power supply, leads, switch and voltage and current sensor.



Design your experiment, plan the measuring procedure and draw conclusions.

6. Worksheet: Resistance and temperature (build your own thermometer)

You have already investigated the behaviour of three elements – resistor, bulb and diode often used in electric circuits. You have surely noticed that they behave differently when placed in a direct electric circuit. Try to sum up in what points these elements differ from each other. In terms of which physical quantity can we describe their differences?

Now you are going to investigate how temperature influences the resistance of an electric element. You will do measurement on different electric element placed in a direct electric circuit. Measuring the voltage across the element and the current through it you will calculate its resistance. You will change the element's temperature emerging it into the water whose temperature will be gradually increased with the help of a heater. You can also use results of measurements that have been carried out beforehand for analysis.

Activity 6-1: Metal conductor

1. Open the file "*Resistance and temperature*". Set up a simple electric circuit with a metal conductor and connect the current sensor and the voltmeter as in the figure. In the experiment you will use a variable power supply to set the appropriate voltage. You have to connect the temperature sensor, as well. Emerge the conductor into a water tank equipped with a heater and place the temperature sensor next to the conductor In order to measure its temperature.

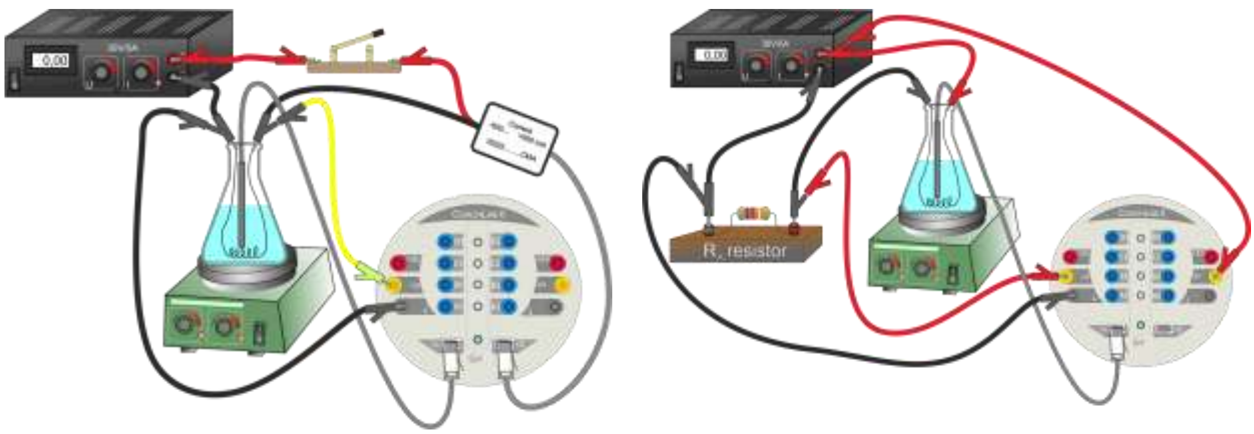
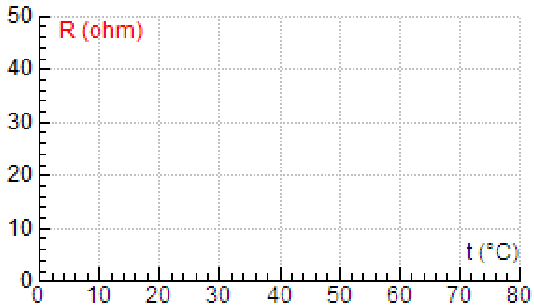
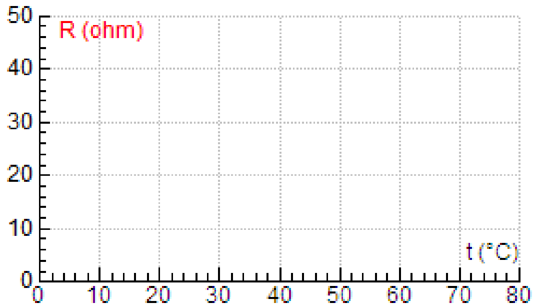


Fig. Simple electric circuit with a metal conductor emerged into a water tank with a heater

2. Set the voltage on a variable power supply on the appropriate value (e.g. 5V). Do not start measuring yet. Imagine you turn the heater and hence increase the temperature of the conductor. What happens with its resistance? Draw your prediction into the graph below.

Prediction ***Result***





3. Switch on the heater and set it so that you increase the temperature by approx. 60°C in 15 minutes. Start the measurement in which you measure the voltage across the conductor and the corresponding current. Stop the measuring procedure when the temperature reaches approx. 80°C. Disconnect the power supply.

4. Based on the measuring results of current and voltage create a resistance vs. temperature diagram. How do you calculate the conductor's resistance?

5. Compare your results with the prediction. Does it agree? How are the temperature and the corresponding metal conductor resistance related?

6. Find the best fit for your measurement data using the fitting tools of your software. What function type will you choose? Write it down together with the corresponding coefficients.

   f(x) = *a*= *b*=

7. Which physical quantity in our measurement corresponds to the independent variable x and the dependent variable *y=f(x)*?

   x = *f(x)* =

8. What could be a physical meaning of the coefficients *a, b*?

9. Does the resistance of the metal conductor increase significantly with the temperature? Which parameter tells you about that?

10. Draw conclusions.

Activity 6-2: Thermistor

1. Now you are going to measure the temperature dependence of the resistance for an element called thermistor. Open the file “*Resistance and temperature*”. Set up a simple electric circuit with a thermistor and connect the current sensor and the voltmeter as in the figure. In the experiment you will use a variable power supply to set the appropriate voltage. You have to connect the temperature sensor, as well. Emerge the thermistor into a water tank equipped with a heater and place the temperature sensor next to the thermistor In order to measure its temperature.

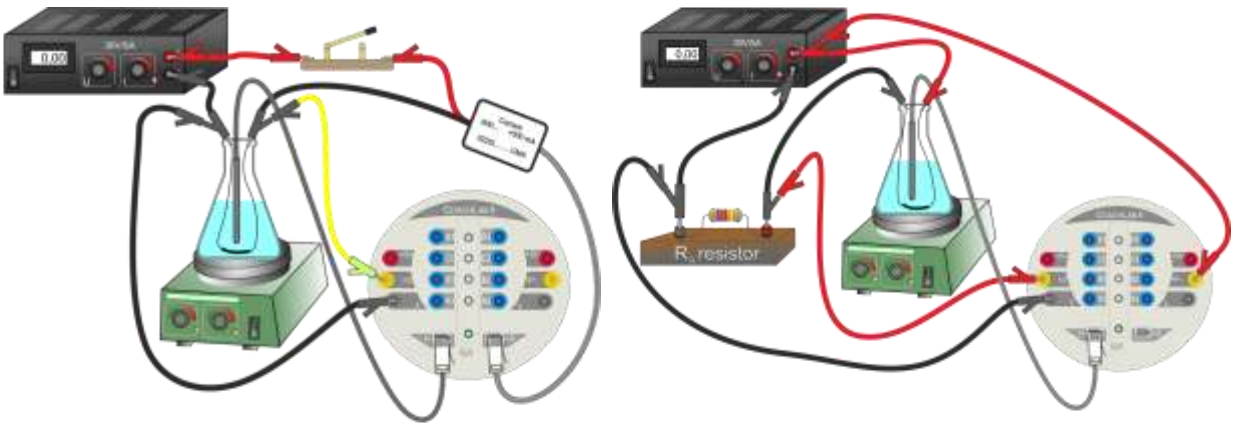
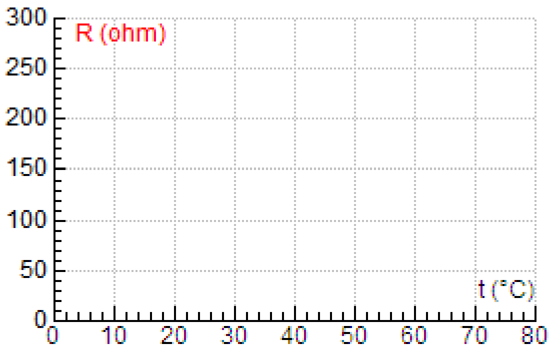


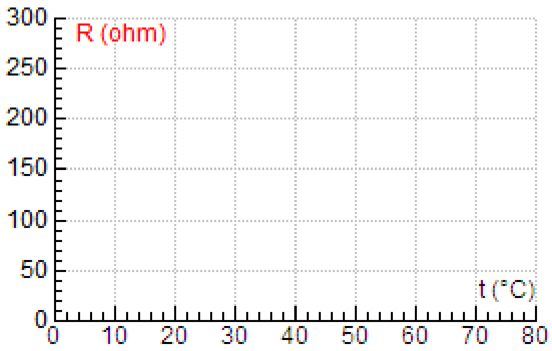
Fig. Simple electric circuit with a thermistor emerged into a water tank with a heater.

2. Set the voltage on a variable power supply on the appropriate value recommended by the producer (e.g. 10V). Do not start measuring yet. Imagine you turn the heater and hence increase the temperature of the thermistor. What happens with its resistance? Draw your prediction into the graph below.

Prediction



Result



3. Switch on the heater and set it so that you increase the temperature by approx. 60°C in 15 minutes. Start the measurement in which you measure the voltage across the thermistor and the corresponding current. Stop the measuring procedure when the temperature reaches approx. 80°C. Disconnect the power supply.

4. Based on the measuring results of current and voltage create a resistance vs. temperature diagram. How do you calculate the conductor's resistance?

5. Compare your results with the prediction. Does it agree? How are the temperature and the corresponding thermistor resistance related? Compare it with the result for a metal conductor.

6. You see that the thermistor´s resistance and its temperature are mutually connected. Each value of resistance corresponds to the certain value of temperature. As a result, knowing this relationship, if we know the resistance we can find the corresponding temperature. This fact enables to use thermistors as thermometer. Save your results that represent the thermistor calibration.

7. Emerge the thermistor into the water of unknown temperature. Determine its temperature with the help of thermistor. Measure its resistance and with the help of the resistance-temperature diagram find the temperature of water.

$R =$ $t =$

8. The relationship between the resistance and the temperature for the thermistor seems to be much more complicated than that of the metal conductor. Find the best fit for your measurement data using the fitting tools of your software. Is there any kind of a function type that fit well?

9. This relationship is not easy to fit with common function types since it follows much more complicated function. For those who are already familiar with exponential function we can reveal that the relationship between resistance and the temperature behaves approx. according to the following function:

   $$R = A.e^{\frac{B}{T}},$$

   where the value *e* is Euler number and *R, A, T, B* mean: *R* - resistance, *T* - thermodynamic temperature, *A, B* constant values typical for each thermistor. Apply natural logarithm on both sides of the equation. What will you get?

10. What is the relationship between the values of *lnR* and *1/T*?

11. Create a new diagram of *lnR* vs. *1/T*. Find the best fit for these data using the fitting tools of your software. What function type will you choose? Write it down together with the corresponding coefficients.

    f(x) = *a=* *b=*

11. Which physical quantity in your data corresponds to the independent variable x and the dependent variable *y=f(x)*?

    x = *f(x) =*

12. What could be a meaning of the coefficients *a, b* in the function that you used for fitting?

    a= *b=*

13. What is the value *of* $\ln A$ and A, B constants of the thermistor?

$\ln A$ = A= B=

14. Write down the equation expressing the resistance-temperature relationship for your thermistor using the known constants A, B.

15. Now, from this equation express the temperature in degrees Celsius.

16. Create a temperature-time diagram expressing temperature in terms of thermistor´s resistance.

17. What you have created is a thermometer based on resistance-temperature dependence. The same principle is used in your temperature sensor. Now measure the temperature with the help of the thermistor as well as with the help of the temperature sensor. Compare the results.

t_{sensor} =

$t_{\text{thermistor}}$ =

18. Draw conclusions.

7. Worksheet: Model of electric circuit (why is it more or less resistive)

In this activity you are going to analyze how a simple direct electric circuit works and what happens when we connect several resistors into the circuit. You are going to work with your teacher and your peers in order to find out the answers to the following questions. Write down the final explanations.

1. When is the object electric?

2. What is an electric power source?

3. How does electric current flow through a conductor?

4. How does electric current flow through a resistor?

5. Why is the voltage on the current-carrying resistor?

-
-
-

6. Model of the electric circuit.

   Try to explain similarities between the stiff ring with a drive and brake and an electric circuit.

Stiff ring	**Electric circuit**

7. Simulation of current and voltage in a circuit.

   Build up your own simple electric circuit using the interactive applet.

   Explain the surface charges distribution in your circuit.

8. When do electrons pull together (resistors in series)?

-
-
-
-

- Build up your own electric circuit with resistors in series using interactive applet.
- Explain surface charges distribution in your circuit.

9. How is the current divided in a junction?

-
-

- Build up your own electric circuit with resistors in parallel using interactive applet.
- Explain surface charges distribution in your circuit.

-

10. What is the resistance of two resistors connected in parallel?

-
-
-
-
-

8. Worksheet: Human body and Ohm´s Law

In simple terms the human body can be considered as a circuit through which an applied potential difference will drive a current. The body acts as a resistor with resistance R depending on the path the current flows in the body. As we know from Ohm's Law $I = \frac{U}{R}$, the current flowing will depend on the voltage applied as well as on the resistance of the current path. For example, if you touch a high voltage wire in a cable, current passing from the wire through you to the ground can cause an electric shock. Your body is controlled by electrical nerve impulses, so electric currents can disrupt normal bodily functions. It is the current, not the voltage that determines the severity of the electric shock. The current travelling through a body can damage your organs, with the heart, brain and spinal cord being particularly susceptible.

Resistance of the human body

The human body composed largely of water has very low resistance. That means that your blood and fluids with high amount of conductive chemicals are good conductors with a resistance of about 200 Ω. However, current must first pass through the skin that has very high resistance, the value depending on its nature, on the possible presence of water, and on whether it has become burned. Thus, most of the resistance to the passage of current through the human body is at the points of entry and exit through the skin. A person with naturally hard and dry skin can have a resistance of 500 000 Ω while soft and sweaty palms may have resistance 10 to 50 times lower. The skin resistance becomes very low if it has been burned because of the presence of conducting particles of carbon or if it has been wounded because of the presence of blood or much thinner skin. A person standing in saltwater has a skin resistance of only 500 Ω.□

When current travels through your body it must pass basically through three series resistances: your skin (your fingers), internal part of your body, and your skin again (your toes). Adding up the resistance of your moist fingers (e.g. 20000 Ω), your body fluids (e.g. 200 Ω) and your toes (e.g. 30 000 Ω) under the voltage of 230V you get a current of approx. 0,005A that passes through your body.

How much current is harmful?

Individual body chemistry has a significant impact on how electric current affects on individual. Also the alternating current is more dangerous than the direct one. There are few reliable figures for shock current effects because they differ from person to person and for a particular person with time and also depend on the current path. For example, the shock current of 500mA may have no lasting ill effects if its duration is less than 20ms, but 50mA for 10s could well prove to be fatal. The most dangerous results are ventricular fibrillation (where heart beat sequence is disrupted) and compression of the chest, resulting in a failure to breathe.
Rough limits say:

- Current **greater than 1mA** causes discomfort.

- **Above 16mA** you loose control of your muscles and they undergo contractions.
- **Between 25mA and 100mA**, you have difficulty breathing and eventually respiration stops.
- **Between 100mA and 200mA**, your heart stops pumping and undergoes contractions called ventricular fibrillation.
- **Above 200mA** irreversible heart damage occurs.

How to increase safety?

The best protection against shock from a live circuit is resistance, and resistance can be added to the body through the use of insulated tools, gloves, boots, and other gear. Wearing insulating shoes increases the total resistance. Rubber shoes have a resistance of around 20 MΩ, whereas dry leather soles provide a resistance of 100 - 500 kΩ. Wet leather soles only provide 5 - 20 kΩ.
In figure is a simplified representation of the shock path through the body, with an equivalent circuit which indicates the components of the resistance concerned.

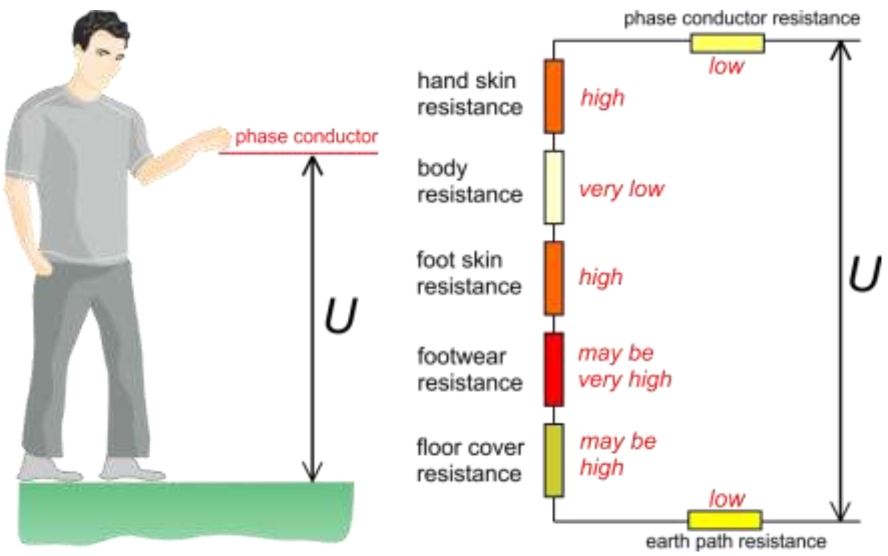


Fig. Path of the electric shock current (picture from http://www.tlc-direct.co.uk/Book/3.4.2.htm)

Safety is one of the reasons electrical wires are usually covered with plastic or rubber insulation: to vastly increase the amount of resistance between the conductor and whoever or whatever might contact it. Unfortunately, it would be prohibitively expensive to enclose power line conductors in sufficient insulation to provide safety in case of accidental contact, so safety is maintained by keeping those lines far enough out of reach so that no one can accidentally touch them.

Deliberate uses of electric current in human body

Medical uses
Electric shock is also used as a medical therapy under the controlled conditions.
Bioelectrical impedance analysis
This simple device actually determines the electrical impedance, or opposition to the flow of an electric current through body tissues which can then be used to calculate an estimate of total body water and hence the body fat.

Lie detector

It measures skin resistance along with other physiological factors

Resources:

http://c21.phas.ubc.ca/article/electric-shock

http://www.tlc-direct.co.uk/Book/3.4.2.htm

http://en.wikipedia.org/wiki/Electric_shock#Body_resistance

http://www.allaboutcircuits.com/vol_1/chpt_3/4.html

9. Worksheet: Intriguing behaviour of bulbs

If you connect two identical bulbs (e.g. 6V/0,3A) in series in a dc circuit, they shine equally brightly. If you connect two identical bulbs (e.g. 6V/0,05A) in series in a dc circuit, they also shine equally brightly. When we combine two different ones, then one bulb lights up and the other does not (or very faintly). Do investigation and explain.

Activity 9-1: Two identical bulbs in series

1. Imagine that you first connect an individual bulb to a dc power supply. Then you connect two identical bulbs in series to the same power supply. Compare their brightness to when they were alone in the circuit. Choose one of the following answers:
    a) The bulb brightness **decreases**
    b) The bulb brightness **increases**
    c) The bulb brightness **stays the same**

First predict and then check experimentally.

Prediction	***Result***

2. Now check your prediction experimentally. Sketch the circuit diagram first.

One bulb in a dc circuit	***Two bulbs in series in a dc circuit***

3. Explain your observation and results.

4. Design a measurement (with the help of sensors) in order to explain your findings. You have to realize that for the bulb brightness the power (energy) dissipated in the bulb is crucial. **What physical quantities** are you going to measure in order to determine the power dissipated in each of the bulbs?

5. Open the file "*Bulbs in series*". Set up the circuit with one single bulb. Connect the current and the voltage sensor as in the figure. Set the power supply to the bulb's voltage.

One bulb in a dc circuit

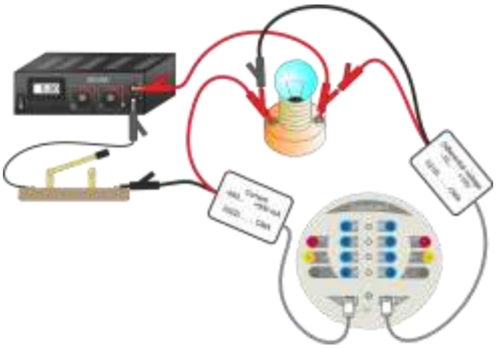


Fig. Simple electric circuit with one bulb

Two bulbs in series in a dc circuit

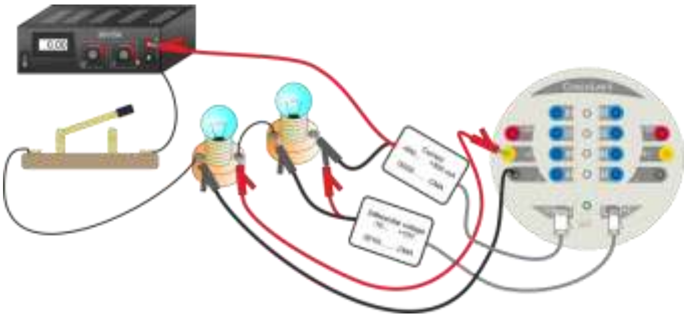
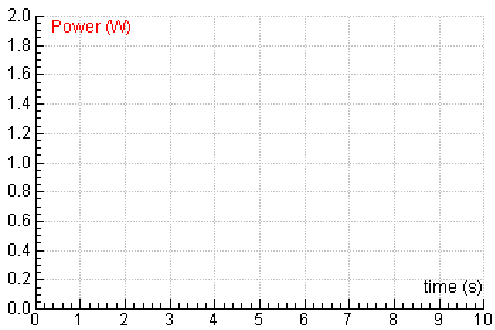


Fig. Simple electric circuit with two bulbs

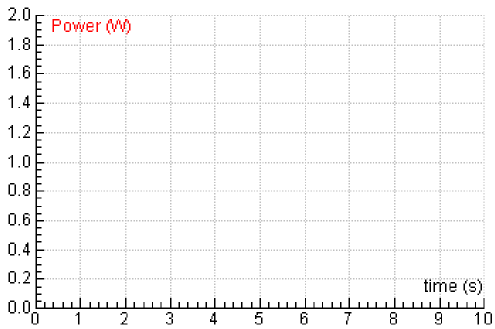
6. Do not start the measurement yet. What happens with the power delivered to the single bulb and to the bulbs connected in series to the same power supply? Draw your prediction.

Prediction

Single bulb



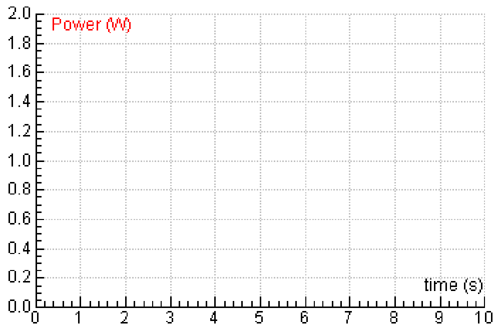
Bulb in series



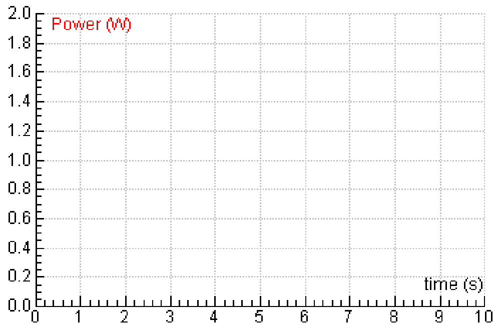
7. Start measuring current and voltage across the single bulb. Create the power diagram. Compare your result to your prediction. Does it agree?

Result

Single bulb



Bulb in series



8. Do the same with series connection of two identical bulbs. Check your prediction. Does it agree?

9. Draw conclusions.

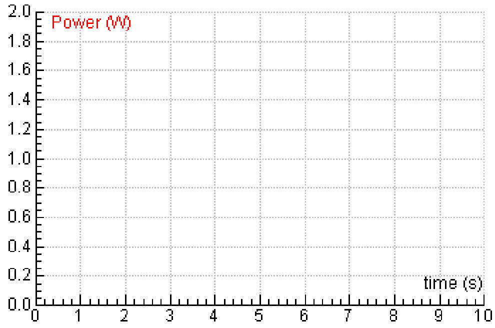
Activity 9-2: Two different bulbs in series

1. Now connect two identical bulbs (6V/0,3A) in series to a 6V power. Then connect two identical bulbs different form the first one (6V/0,05A) in series to 6V power supply. Connect two different bulbs in series to 6V power supply. Describe what happens and explain your results.

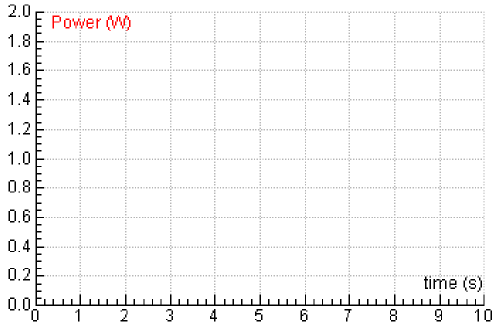
2. You know already that for the bulb brightness the power (energy) dissipated in the bulb is crucial. Draw your prediction about how the power dissipated changes for different situations.

Prediction

Single bulb 6V/0,3A

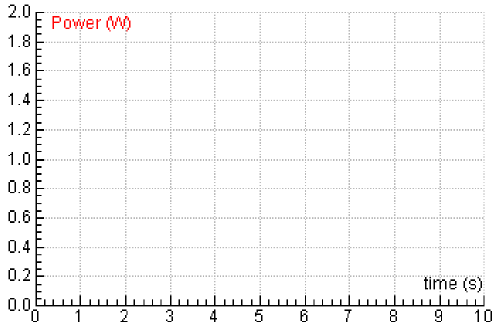


Single bulb 6V/0,05A

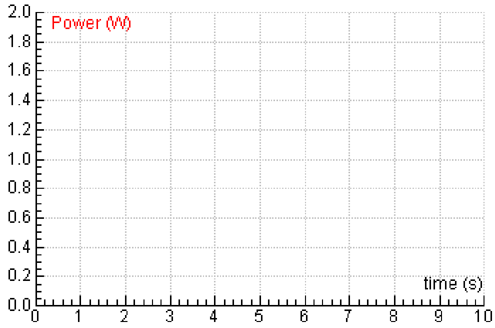


Two different bulbs in series

Bulb 6V/0,3A in series



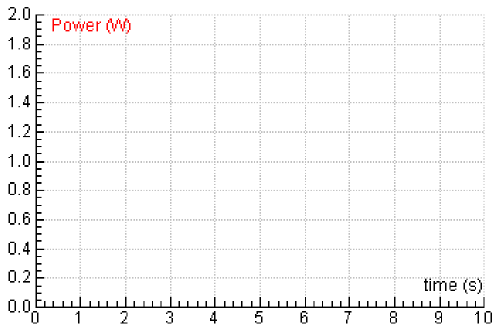
Bulb 6V/0,05A in series



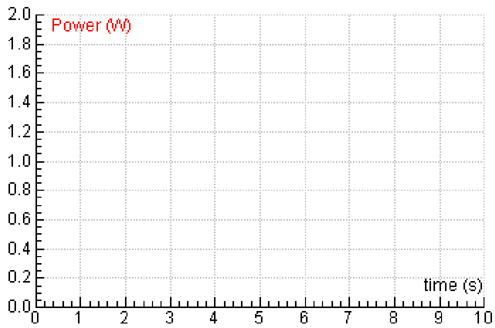
3. Open the file "*Bulbs in series*". Set up the circuit with one single bulb. Set the power supply to the bulb's voltage. Then start measuring current and voltage across the single bulb. Create the power diagram. Compare your result to your prediction. Does it agree?

Result

Single bulb 6V/0,3A

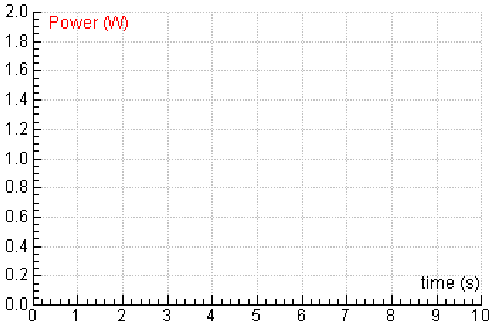


Single bulb 6V/0,05A

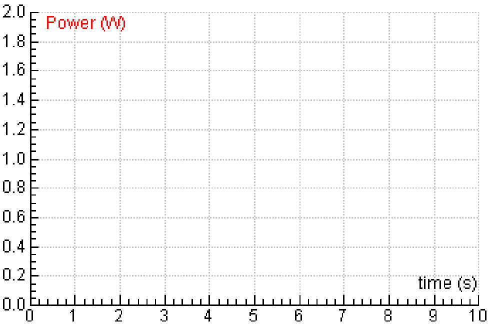


Two different bulbs in series

Bulb 6V/0,3A in series



Bulb 6V/0,05A in series



4. Do the same with series connection of two different bulbs. Check your prediction. Does it agree?

5. Draw conclusions.

Activity 9-3: Switch on the circuit

If you connect two different bulbs (e.g. 6V/0,05A, 6V/0,3A) in series in a dc circuit, one of them will light up later than the other. There is a noticeable delay between the two bulbs. Do experiment, decide about measurements, do investigation, explain and draw conclusions.

Activity 9-4: Two identically labelled bulbs

Do investigation on the behaviour of identically labelled bulbs from different sources or even from the same producer but different batches.

10. Worksheet: Build your own battery

In these activities you will study some basic principles of electrochemical cells using simple materials. These simple experiments will help you to understand how the batteries we use in everyday life work. Their environmental aspects will be also introduced.

Activity 9-1: Coins in a solution

In this activity you will build your own electrochemical cell. You will place small pieces of two different materials into a solution and measure the voltage produced in order to build a non-chargeable battery and to understand how it works.

1. Take two coins made of different metals and put between them a paper tissue that has been moisten by the salt, acid or alkaline solution. Connect the alligator clips attached to the voltage sensor to the coins and measure the voltage. Observe the reading. Does the value stay constant, rise or drop?

2. Observe the reading. Does the value stay constant, rise or drop? What happens if you switch the positions of connecting leads?

U =

Voltage:

a) constant

b) rises

c) *drops*

After switching the position of leads:

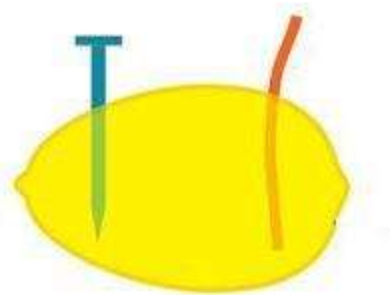
U =

3. Repeat the measurement for other combinations of metals and solutions. Record your findings into the table below.

Solution	Materials inserted	Voltage (V)	Constant, drops, rises

Activity 9-2: Fruit cell

1. Take a piece of lemon (you can also use orange, apple or potato) and cut two 1 cm slits in the lemon peel. Insert a short graphite pencil sharpened at both ends into one of the slots and an iron nail into the other. Connect the alligator clips attached to the voltage sensor to the pencil and to the nail.



2. Observe the reading. Does the value stay constant, rise or drop? What happens if you switch the positions of connecting leads?

3. Repeat the measurement for other combinations of materials inserted into the lemon. Record your findings into the table below.

Materials inserted into the lemon		Voltage (V)	Constant, drops, rises	Materials inserted into the lemon		Voltage (V)	Constant, drops, rises

4. Draw conclusions comparing different battery properties.

5. Several cells create a battery. Repeat the measurement using several cells connected in series. Describe your findings.

6. Light up a bulb using your own battery. How long does it shine? Describe your observation.

7. Draw conclusions.

Activity 9-3: Lead storage battery

In the previous experiment you have built a battery made from cells that discharge or "run down". This is an example of "primary" cell that cannot be reused. Now you are going to study batteries made of cells that can be discharged or recharged several times. A car battery is an example of such a "secondary" cell.

1. Set up the experiment as in fig. Before the use remove all the coating from the lead strips with the sand paper, rinse and dry. Clean the beaker. Place lead strips into the beaker and add sulphuric acid solution. Connect the strips to the dc power supply. Connect the voltage probe to the lead strips with the help of alligator clips.

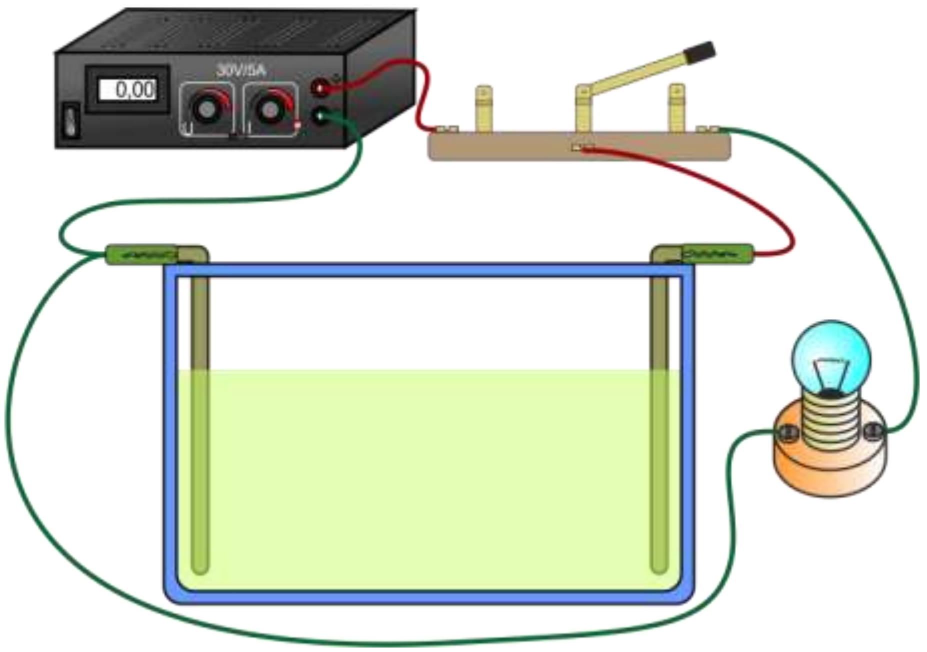
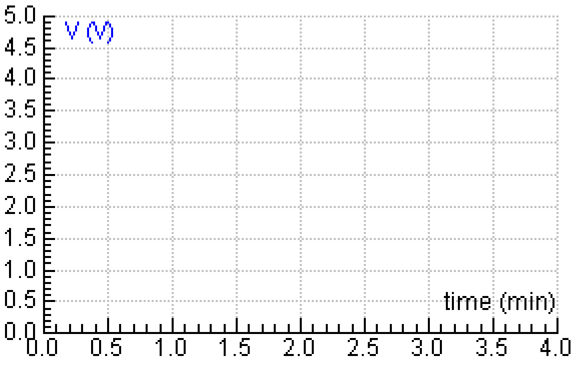


Fig. Lead storage battery – charging and discharging

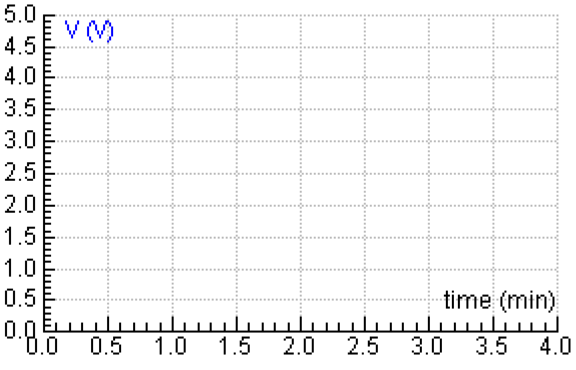
2. Open the file "*Build your own battery*". Start charging and measuring. Let the battery charge for 4 minutes. Then disconnect the power supply. Record your findings.



Voltage after charging:

U =

3. Connect the battery to a small bulb. Connect the voltage probe to the lead strips again. Close the switch and start measuring. Measure the time until the bulb fades away. Record your findings.



Voltage after discharging:

U =

4. Charge your cell again using a 2 minutes charging time and repeat the procedure. What is the cell voltage after charging?

   Voltage after charging: *U* =

5. A car battery usually produces a voltage of 12V. How many of your cells would you need?

6. What are the chemical reactions for charging and discharging? Can you look them up?

   Charging:

   Discharging:

7. Draw conclusions.

11. Worksheet: Battery and its basic parameters

There are different types of batteries to use for different purposes. What properties of a battery are crucial to consider in order to functioning well?

Activity 10-1 Terminal voltage

In this activity you will find out the main parameters of a battery and investigate how these parameters influence its behaviour in a dc circuit.

1. Open the file "*Battery in dc circuit*". Set up a simple electric circuit with an adjustable resistor and connect the current and voltage sensor as in figure. In the experiment you will use a 4,5V zinc-carbon battery.

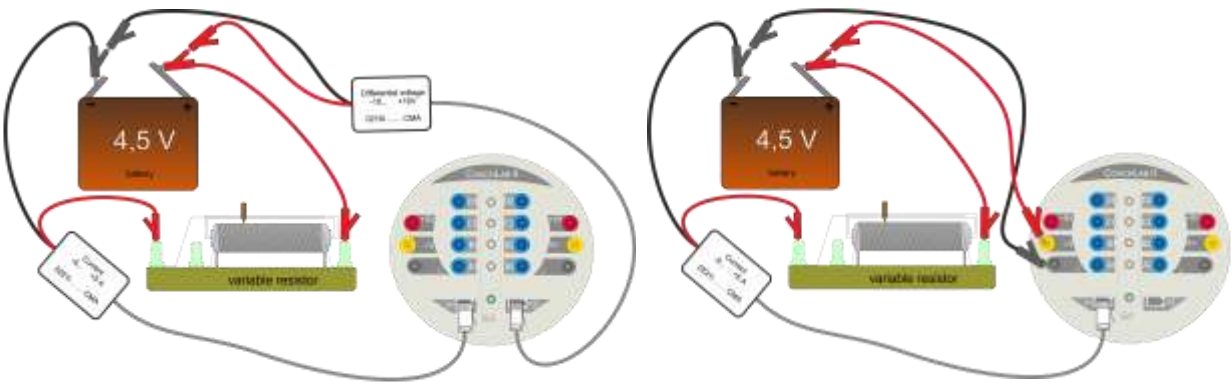
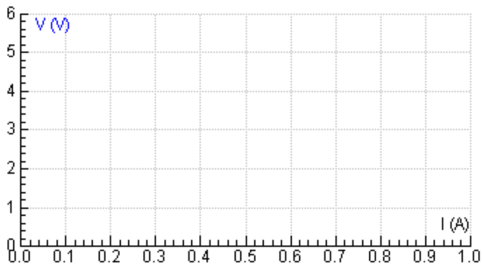


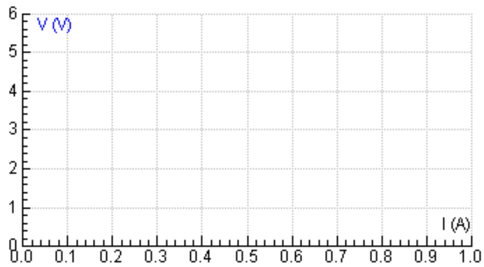
Fig. Simple electric circuit – battery, adjustable resistor, current sensor, voltmeter across battery

2. Do not start measuring yet. Imagine you gradually decrease the resistance of the adjustable resistor starting from its maximum value in order to change current in the circuit. What happens with the voltage across the battery terminals? Draw your prediction into the graph below.

Prediction



Result



3. Start measuring current and voltage. Change the current in the circuit decreasing the resistance of the adjustable resistor starting from its maximum value within 10

seconds. After it do not forget to set its resistance to its maximum value again. Compare your result with the prediction. Does it agree?

4. What is the relationship between the terminal voltage and the current in the circuit?

5. Fit the measured relationship with the appropriate mathematical function. Write down the function type and its coefficients.

   f(x) = *a=* *b=*

6. What physical quantity is represented by the independent variable *x*?

   x =

7. What physical quantity is represented by the dependent variable *y=f(x)*?

   y = f (x) =

8. What physical quantities are represented by the coefficients *a* and *b*?

   a = *b =*

9. Repeat your measurement for another battery of the same type or a different type battery.

10. Summarize your results.

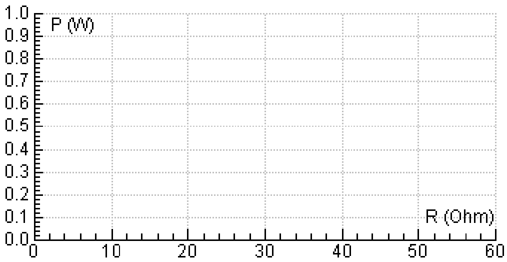
Activity 10-2 Power transfer to the load

In this activity you will measure the power dissipated in the external part of the circuit (load) and investigate how this power depends on the load resistance.

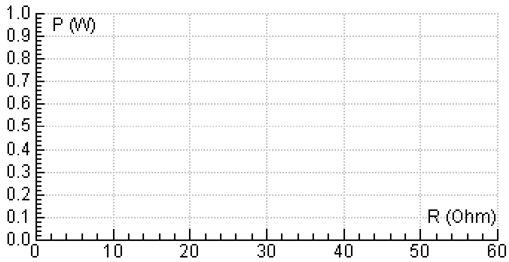
1. In the first activity you have measured how the voltage across the battery terminals depends on the current flowing through the circuit. You were changing the current by changing the external resistance of the circuit. Now express the power dissipated in the load in terms of terminal voltage and current as well as in terms of emf, internal resistance and load resistance.

2. Try to predict how the power dissipated in the load depends on its resistance.

Prediction



Result



3. Based on your voltage and current recordings create a diagram of power dissipated in the load related to the load resistance. Compare your result with your prediction. Does it agree?

4. Determine the maximum power and the corresponding load resistance. Compare its value with the battery internal resistance.

$R =$ $P = P_{max}$

$R_i =$

5. Explain your results.

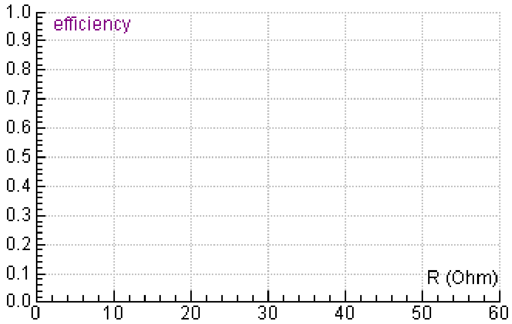
Activity 10-3: Power transfer efficiency

In this activity you will measure the power efficiency and investigate how it is related to the load resistance.

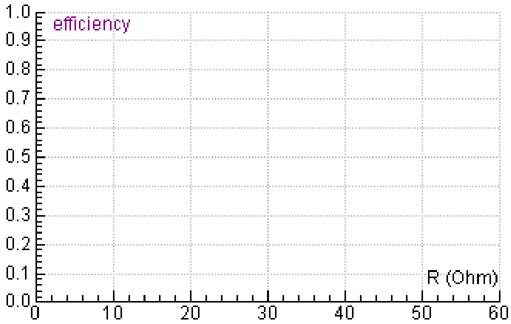
1. In the previous activities you have measured how the voltage across the battery terminals depends on the current flowing through the circuit and how the power dissipated in the load is related to its resistance. Now think about the power transfer efficiency, i.e. determine how much power is dissipated in the external circuit in relation to the whole amount of power created by the battery (ratio of output power to input power). Express the power transfer efficiency in terms of the load and internal resistance.

2. Try to predict how the power transfer efficiency depends on the load resistance.

Prediction



Result



3. Based on your voltage vs. current and power vs. load resistance recordings create a diagram of power transfer efficiency related to the load resistance. Compare your result with your prediction. Does it agree?

4. Determine the battery efficiency for load resistance equal to the internal resistance $R=R_i$.

$\eta =$

5. How much power is dissipated in the load compared to the power dissipated in the battery in the condition of equal resistances?

6. What is the battery efficiency getting close to for increasing load resistance?

$\eta \rightarrow$

7. What is more important: to maximize the power transfer or maximize the power transfer efficiency? Discuss with your peers and try to explain.

8. The torch has a battery of two cells in series (a cell of U_e=3V, R_i=0,7Ω)) connected to the bulb of 3,5V/0,25A. The starter is connected to the lead battery (U_e=12V, R_i =0,06Ω) and when switched on the current of 120A flows through the circuit for a short time. Compare the torch and the car starter in terms of power transfer and power transfer efficiency.

Activity 10-4: Build up a model of battery behaviour in a dc circuit

In this activity you will build a theoretical model on the phenomena investigated experimentally in the previous activities. Compare your experimental data with the model and set the model parameters in order to gain the best correspondence.

12. Worksheet: Batteries in series and parallel

It is possible to vary total voltage and current from a number of batteries by connecting them in different ways in the circuit.

In this activity you will investigate the behaviour of batteries connected in series and parallel in dc circuit. Find out what is the purpose of these connections. Plan your own investigation and draw conclusions.

13. Worksheet: How electric eel kills its prey

The electric eel (Electrophorus) lurks in rivers of South America. It lives on fish which it kills by electric shock of pulses of current. It does so by producing a potential difference of several hundreds of volts along its length. The resulting current in the surrounding water can be as much as one ampere.

The voltage is generated in special sets of cells called **electroplaques**. These are physiological emf devices that are arranged in tens of rows, each row stretching horizontally along the body containing several thousands of electroplaques. Each electroplaque has an emf of 0,15V and an internal resistance of 0,25 Ω. The water around the eel completes a circuit between the two ends of the electroplaque array, one end at the animal's head and the other near its tail.

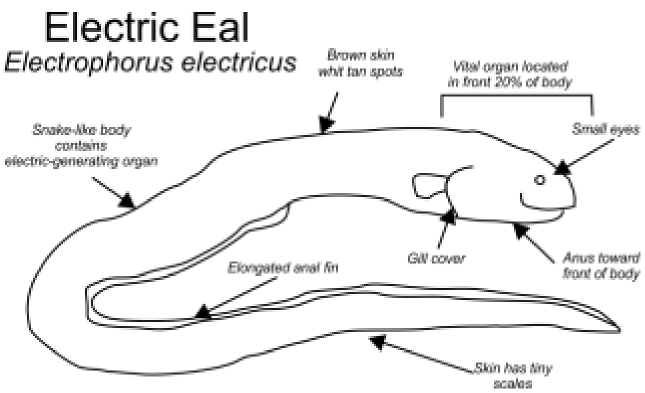


Fig. Schematic picture of electric eel (http://www.chm.bris.ac.uk/webprojects2001/riis/Electr2.gif)

Other resources:
http://www.electricshock.org/electric-animals.html
http://hypertextbook.com/facts/BarryLajnwand.shtml
http://en.wikipedia.org/wiki/Electric_eel

In this activity you will investigate how is electricity used in animal world. Search information about the electric eel and other animals that are able to create electricity. Try to explain what enables the eel to use electricity to kill the fish but not to kill itself. Find out what values of voltage and current the certain eel can produce. Draw a schematic model of the eel's physiological emf device. Use the text and other resources in order to prepare a presentation for your peers.

14. Worksheet: How much energy supplies a battery?

Batteries provide portable, convenient sources of energy for powering devices without wires or cables. We use batteries to power a wall clock, TV remote control, digital camera, MP3 player, mobile phone, torch, calculator and many other devices. On the market there is a wide selection of non-chargeable and rechargeable batteries. But what criteria shall we use to decide about a battery for the application?

In this activity you compare several batteries measuring their terminal voltage and current during its use until it is exhausted, the capacity, the energy supplied to the load and the corresponding price.

1. Open the file “*Energy supplied by battery*”. Take batteries of the same emf but different producer, e.g. AA batteries: 1,5V of zinc-carbon (Philips), alkaline (Philips-ultra alkaline) and rechargeable (1,2V, GP-NiCd). Set up a simple electric circuit with a battery and bulb (e.g.2,5V/ 0,3A). To measure current and voltage connect the current and the voltage sensor as in figure.

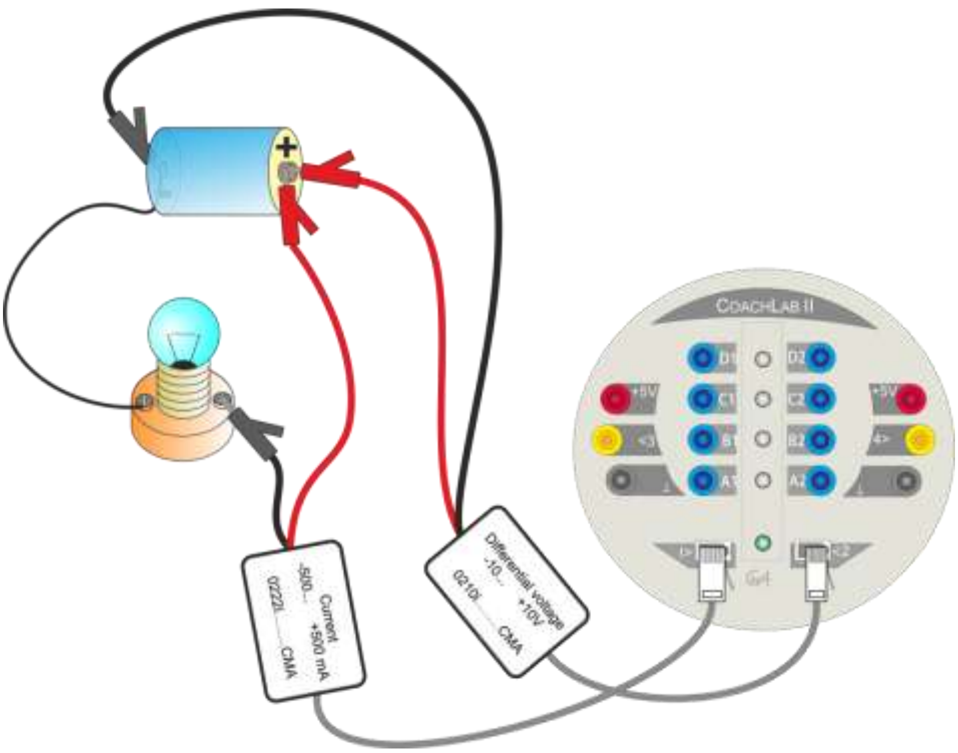
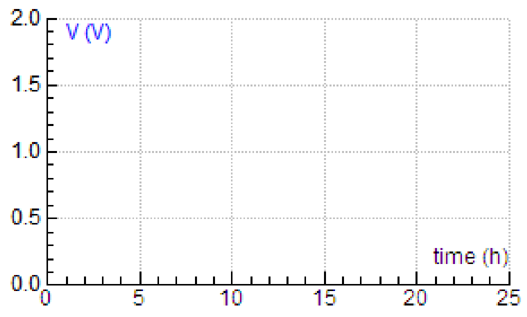


Fig. Simple electric circuit – battery, bulb, current sensor and voltage sensor measuring terminal voltage (connected to the battery)

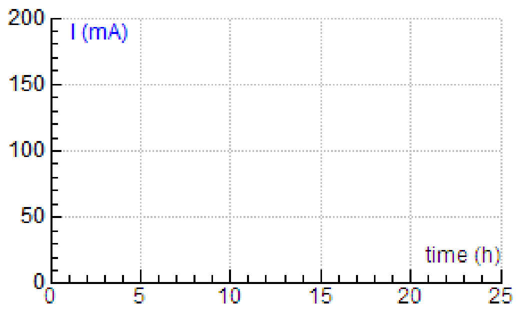
2. Do not start the measurement yet. Draw your prediction for different batteries about voltage-time and current-time graph for different batches. Use different coloured pencil.

Prediction

Voltage-time diagram



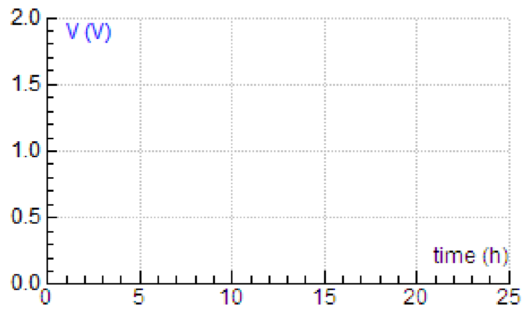
Current-time diagram



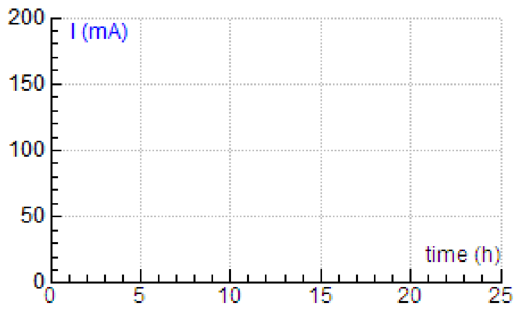
3. Start measuring current and voltage while discharging the battery. Let the measurement run until the battery is exhausted. The measuring time is set for 25 hours. Compare your result with your prediction. Does it agree?

Result

Voltage-time diagram



Current-time diagram



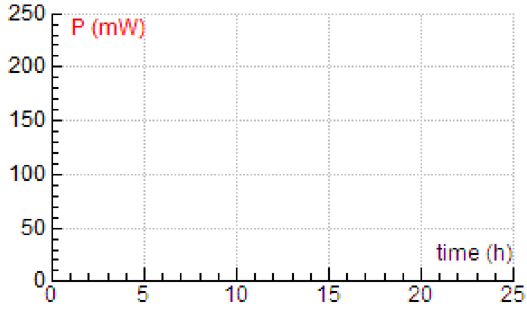
4. One of the parameters of the battery is its capacity. The capacity tells you how much charge it can store. It is measured in Ah (Ampere-hours). Determine the capacity of your battery from current-time diagram. How will you do this?

   Q =

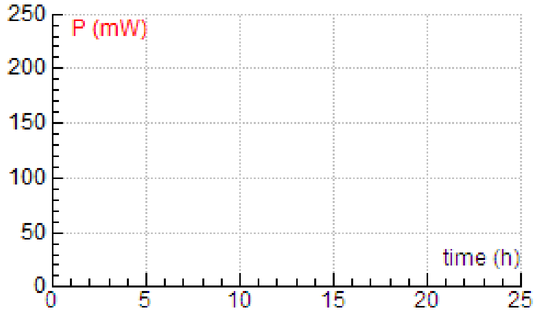
5. Now you are going to compare the batteries in terms of power and energy delivered to the circuit. First draw your prediction about power-time graph. If you analyze more than one battery result, use different coloured pencils. Then create power-time diagram for each of the batteries. Compare results with your prediction. Does it agree?

Power-time diagram

Prediction



Result



6. Which of the batteries delivered the higher (lower) amount of energy to the circuit during discharging? Do your prediction according to power-time diagram. What feature of the power-time graph gives you information about the energy?

7. According to your results determine the exact amount of energy delivered to the circuit. Fill in the values gained by other groups.

	Battery type	Energy (mWh)	Energy (J)	Battery price (EUR)	Price for 1mWh
Battery 1					
Battery 2					
Battery 3					

8. Compare the batteries in term of price. Knowing the price of the battery determine the price of 1mWh of energy for each battery. Which battery gives the most energy for the price?

9. Think about some other properties that are important for the battery. Formulate a research problem and design an experiment to investigate the mentioned battery properties.

10. Draw conclusions.

15. Worksheet: Batteries and their reasonable use

Batteries are devices that you often use in everyday life. They help us in many ways but at the same time when they are exhausted we have to get rid of them somehow. Think about the devices and apparatuses where batteries are used as well as about possible problems we come across while using them.

This is an open inquiry assignment. Formulate a research question connected to the everyday use of batteries and about the environmental aspects of them.

16. Worksheet: Other alternative electrical sources – fuel cell and photovoltaic cell

Try to look for information about an electrochemical cell – fuel cell and a photovoltaic cell. Prepare a presentation for your peers.

WP3 | Blood donation Unit

European Science and Technology in Action Building Links with Industry, Schools and Home

Work Package 3
BLOOD DONATION
A – Teacher Information

European Science and Technology in Action:
Building Links with Industry, Schools and Home

Lead Authors: **Katarína Kimáková et al (UPJS)**

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A. Teacher Information

I. Unit description

Blood is a unique organ in which cells are not bonded together but move freely in plasma. Blood plays an important role in the human body: it transfers oxygen and different substances to places of their effect or processing by cells and carries waste products from tissues so that they could be removed from the body. Significant lose of blood in an accident puts a person in a mortal danger. Additionally, there are diseases in which blood does not carry out one of its functions. Blood transfusion can save a human life in these situations. Up to the present there has not been found/created anything blood could be substituted by.

This unit focuses on blood properties, blood donation and conditions that must be ensured so that transfusion would not endanger patient's life.

Students are given an opportunity to look up information on their own, to process and present this information, work in a team and identify with roles of different experts. They become familiar with aids necessary for taking blood and for its storage. They plan experiments and perform observation.

Photography: Henrieta Kampeová

Student level: 7^{th} grade of lower secondary (elementary) school or upper secondary (grammar) school (13–18 years).

Discipline(s) involved: Biology, Chemistry, Physics and Technology

Estimated duration: 8 -10 hours

Links to Slovak national curriculum:

Goals

The central focus of this unit are: human blood properties and blood donation. Participating students will improve their knowledge of human biology and technologies that help in situations where a human life is endangered by blood loss or disease. They will

- study facts about blood and blood donation from different aspects;
- get in touch with a transfusion center staff;
- become familiar with medical products that are used during blood donation, blood storage and transfusion;
- work as a team in variable groups, practise communication and presentation skills;
- be able to convey the acquired information about blood and its donation to others;
- model and get to know properties of blood.

Outputs

At the end of this unit, the students should be able to:

- ask questions about blood that can only be answered based on research;
- find out what aids are used by medical staff for handling of blood, where and how these aids are made and why they have to be sterile;
- describe composition of blood;
- explain the blood types and why patient must not be given any blood;
- explain, using an example, how blood types are determined;
- explain, using an example, how blood types are inherited;
- understand who needs blood and who can donate it;
- model sedimentation;
- prepare and carry out presentation in front of their peers at “a scientific conference“ and discuss the presented paper;
- consider the importance of blood donation, prepare a magazine article and a TV interview about the topic in the form of a didactic game.

It occasionally happens that some students of upper secondary or grammar school who meet the requirements for blood donation (age, health condition) decide to donate blood after learning about this topic.

II. *IBSE Character*

In this unit students are given an opportunity to ask questions, do research on the topic by looking up information (on the Internet, interview with experts), process the information, present the result of their work and answer questions of their peers.

They have an opportunity to organise their work, model a scientific conference, role-play work of experts and that of reporters and journalists. In the interview with haematological center staff, students become familiar with conditions of blood donation and with necessary instruments.

Reciprocal collaboration of students is required in planning and performing of a short interview. In this interview students have to explain the substance of the issue by asking questions and giving answers in a way that helps to explain the importance of blood donation to common people. They are further required to propose a model of sedimentation and blood type determination, test these models and make conclusions based on their observations.

All proposed activities provide an opportunity to broaden and deepen knowledge of human blood, its properties and its functions. Students are guided to think about and discuss development of biology and technology, possibility of substituting of human blood by artificial blood for medical purposes in the future, and think about completeness of this substituent.

III. *Science Content Knowledge*

The topic of blood can be seen on four levels which are mutually related.

1. Composition: As an organ, blood possesses unique properties and performs several important functions in the human body. It consists of liquid plasma, red and white blood cells and platelets. Changed properties of blood signal a disease, for example changed number of blood cells. That is why doctors do blood tests.

2. Transfer of substances: Blood (red blood cells) transfers respiratory gases in the human body, plasma contains inputs and products of metabolism and hormones, which have a regulatory function.

3. Protection of the body: White blood cells and antibodies in plasma recognise and destroy antigens and foreign proteins that get into the body. Platelets ensure blood clotting and healing of harmed veins to prevent bleeding to death after injuries.

4. Blood types: Human blood has group properties. It is important to be aware of the blood types when saving human life by transfusion and considering possible complications in childbirth. Division of blood into types based on AB0

system and rhesus factor is best-known. Group properties of blood are inherited based on simple rules. Knowing them makes prediction of blood type before a child is born easier or helps in eliminating of paternity.

The main aim of this unit is to assist students in receiving a complete picture of knowledge about blood by means of practical tasks and situations, blood transfusion being the central motive of the topic. For safe transfusion medical staff has to handle blood in a sterile way. They use plastic aids made of polymers, separator and other equipment. It is also necessary to ensure that blood could be stored for some time in such a way that blood cells would remain alive. The cell damage caused by growing ice crystals during freezing can be prevented by addition of some polymers.

IV. Pedagogical Content Knowledge

Existing previous experience of students is based on the fact, that each of them has been injured, has bled and undergone blood tests. They all are also familiar with the fact that in a hospital blood is not only taken from the patients but there are situations when, in contrary, it has to be added to the body to prevent some patients from dying.

Presenting a topical article or local media news that appeal to people to donate blood can be motivating. Students must think why such an appeal has been published and imagine the situation a person in the need of other people's blood might be in.

Biological content is made up of composition, functions and properties of blood. The topic is related to the activity of circulatory and respiratory systems. We assume that pupils have already learnt about blood circulation in circulatory system, about activity of a heart and about gaseous exchange in lungs and tissues. In this unit they will learn about other properties and functions of blood by means of practical tasks, looking up and interpreting information.

V. Industrial Content Knowledge

Technologies are represented by polymers (plastics) and metals which are used in making aids for taking, processing, transport and storing of blood as well as equipment used to ensure sterility of aids utilized when handling blood. Students also learn about polymers that support longterm storage of blood at very low temperatures by protecting cells from being damaged in the process of ice crystals growth. Also of some interest is the information about efforts of scientists to develop a blood substitute which could save life in emergency when there is no suitable donor available.

Some useful web pages in Slovak and English:
http://www.ntssr.sk/
http://www.cervenykriz-ke.sk
http://www.redcross.sk
http://www.blood.co.uk/
http://www.coe.int/14-june-world-blood-donor-day

http://www.europarl.europa.eu/news/en/headlines/content/20110610STO21211/html/Blood-donation-saves-lives-needs-more-promotion
http://www.madehow.com/Volume-5/Artificial-Blood.html

VI. Learning Path(s)

Optimal group size: 24 students

Co-operative forms of pair or group work are recommended. A textbook, the Internet or professional literature can serve as a source of information; digital technologies are an added value.

List of activities

Activity	Discipline	Goals in curriculum
1. Appeal for donating blood	Biology	Blood donor
2. Looking up information	Biology Technology	
3. Study visit at a transfusion center	Biology Physics Chemistry Technology	Transfusion Using polymers
4. Separation of blood constituents	Biology Physics Technology	Composition of blood Gravitation Centrifugal force
5. Scientific conference	Biology	
6. Interview	Biology	
7. Determining blood types	Biology Chemistry	Blood types
8. Is Pavol the father?	Biology	Heredity of blood types
9. Blood as a transporter	Biology Chemistry	Functions of blood
10. Blood as a guard	Biology	Functions of blood
11. Blood preservation	Biology Chemistry Physics	Using polymers Crystal
12. Is it possible to produce artificial blood?	Biology Chemistry Technology	

Activity 1 should introduce the topic and create a need to search for further information (Engage).

Activity 2 first relies on the independent work of pupils, later the groups are supposed to work together and to process the acquired information into one collective output. This activity is preparatory to activities 3–5 (study visit of a transfusion station, components of blood and a scientific conference) (Explore).

Activity 3 Excursion to a transfusion center aims to motivate students to think how aids for taking and storing of blood work and what properties the materials used to make these aids must have (Explore, Extend).

Activity 4 gives students an opportunity to make up a model for simulating separation of individual blood constituents in the way they saw at the transfusion center. Besides, they have to design a model for counting the number of particles in a given volume (Explore, Extend, Explain).

Activities 5 and 6 are based on the fact that students have already acquired enough information about blood (in activities 1–3) and are capable to present this information to others. The aim of these activities is synthesis of knowledge and its interpretation. These activities help students to understand relations and to change knowledge to cognition (Engage, Explain).

Activity 7 is based on a situational interactive animated game and simulation of genuine determination of blood types. Since handling of a real human blood it is not allowed at schools the alternatives to this activity are proposed. In any case, students have an opportunity to experience what happens when two incompatible blood types are mixed and comprehend why this happens. Next, students develop their own model for simulation of blood type determination (Engage, Explore, Explain, Extend, Evaluate).

Activity 8 focuses on the heredity of blood types. Using matches pupils make models to ilustrate how blood types are inherited. They can find out what blood type children could inherit from their parents using a calculator on the Internet and, further, apply the principle on provided example to confirm/exclude fatherhood (Engage, Explore, Explain, Evaluate).

Activities 9 and 10 specify and consolidate the information about physiological functions of blood pupils have already encountered when searching for answers to their questions, at the transfusion center and at the scientific conference. They explain that the red blood cells transport respiratory gases to and from cells and they learn to recognise types of white blood cells on blood smear photo like "experts" (Engage, Explore, Explain, Extend, Evaluate).

Activities 11 and 12 provide an opportunity for reflexion on the topic and looking into the future by means of contemplating possibilities of technologies (Engage, Explore, Extend, Evaluate).

VII. Assessment

There is a certain feedback expected, mostly from the peers. A teacher must realise that by these activities students learn new things and that is why they should not make comments that might cause a loss of motivation. Possibilities of assessment vary from activity to activity. The output of activity 2 is a work text created by a group of pupils and further used in activities 5 “Scientific conference” and 6 “Interview”. Following the activities it is possible to discuss whether the produced work texts contained all the important information, what their quality was and what they lacked. In activities 4 and 7–10 the concern is to understand relations and to apply the knowledge. The topic should be concluded by reflexion (activity 11, 12) based on which a teacher can assess how students incorporate new information into their own ideas.

The teacher can assess whether students

- adequately interpret notions, such as blood cell, blood type, antigen, antibody and other;
- can explain what happens after incorrect transfusion;
- can determine child’s possible blood types based on blood types of parents;
- can speak about a protective role of white blood cells and antibodies in plasma;
- are familiar with the ways blood transfers substances from the environment to cells and the other way around.

VIII. Student Learning Activities

Activity 1	**Appeal to donate blood**
Learning aims:	
• *Introductory presentation from local media or from the Internet appealing to people to donate blood.* • *Students should be aware of the fact that anyone can get into a situation when their life depends on other people willingness to help. Not everyone, however, can help, even if they wanted. Sometimes complete strangers help us and it is our moral duty to help others when possible.* • *Students should think about biological properties of blood and technical possibilities of keeping blood suitable for transfer into another body.*	
Materials:	
An article from a local paper, web page or a recording of TV news appeal to people to donate blood.	
Suggestions for use:	
Pupils get acquainted with the appeal and then talk with the teacher about who and why might need blood transfusion. Further in discussion they are expected to come to a conclusion that if we are to help someone who needs blood transfusion, we need to find out the answers to the following questions: • Who and on what conditions can donate blood? • Can a patient be given blood of any donor? If not, why? • Is it possible to keep a donated blood for later use? Which blood properties must be preserved? Pupils first try to answer these questions on their own but will probably soon realise they do not have enough information to work out a satisfactory answer.	
Possible questions:	
• *What diseases might a patient who needs a blood transfusion have?* • *How much blood can be taken without endangering the donor?* • *How long can a blood be stored?*	

Activity 2	**Looking up information**
Learning aims:	

Students are expected to look up information that will help them answer the questions resulting from activity 1.
Materials:
The Internet, professional literature
Suggestions for use:
The activity consists of two parts. Students are divided (optimally) into four 6-member groups. Each group is supposed to find different information on blood as well as to look up the answers to the questions of activity 1 on the Internet. At the same time they are given questions that specify what sort of information they should look for. Group 1: – Why do people need blood transfusion? – What is the health condition of people who need blood? – Is blood from one donor enough? Group 2: – What are the conditions for donating blood? – Who may become a blood donor? – How often can one donate blood? Group 3: – Why a patient cannot be saved by blood of any donor? – What does one's blood type depend on? – What blood types are there? Group 4: – What properties does blood have? – What does it consist of? – How can it be stored? The answers can be found on the website of transfusion centers. First, each group member looks up the answers to given questions, a pair work can be used alternatively. They are required to write down everything they consider relevant information. In the second part of this activity the members of each group meet at one desk and work out a collective text containing the answers to the questions (a printed text of approximately 180 words).
Possible questions:
• *We heard about donating plasma. How can we donate only plasma without blood cells?* • *How is it technically possible to implement?* • *Who produces equipment and tools for taking a blood for transfusion?*

Activity 3	**Study visit at a transfusion center**

Learning aims:

Students should be able do describe where blood is taken, who works at a transfusion center and what qualifications they are required to have.

Materials:

The Internet, professional literature

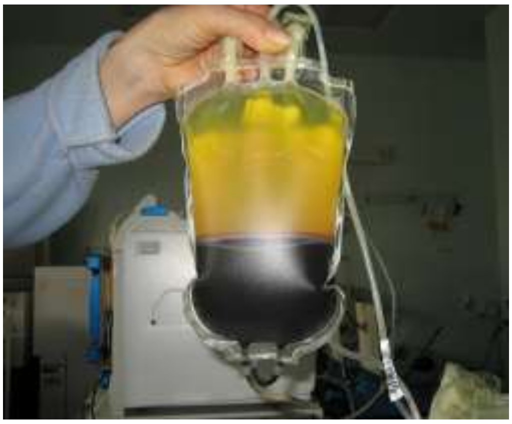
Suggestions for use:

Before the study visit, ask students what work they think is done at the center. Then ask them to write down questions they would like to ask the staff to get complete information (based on their search on the Internet, activity 1 and 2). Each student should prepare at least two questions. The size of group as well as the time of the excursion should be arranged with the staff of the transfusion center beforehand. The visit can be repeated with small groups. Alternatively, if the study visit is not possible, a member of the transfusion center staff and/or a representative of a company producing or selling aids for blood transfusion can be invited to school to demonstrate some aids used in taking and storing blood. More sophisticated equipment can be presented by means of short video recording.

1. Disposable sterile blood taking set

2. Blood taken with anti-clotting agent

3. Bags with taken blood in a separator



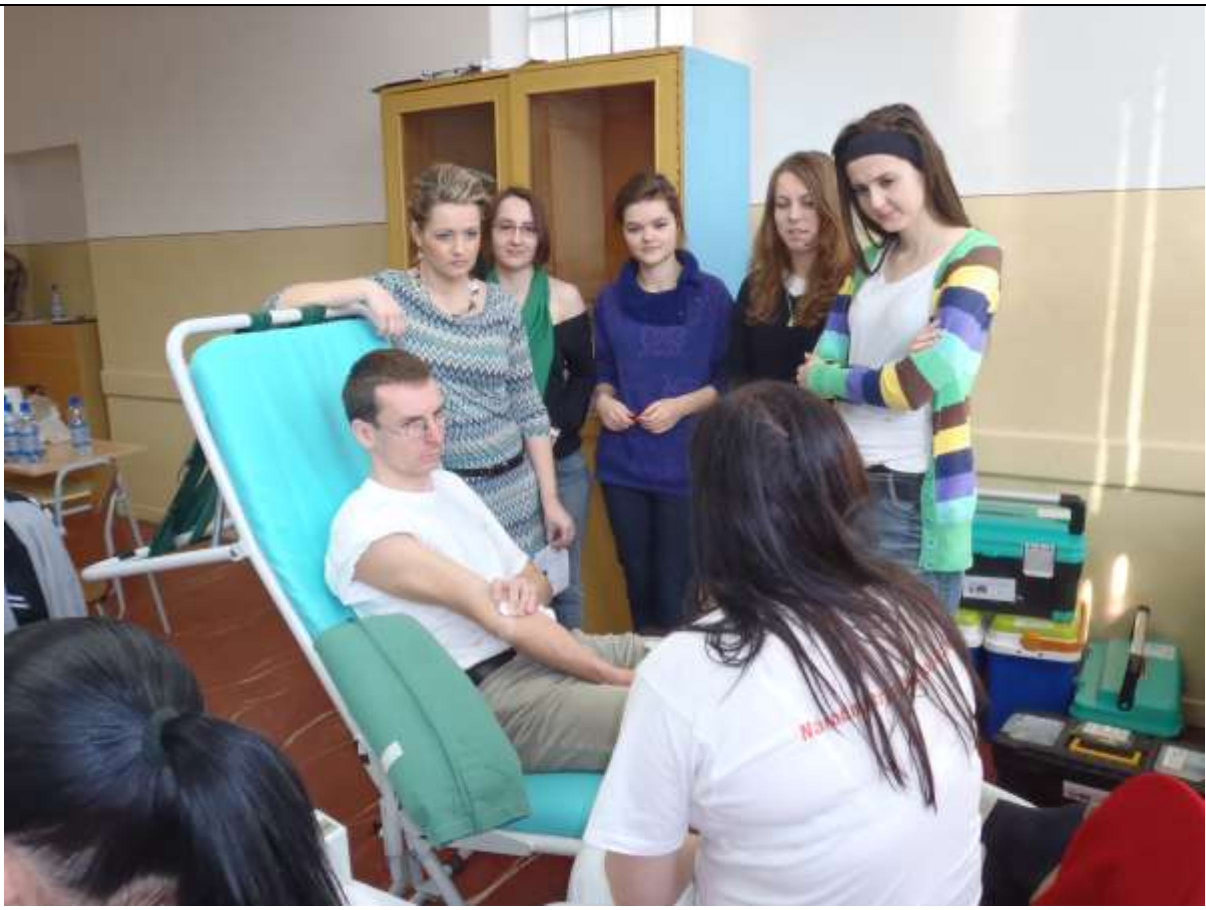
4. Three constituents of blood separated by separator

5. A press for separating individual blood constituents

6. Equipment for separating individual blood constituents

Source of pictures on this page: http://www.ntssr.sk with agreement of National Transfusion Service in SR

Following the meeting with a member of transfusion center staff students should be aware of the fact that saving a human life by blood transfusion requires thorough preparation. First of all, there has to be enough blood donors that are healthy and of a specified age. Donated blood is not given directly from one person to another but must be examined, processed and stored until it is used. Blood is a live organ and must not get in contact with the environment. All instruments and aids must be sterile. Material they are made of must also be sterilised. Blood is not given to a patient as a whole but its constituents are separated. A separator is used to do this. Different constituents are stored by cooling or freezing at very low temperatures.



Photography: Henrieta Kampeová

Also, inviting the mobile transfution unit to school proved to be an excellent alternative.

Possible questions:

- *What qualities must plastic bags for collection of blood have?*
- *What is anti-clotting agent?*
- *How does the separator separate the components of blood?*
- *How to make sure that everything is sterile?*

Activity 4 Separating blood constituents

Learning aims:

Students have to design a model by using of which they can show how to count the number of particles in a given volume and propose a model of sedimentation.

Materials:

a photo of blood smear, fine starch (powder), household semolina or corn flour, water, a glass (glass beaker), teaspoon, timer, detergent, worksheet

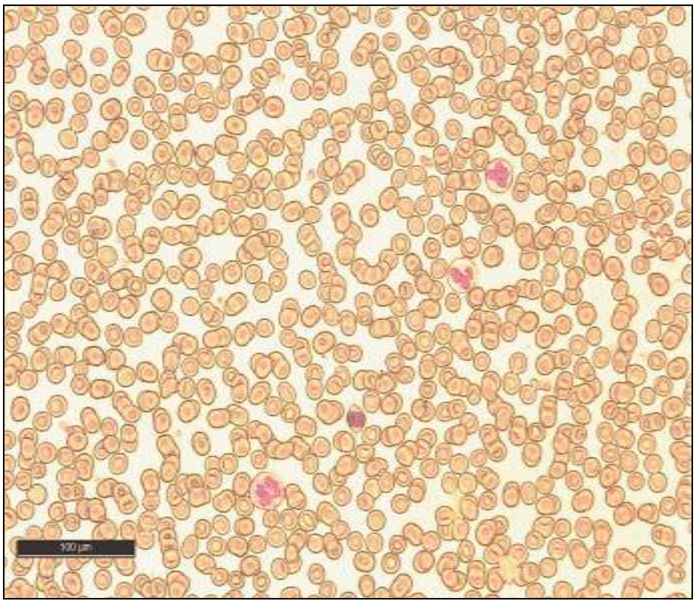
Suggestions for use:

Exercise 1

Blood count

Ask students why doctors want to know patient's blood count.

Students are asked to look at the photo. They are supposed to name different objects they see.



Photography: Edita Pauliková

Let them express their assumption about different objects seen in the photo and what these objects may represent.

Ask students to design a way to determine the number of different blood cells in a given volume of blood. They should invent a model to explain their procedure on. One of the possibilities is to put a grid over the photo, count the red blood cells in three windows of the grid, make an average and multiply it by the number of windows. In this case, however, we need to know the volume of blood that we see in the field of vision or in one window. White blood cells (leukocytes) can't be counted this way because there are few of them in comparison with red blood cells (erythrocytes).

Students can invent a model in which they substitute blood cells with marbles or small candies and fill a one-litre jar with them. In order not to count all the marbles or candies, it is enough to count them in a smaller jar with the volume of let say 50 ml and work out the number for the whole volume. Ask students how to increase accurateness of the estimate of the small particles number in a large volume. Then they should find out optimal values of blood count on the Internet or in professional literature.

Exercise 2

Sedimentation

Provide students with different aids and the worksheet to plan their experiment. Alternatively, they may use a notebook to write and draw their findings and results.

Ask students to design and carry out an experiment to observe the speed of sedimentation.





Let them try to explain why erythrocytes fall down to the bottom faster when there is an inflammation in the patient's body. The speed of blood cells sedimentation is determined by viscosity of plasma. Viscosity depends on the ratio of the present plasma proteins. During an illness, representation of proteins in plasma changes as a result of an immune reaction, and thus viscosity changes, too. Students may come to the conclusion about viscosity only based on a new experiment with a sedimentation model after they find out that adding a detergent into water increases speed of sedimentation and they will start to search for the reason of the phenomenon.

Possible questions:

- *Why doctors want to know patient's blood count?*
- *Why there are a lot of erythrocytes and a few leukocytes?*
- *What a doctor learns from the speed of red blood cells sedimentation?*
- *Can we speed up the sedimentation of particles?*

Activity 5 Scientific conference

Learning aims:

Students have to link information about blood they have acquired so far and interpret it. They have to identify with their roles, speak in front of others, ask questions and answer their classmate's questions. They do it by simulating a scientific conference at which apart from experts, media are present. Their knowledge of blood becomes consolidated.

Materials:

texts prepared by the groups in activity 2 and 3, transparencies, felt tip pens and an overhead projector or a computer for each group and a data projector

Suggestions for use:

Students who worked together on the text in activity 2 meet again. Two new groups will be formed in the following way: one student leaves each group and a new group is created the members of which will get the role of REPORTER. One more student will leave each group and a new group will be created from these students that will get a role of TV STAFF

Students of the groups in activity 2 will also be given roles:

1. group - DOCTOR
2. group - TRANSFUSION CENTER STAFF MEMBER
3. group - GENETICS EXPERT
4. group - PHYSIOLOGY EXPERT

The task of groups 1. – 4. is to prepare a presentation at the conference about blood.

Each of groups 1. – 4. appoints a representative who will present their findings.

Other group members will help their representative to prepare for the presentation. They can use the text they worked out in activity 2 and all the knowledge acquired during the excursion at the transfusion center. Together they will prepare notes on transparency or a short digital presentation as if presented by an expert in the appointed role. The length of the presentation should be set ahead of the time.

The task of the **group of reporters** is to prepare questions for experts presenting at the conference to get material for writing an article about blood donation in the local paper (school magazine).

The task of the **group of TV staff** is to prepare questions for experts presenting at the conference to get prepared for broadcasting an interview with experts about a topical issue of blood donation.

The teacher takes the role of the conference chair. Their task is to open the conference, introduce the presenters and open a discussion after each presentation. In the discussion everybody can ask questions – media as well as other experts.
A presenter has to give a satisfactory answer or other students take part in the discussion. The teacher will close the conference by informing about the presence of press and TV representatives who will publish the information for the public and will thank all the participants for their contribution.

Possible questions:

Students will formulate their own questions. There are many possible questions for this activity.

Activity 6	**Interview**
Learning aims:	
To continue interpreting the knowledge about blood, its completing and presentation. Students learn from one another.	
Materials:	
common classroom furniture and writing aids, camera (not a condition)	
Suggestions for use:	
Students remain divided in groups 1. – 6. as in activity 5. Students who play the role of reporters meet and agree on working out and publishing an article about blood donation in a local (school) paper, on the Internet or on a school notice board. If they still have doubts they can ask peer-experts (excluding those presenting at the conference, activity 5). They can finish the article at home and have it published by the following lesson. Students who take the role of reporter (TV staff) are supposed to organise a 5-minute interview with a doctor, genetics and physiology experts, and a transfusion center staff member. They can ask experts (excluding those presenting at the conference). Their task is also to arrange the furniture to imitate a TV studio and the rest of the students watch the interview as audience. An interviewer can ask each expert two questions that have to be brief and interesting for the audience – common citizens. They can divide the roles as they want: who will be the chair, who will prepare the scene, who will take the part of the director, who will be in charge of the camera. When the interview is ready, students role-play it. If there is a camera available, the role-play can be recorded and used as an introduction to the topic related to blood or can be placed on the class web page.	
Possible questions:	
Students will formulate their own questions. There are many possible questions for this activity.	

Activity 7	**Determining blood types**
Learning aims:	
Students are supposed to learn what the basis of blood types division is. They will also learn about the basic blood types.	
Materials:	

school set for determining blood type, a picture to explain the antigen – antibody bond, Internet connection, interactive board or computers for pairs of students, plastic tubes, stickers, marker, slides, measuring cup, teaspoon, distilled water, citric acid, *washing soda (soda ash, Na_2CO_3), low-fat milk, calcium chloratum, starch*

Suggestions for use:

The blood type determination and transfusions games, that students can find on Internet, enable them to play roles of medical staff and decide about patient's lives by determining their blood type and infusing them with the right blood type*.

While doing this they learn that on the surface of red blood cells there are antigens that react with antibodies in blood plasma of a different blood type.

Exercise 1

Student's task is to determine the blood type of unknown blood sample (imitation with the set for school). It is possible to get an educational set designed for this exercise, where students do not work with real blood, but with a model "blood" that works just like real one.

If there is no set available, you can use the following alternative model*:

Colour all "blood" samples with the red food dye or waterpaint.

Blood type A
Colour the low-fat milk.

Blood type B
Use syrup Calcium chloratum (available in a pharmacy).

Blood type AB
Carefully mix the low-fat milk and Calcium chloratum in the ratio 1:1

Blood type 0
Boil the distilled water and add a small amount of starch dissolved in water.

Reagent Anti-A
Dissolve 1 small teaspoon of citric acid in 40 ml of distilled water.

Reagent Anti-B
Dissolve 1 small teaspoon of washing soda in 40 ml of distilled water.

Procedure:

On the slide (better with two shallow holes) marked by the letters A and B add two drops of chosen samples ("blood type" unknown to pupils).
Add a drop of reagent anti-A to the drop of the sample marked with the letter A, and add a drop of reagent anti-B to the other drop of sample marked with the letter B.

In the real blood the antibody in the reagent anti-A reacts with antigens on the surface of red blood cells of blood types A and AB. The antibody in the reagent anti-B reacts with antigens on the surface of red blood cells of blood types B and AB.

The precipitation in our model occurs in 30 seconds in all cases.

Group A blood does not react with anti-B, group B blood does not react with anti-A, group 0 blood does not react with either anti-A or anti-B. In these cases, no coagulate is observed.

According to the reaction of the tested sample and reagent anti-A and anti-B (clot apperas in both or only in one or in none of two drops), blood type of “unknown” sample can be determined.

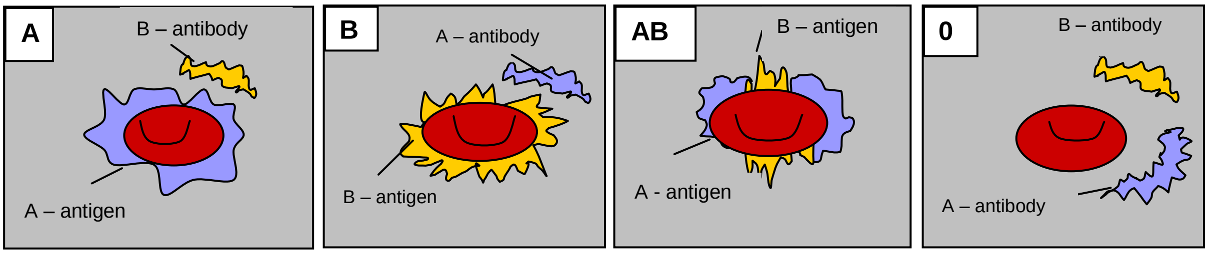
Important notes

1. "Blood" can be stored in a refrigerator up to one day.
2. Use distilled water for the preparation of reagents and blood type 0.
3. Prepare 20 ml of each blood sample and 40 ml of each reagent (anti-A and anti-B).
4. A drop of blood and a drop of reagent on the slide should be approximately of the same size.

Ask students to explain what they think happened during blood testing.

Why does blood coagulate somewhere but does not somewhere else? How does the test work?

Let them describe the situation in the pictures in their own words.



Students have to be able to explain that antigens and antibodies in blood are of two types: A and B. A type blood contains antigens A on the surface of red blood cells and antibodies B in plasma that do not react with each other. Red cells of B type blood carry antigens B and plasma contains antibodies A which react with antigens of group A. Therefore, blood of types A and B coagulates when the two are mixed. Blood cells of group AB do not contain any antibodies but in plasma both types of antigens are present. Blood cells of group 0 do not have antigens but in plasma there are both antibodies A and B. A different type of blood type is a rhesus factor which can be positive if its antigen is present or negative if the antigen is not present in blood.

It can encourage students to design "recipe" for a similar model. As the blood type B they can use, for example, a solution of baking soda (sodium bicarbonate) or an aqueous solution of egg white – (2 parts water and one part of the egg whites; allow the precipitate to settle; collect the clear solution for use). As the reagent in both cases, use 70 % ethanol (alcohol for disinfection, available in a pharmacy).

Exercise 2

Angela was told by her doctor that her newly born baby needs intensive care because he inherited rhesus positive factor from his father.
Look up in your textbook or on the Internet what rhesus factor is.
The doctor did not tell Angela why rhesus positive factor of her child is a problem. Can you explain it?

Students can find an interactive game for example on following web page:
http://nobelprize.org/

Possible questions:

- *Do animals also have blood types like people?*
- *I do not know my blood type. Where can I determine my blood type?*

Activity 8 Is Pavol the father?

Learning aims:

Students should understand the laws of heredity of blood types. They should be able to explain that it is the presence of antigens and their antibodies that is inherited. It is inherited from both parents. Each person has two alleles of a blood type gene – one is from the father, the other from the mother when only one of each parent's is randomly given to the child. That is why siblings can have different blood types and blood type of children can be identical with that of their mother or their father but it does not have to be.

Materials:

calculators for determining possible blood type of a child based on the information about parents' blood types (find on the Internet), matches of 2 colours

Suggestions for use:

Tell the students to open the calculator* and try to design some examples. Then ask them, to explain how heredity of blood types relates to what they have found out about them in connection with transfusion.

Ask the students to model genes of blood types using the matches:

antigen A present – red head,

antigen B present – blue head,

no antigen – broken head

Every gene consists of two matches – gene parts (called allele). One comes from the mother, the other from the father. In case of blood types both alleles manifest themselves together and the result is a blood type A, B, AB or 0.

What alleles did a man with the blood type AB inherit from his parents?

Ask students to make a table in which they show heredity of blood types by means of AB0 system. They can work individually and then compare their result with others.

Suggested table:

blood type	genotype	alleles
A	**dominant homozygote**	$I^A\ I^A$
	heterozygote	$I^A\ I^0$
B	**dominant homozygote**	$I^B\ I^B$
	heterozygote	$I^B\ I^0$
AB	**heterozygote**	$I^A\ I^B$
0	**recessive homozygote**	$I^0\ I^0$

Exercise:

Erika has a blood type A and she has had a baby with a blood type AB. She appointed Pavol, who has a blood type 0, as the father. Can Pavol really be the father of Erika's child?

Students have an opportunity to discover combinations of parents' blood type, when a child is born with blood type 0, and explain why a child may have blood type 0 when both parents have blood type A.

* Calculator examples:
http://www.babymed.com/tools/blood-type-calculator

http://www.pediatriconcall.com/fordoctor/pedcalc/blood_group_detection.aspx
http://primar.sme.sk/kalkulacky/krvna-skupina-dieta.php (Slovak)

Possible questions:

- *How does heredity of blood types relate to what we have found out in connection with transfusion?*

Activity 9 Blood as a transporter

Learning aims:

Students are supposed to learn that red blood cells are the transporters of respiratory gases, oxygen and carbon dioxide. They contain haemoglobin that makes temporary bonds with the molecules of the gases. Apart from that, blood carries substances in the body that are vital to cells or which, on the contrary, are excreted by cells. Some of the substances play an important role, for example hormones that regulate different processes in the body.

Materials:

A textbook

Suggestions for use:

Ask pupils to describe their idea of what happens to oxygen on its way from lungs to brain tissue. They can possibly work in pairs or groups. They present their description of oxygen journey and then work on making their ideas more accurate. Different sources of information can be used.

Students can propose a procedure to prove carbon dioxide in exhaled air.

Talk about other substances blood carries.

Ask students to design and make a toy (a puzzle) for younger pupils – to match a source of production of substances carried by blood in the body and target organs where the substances are needed.

Possible questions:

- *If there is not enough oxygen in the brain, a brain death occurs. How does oxygen get from lungs to brain?*
- *What other substances blood carries? Whence and whither?*

Activity 10 Blood as a protector

Learning aims:

Students are supposed to find out that leukocytes protect the body from pathogens. Some of them absorb and digest the pathogens, other produce antibodies that function in a similar way as in the case of blood types.

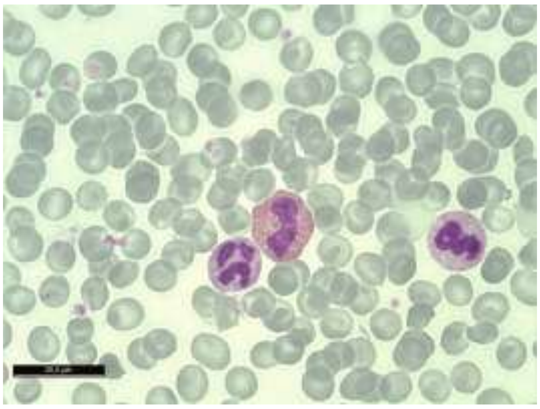
Materials:

Internet connection, pictures in the textbook, photographs of human blood smear (see in classroom materials)

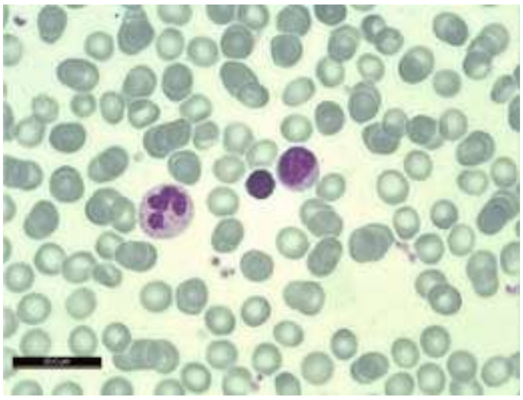
Suggestions for use:

Tell students that they can become experts in recognizing leukocytes. Then let them look at the text and photos in worksheet and ask them: Which types of white leukocytes can you recognise on these photos?

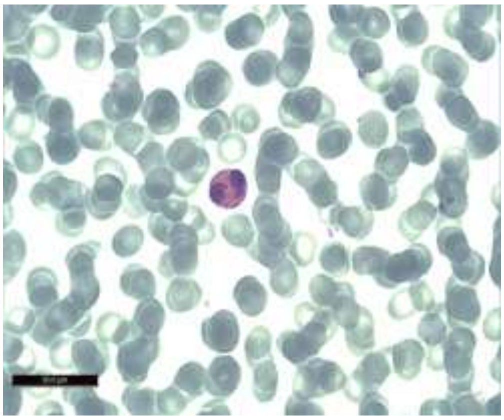
Picture examples (Photography: Edita Pauliková)



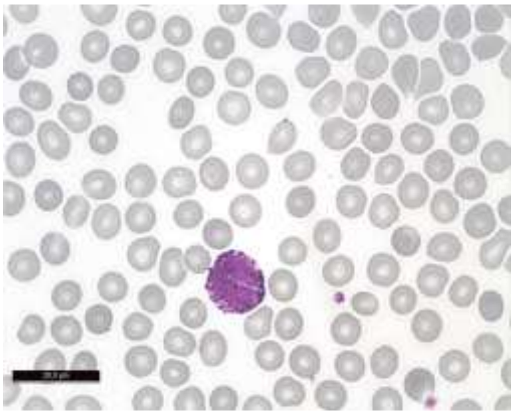
1 – one eozinophil, two neutrophiles



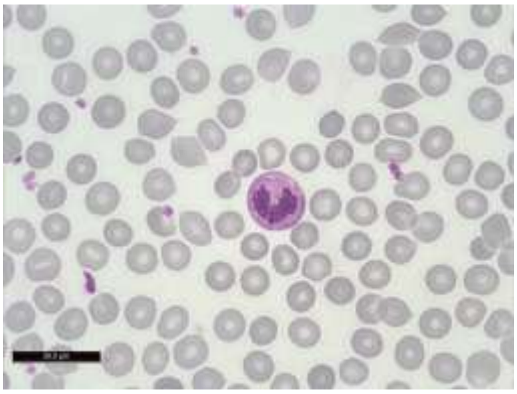
2 – neutrophil, small and larger Lymphocyte

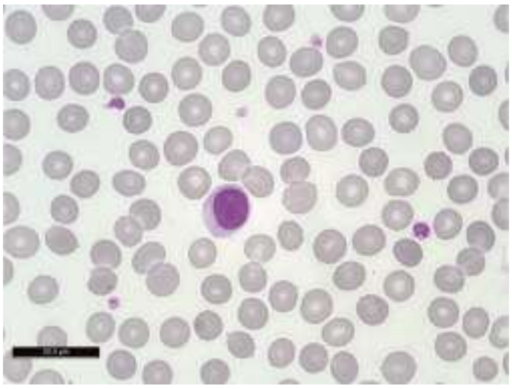


3 – eosinophil



4 – basophil


5 – monocyte


6 - killer

All samples also contain red blood cells and platelets.

Ask students to look up on the Internet (in the textbook) more photos or pictures of humane leukocytes. Students can explore the relationship between the stainig of leukocytes and their names.

Talk with the students about the function different types of leukocytes have and what would happen if they were not present in blood or there were too many leukocytes. How do they protect the body from pathogens?

Exercise (task for students): Find on YouTube a blood clotting animation and explain: what is the function of platelets?

Possible questions:

- *Why are human erythrocytes without nucleus?*
- *What happens in the blood during inflammation?*
- *Why are too many leukocytes in the blood a sign of leukemia?*
- *Why a bruising appears after being hit?*
- *Who needs to receive platelets by transfusion?*

Activity 11 Blood preservation

Learning aims:

Students are supposed to link knowledge about blood, water, crystals and polymers. They should understand what damage freezing water causes in cells and how to prevent damages during freezing of the cells.

Materials:

frozen fruit (strawberries or raspberries), interactive applet on attachement

Suggestions for use:

Let frozen fruit defrost and ask your students meanwhile:

- Why does it not look like fresh?
- What will happen when the fruit defrosts?
- What could have happened to the fruit cells?
- Where does the released water come from?

However, cooling and freezing at very low temperatures in liquid nitrogen is a well-known way to conserve live tissue. There are ways to protect tissues from being damaged during crystal growth. When crystals develop inside a cell or in its neighbourhood, they are very small. But they grow and tear the cell membranes.

Let students plan and carry out an experiment in crystallization of salt. Let them experimentally investigate under what conditions small crystals grow, and when bigger ones are created.

Imagine a crystal of water. It is, in fact, a snowflake with sharp edges.

When working with an interactive applet students should find out optimal conditions – how many polymers and when they should be added to the solution for the best possible protection of cell membranes (during a cooling or before the start of cooling).

Error! Objects cannot be created from editing field codes.

Polymers added to tissues wrap the nuclei of crystals and prevent them from growing.

Use the model and explain how the polymer inhibits the growth of crystal.

Possible questions:

- *Some parents wish to preserve umbilical cord blood by freezing at birth of child. What is the aim of this?*
- *What could have happened to the frozen blood cells?*
- *What can reduce the water content of cells?*
- *What happens to a cell when we drain it completely?*

Activity 12 Is it possible to produce artificial blood?

Learning aims:

Students are supposed to apply their knowledge about blood.

Materials:

worksheet in classroom materials, Internet connection

Suggestions for use:

Ask students to think about what properties artificial blood should have so it would enable to save a human life. Discuss the topic. Start with a story:

There has been an accident and the patient has lost a lot of blood. He is threatened with failure of organs and death caused by the lack of oxygen. No blood tin is available to save his life.

Ask students:

Could an artificial blood save him? It cannot have all the properties of human blood. Which properties must it have so it could help until a donor is found?

Let students find on the Internet whether artificial blood has already been made and used for saving a patient.

Example of internet source:
http://www.madehow.com/Volume-5/Artificial-Blood.html

Possible questions:

- *What industry could produce artificial blood?*
- *Which scientists participate in its development?*

WP3 | Blood donation Unit

European Science and Technology in Action Building Links with Industry, Schools and Home

Work Package 3
BLOOD DONATION
B-Classroom Materials

Lead Authors: **Katarína Kimáková et al (UPJS)**

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Total Number of Pages: **19**

B. Classroom Materials

Activity 1

Appeal for donating blood

Carefully listen to the appeal.

Why do such appeals appear in media?

Discuss:

- Who and on what conditions can donate blood?
- Can a patient be given blood of any donor? If not, why?
- Is it possible to keep a donated blood for later use? Which blood properties must be preserved?

Picture: http://www.redcross.sk/

Activity 2

Looking up information

Look up the answers on the Internet.
Note down everything you consider a relevant information.

Meet at one desk and work out a collective text containing the answers to the questions (a printed text of approximately 180 words).

Group 1:

- *Why do people need blood transfusion?*
- *What is the health condition of people who need blood?*
- *Is blood from one donor enough?*

Group 2:

- *What are the conditions for donating blood?*
- *Who may become a blood donor?*
- *How often can one donate blood?*

Group 3:

- *Why a patient cannot be saved by blood of any donor?*
- *What does one's blood type depend on?*
- *What blood types are there?*

Group 4:

- *What properties does blood have?*
- *What does it consist of?*
- *How can it be stored?*

Activity 3

Study visit at a transfusion center

We will meet staff of a transfusion center. Write down what you need to ask about the following aids to be able to complete the text prepared by your group with new information.

Disposable sterile blood taking set

....?

Blood taken with anti-clotting agent

....?

Bags of taken blood in a separator

....?

Three constituents of blood separated by a separator

………………………………………………………………?

Look carefully at the process of separating blood constituents and ask questions:

A press for separating individual constituents

Equipment for separating individual blood blood constituents

………………………………………………………………?

………………………………………………………………?

Source of picture on this page: http://www.ntssr.sk

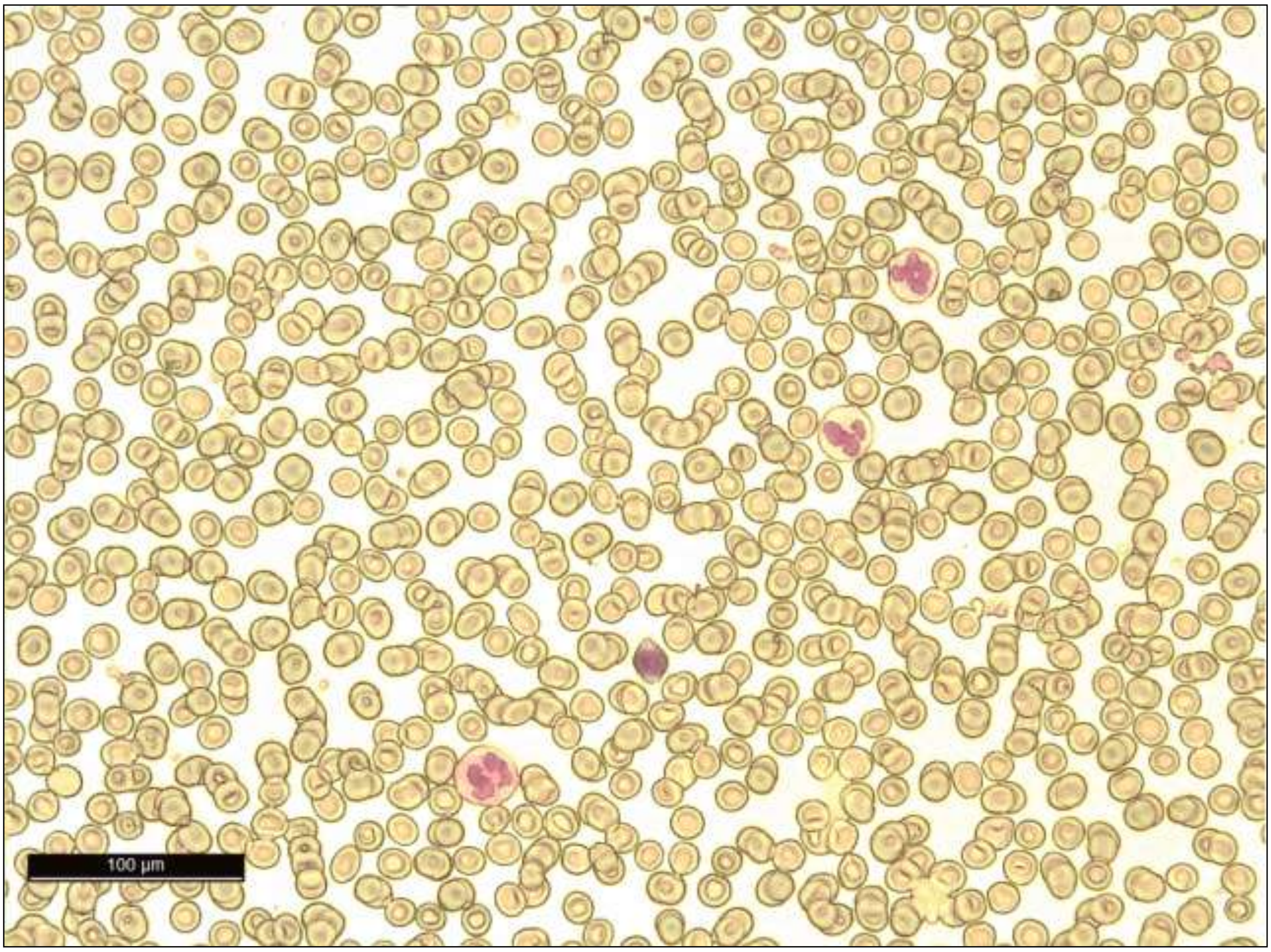
Activity 4

Separating blood constituents

Exercise 1
Blood count

Study the photo carefully.

What objects can you see in it? What could it be?



Photography: Edita Pauliková

Why doctors want to know patient's blood count?

Design a way to find out the number of different blood cells in a given volume of blood. Invent and device a model by means of which you can clearly explain your idea.

Where can you find out optimal number of blood cells of a healthy man?

Exercise 2

Sedimentation

We know already that blood consists of several constituents: liquid plasma, red and white blood cells and platelets.
We have seen that the different constituents can be separated by a centrifuge. Sometimes, a doctor takes your blood to find out how fast the constituents get separated by gravitation effect. It is called examining sedimentation.

What a doctor learns from the speed of red blood cells sedimentation?

Choose from the aids that are available and design a model to observe sedimentation. Plan an experiment to find out the speed of sedimentation of particles at the certain time points.

Experimental design:

Write a procedure here how you would model sedimentation of blood cells using the aids that are available for you:	Make a drawing of the trial result here: After 5 minutes After 10 minutes
Which particles settled faster? Why?	

Try to explain why erythrocytes fall down to the bottom faster when there is an inflammation in the body.

Would it be possible to make the particles settle faster when modelling sedimentation?

Activity 5

Scientific conference

Take texts that you prepared in groups with the help of the Internet or answers of the experts at the transfusion cente (activity 1 and 2). The texts are numbered the same way as groups.

1. group - DOCTOR
2. group - TRANSFUSION STATION MEMBER OF STAFF
3. group - GENETICS EXPERT
4. group - PHYSIOLOGY EXPERT

***The task for the groups*:** to prepare a presentation at the conference about blood.

Each group (1-4) will appoint one representative who will present their findings. Other group members will help their representative to prepare for the presentation.
Use the texts you have prepared earlier and completed with the answers to the questions (activity 2).

5. **group of reporters** is to prepare questions for experts presenting at the conference to get material for writing an article about blood donation in the local paper (school magazine).

6. **group of TV staff** is to prepare questions for experts presenting at the conference to get prepared for broadcasting an interview with experts about a topical issue of blood donation.

Organise a conference:

The chair of the conference welcomes the participants and asks speakers to make their presentations. After each presentation, there will be a discussion. All can join it, not only media representatives.

Activity 6

Interview

The task of reporters:

Write an article about the conference on blood donation.

The task of the TV team:

Simulate a TV broadcast of an interview with guest experts on blood – a doctor, a transfusion centre staff member and biologists: physiology and genetics experts.

Activity 7

Determining blood type

Find online games for rescuers who are deciding what kind of blood they can give to their patient. Play a rescue team member.

How did the medics find out a patient's blood type?

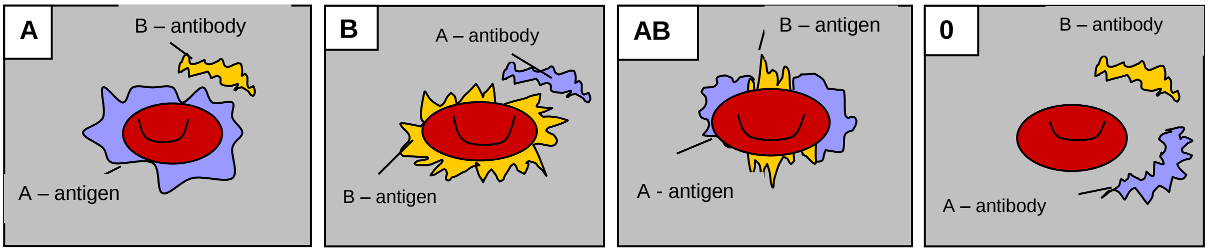
Exercise 1

Determine the blood type of unknown blood sample imitation

The test enables you to determine the blood type. Mix the blood with a drop of reagent anti-A then another drop of the same blood sample with reagent anti-B on the testing card. It is possible, that your set also enables determination of Rh factor.
Within a few minutes you will be able to determine blood type.

The blood type of unknown blood sample is: Make a drawing of your test result into the squares.	anti-A	anti-B	Rh

How does the test work? Describe the situation in the pictures in your own words.
Explain what you think happened during blood testing. Why does blood coagulate somewhere but does not somewhere else?



What does the reagent anti-A contain?
What is in the reagent anti-B?
Can you suggest the composition of the artificial blood samples and reagents corresponding to anti-A and anti-B that would imitate determination of blood type?
Use your knowledge of chemistry and experience in the kitchen.

Exercise 2

Rh – the rhesus factor

Angela was told by her doctor that her newly born baby needs intensive care because he inherited rhesus positive factor from his father.
Look up in your textbook or on the Internet what rhesus factor is.
The doctor did not tell Angela why rhesus positive factor of her child is a problem.
Can you explain it?

Activity 8

Is Pavol the father?

Find an online calculator to determine the blood type of the child by blood types of parents and try a few options.

Invent some examples.

Can you explain how heredity of blood types relates to what you have found out about them in connection with transfusion?

Exercise 1

Model genes of blood types using the matches:

antigen-A present – red head,
antigen-B present – blue head,
no antigen – broken head

Every gene consists of two matches – gene parts (called allele). One comes from the mother, the other from the father. In case of blood types both alleles manifest themselves together and the result is a blood type A, B, AB or 0.

What alleles did a man with the blood type AB inherit from his parents?
Make a table in which you will show heredity of blood types of AB0 system.

blood type	genotype	alleles
A		
B		
AB		
0		

Exercise 2

A real situation:

Erika has a blood type A and she has had a baby with a blood type AB. She appointed Pavol, who has a blood type 0, as the father. Can Pavol really be the father of Erika's child?

Write all possible combinations of blood types of a mother and a father who can have a child with the blood type 0:

Briefly explain why a child with a blood type 0 can be born to parents who both have the blood type A.

Activity 9

Blood as a transporter

If there is not enough oxygen in the brain, a brain death occurs. How does oxygen get from lungs to brain?

Describe your idea of what happens to oxygen on its way from lungs to brain tissue.

Present your description of oxygen journey. Compare your description with that of others and see the differences.

Are some of the statements unclear or incomplete?

Consult professional literature to find out.

Design and try out a procedure to prove carbon dioxide in exhaled air.

Talk about what other substances blood carries.

Design and make a toy (a puzzle) for younger pupils – to match a source of production of substances carried by blood in the body and target organs where the substances are needed.

Activity 10

Blood as a protector

White blood cells provide defense against foreign substances, viruses and bacteria.

You become an expert, at finding their presence in a blood smear.

To make blood cells easily recognizable, blood smeared on a slide is specially coloured.

You can easily recognize ***erythrocytes*** in the photographs of human blood smears. Their size is 7µm. They are without cell nuclei and they have a typical flattened shape. There is a hollow in the middle of the cell which can sometimes remind a nucleus, do not be mistaken!

Platelets are square and smaller than the red blood cells.

Several types of ***leukocytes*** exist: monocytes, lymphocytes, eozynophils, neutrophils and basophils. Pay attention to:

- cell size,
- presence of granules in the cytoplasm and their colour,
- the shape of nucleus

Read carefully:

- The nucleus of ***lymphocyte and monocyte*** is in the center of the cell, it looks dark blue or violet.

  Small-sized ***lymphocytes*** are only slightly larger than red blood cells (10 microns). They have only a narrow strip of cytoplasm around the round nucleus. Medium-sized (15 µm) growing lymphocytes have more cytoplasm. Active lymphocytes, called killers, are the largest. They contain a few red granules in the cytoplasm.

  Monocytes are the largest leukocytes (20 µm). They have a different shape of the nucleus, which may remind horseshoe, butterfly or embryo. Colouration of the nucleus and cytoplasm are less intense in comparison with monocytes. There are light pink granules in cytoplasm.

- Nuclei of ***neutrophils, basophils and eosinophils*** can be divided into segments, so it looks that we see more than one nucleus in the cell.

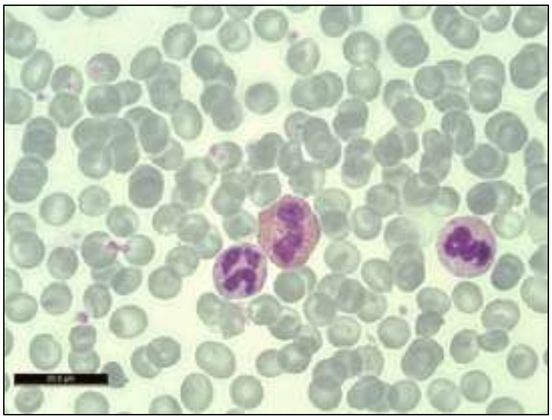
  Neutrophils and ***basophils*** are about two times larger than erythrocytes (15 µm).

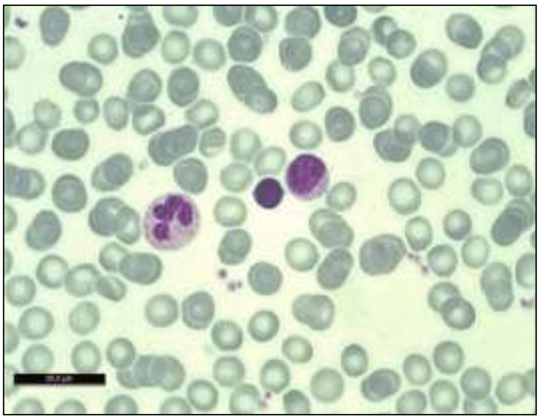
  Eosinophils are slightly larger, measuring up to 17 µm. There are pink coloured granules in the neutrophil cytoplasm. Two parts of the nucleus of eosinophil can remind sunglasses. Eosinophils have brightly red colored granules resembling caviar.

Basophils have dark blue to black granules, which sometimes overlap the nucleus. They remind poppy seed cake.

Neutrophils have very small pink granules in the cytoplasm.

Look at these photos. How many types of while blood cells can you recognise?





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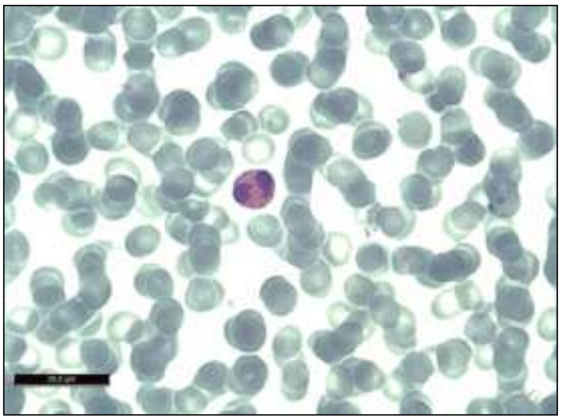

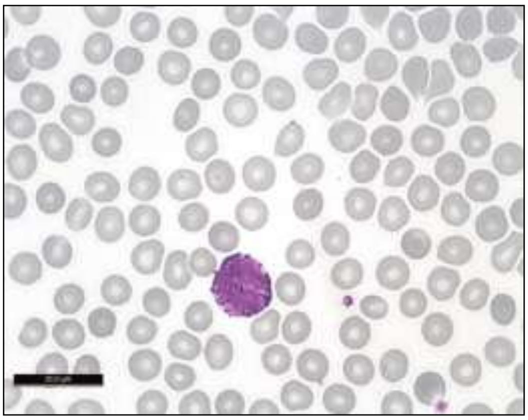

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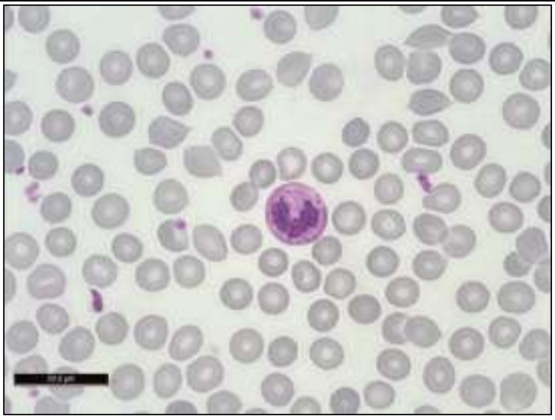

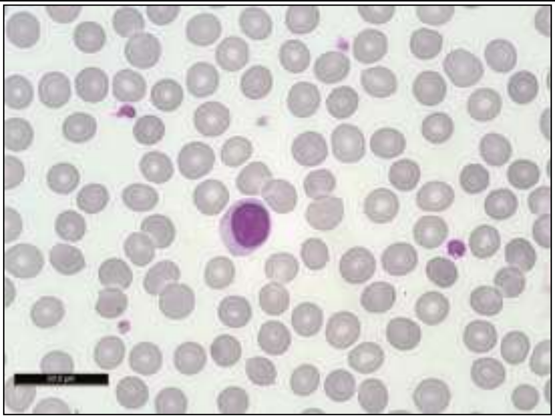

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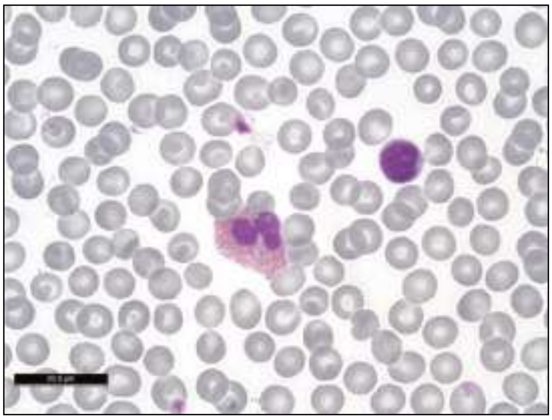

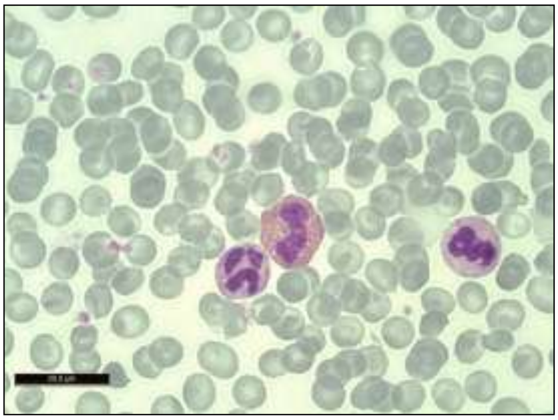

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Explore the relationship between the colouring of leukocytes and their names!

Find more photos of microscopic sections of human blood on the internet. Identify particular types of blood cells in the sample.

How do leukocytes protect our body from the pathogens?
What would happen if we lacked lymphocytes, phagocytes and other cells in our blood?
Do you think it's good to have too many of certain white blood cells in one's blood?

Find a blood clotting animation on YouTube.
What is the function of platelets?
Who needs to receive platelets by transfusion?

Activity 11

Blood preservation

Let frozen fruit defrost.

- ***What will happen when the fruit defrosts?***
- ***Will it look the same as fresh?***
- ***Where does the released water come from?***
- ***What could have happened to the fruit cells?***
- ***Will the same happen to blood cells if they are frozen?***

Imagine a crystal of water.
It is, in fact, a snowflake with sharp edges.
When crystals develop inside a cell or in its neighbourhood, they are very small. But they grow and tear the cell.

Plan and carry out an experiment to observe salt crystals growth.

Cooling and freezing at very low temperatures in liquid nitrogen is a well-known way to conserve live tissue. There are ways to protect tissues from being damaged during crystal growth.

What can be done to have crystals in the freezing water as small as possible?

Polymers added to tissues wrap the nuclei of crystals and prevent them from growing.

Use the applet and find out optimal conditions. (freezin_cells.jar)

How many polymers and when (during a cooling or before the start of cooling) they should be added to the solution for the best possible protection of cells?

Activity 12

Is it possible to produce artificial blood?

A real situation:

There has been an accident and the patient has lost a lot of blood. He is threatened with failure of organs and death caused by the lack of oxygen. No blood tin is available to save his life.

Could artificial blood save him?

It cannot have all the properties of human blood.

- ***Which properties must it have so it could help until a donor is found?***
- ***What properties should artificial blood have and which may not be so important in order to save lives?***

Mark in the table and explain the reason:

Carries oxygen	☐ Yes	☐ No
Coagulates	☐ Yes	☐ No
Carries carbon dioxide	☐ Yes	☐ No
Carries hormones	☐ Yes	☐ No
Contains antibodies	☐ Yes	☐ No
Destroys bacteria	☐ Yes	☐ No
Has red colour	☐ Yes	☐ No
Receives products of cells	☐ Yes	☐ No
Imitates patient's blood type	☐ Yes	☐ No

Find on the Internet information if artificial blood has already been made and used for saving a patient.

- ***What industry could produce artificial blood?***
- ***What scientists participate in its development?***

WP3 | Chemical Care Unit

European Science and Technology in Action:
Building Links with Industry, Schools and Home

Work Package 3
UNIT CHEMICAL CARE
A - Teacher Information

European Science and Technology in Action:
Building Links with Industry, Schools and Home

Lead partner for unit — Leibniz- Institute for Science and Mathematics Education (IPN)

The ESTABLISH project has received funding form the European Community's Seventh Programme [FP7/2007-2013] under grant agreement n^{o} 244749
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Total Number of Pages: 48

Authors of this unit: Stefanie Herzog, Kirsten Fischmann & Ilka Parchmann; translations by Kirsten Fischmann & Stefanie Herzog; drawings of “Little Researchers” in Classroom Materials of Subunit 1 by Ilka Parchmann; other sources included as follows:

The worksheets, materials and experiments belonging to Activities 1.8, 3.6, & 3.8 were developed by:
Prof. Dr. Ilka Parchmann *(IPN Kiel),* Kerstin Haucke *(Carl-von-Ossietzky University of Oldenburg),* Prof. Dr. Alfred Flint, Alexander Witt, and Katja Anscheit *(University of Rostock) and* Dr. Romy Becker *(Henkel AG & Co. KGaA, Düsseldorf);* further worksheets and experiments are available in English at the following website:
http://www.henkel.com/com/content_data/106612_4.8.2_Sustainable_washing_for_a_clean_environment_Chemistry_for_Advanced.pdf

Worksheets and materials in Subunit 3 were also developed in cooperation with Dr. Norbert Stelter *(Henkel AG & Co. KGaA, Düsseldorf).*

Other experiments and ideas were taken from the projects “Chemie fuers Leben” (German website with further links to experiments and material in German: http://www.didaktik.chemie.uni-rostock.de/en/forschung/chemie-fuers-leben/) and “Chemie im Kontext” (textbooks in German for lower and upper secondary level published by Cornelsen).

Sources are also listed on the worksheets.

A. Teacher Information

I. Unit description

"Forces and interaction between substances" is the central focus of this unit, including both concepts of chemical bonding and chemical reaction. The goal is to point out and develop the relevance of explaining properties and behaviour of substances as an interaction of the substance in a certain environment.
This principle is not only important for chemists but also for an understanding of phenomena and products in daily-life and industrial contexts. That is why a large number of activities in all of the three subunits deal with everyday substances, such as household cleaners or textiles/clothes. From this students can see that they are able to explain "trivial" processes such as drying their sport jacket on the radiator on a chemical basis.

The unit is divided into three subunits, based on the same developmental structure as the first ESTABLISH chemistry unit "Exploring Holes":

Sub unit	**Student level**	**Title**
Subunit 1:	Early secondary level (10-12)	Become a Household Detective!
Subunit 2:	Mid secondary level (13-15)	Chemical Care at home
Subunit 3:	Upper secondary level (16-18)	Chemical Care for Functional Products

In Subunit 1, students will find out about household substances. They plan investigations to find out what happens if some of these substances are mixed and explain their findings on a phenomenological level.
In Subunit 2, students will focus more on the submicroscopic structure of household substances such as acids and bases, and learn to explain their functionality based on chemical explanations.
In Subunit 3, students look at textiles, their production processes and especially investigate the structure of and care for different types of fibres.

Linkage to the national curriculum:
For other national versions, please indicate links to the national curricula.

The chemistry curriculum in Germany follows the same structure as applied by the three sub-units: students first learn to observe and explain phenomena on a macroscopic level and to carry out simple experiments, mostly based on given instructions. Often in their second year of chemistry, particle models and the big idea of atoms are introduced and applied for different explanations. Further on, such models are specified and differentiated.
The National Standards for all German states structure the chemical content by four so-called basic concepts: (1) matter and particles, (2) structure-property-relations, (3) chemical reaction and (4) energy changes based on chemical processes. The three sub-units of this unit focus mainly on the concept of structure-property-relations.
The first sub-unit can be integrated in the curriculum of the first year in science or chemistry, often year 5 or 6 (age 10 - 12). In almost all German states, curricula demand the observation, description and identification of substances at this level, also their separation and first experimental analyses.
Sub-unit 2 can easily be connected to the curriculum topic of acids and bases which is usually treated on a submicroscopic level around year 9 (age 13/14). The students classify acids and bases using the definitions by Arrhenius or Brönstedt.

Sub-unit 3 builds on knowledge on organic substances and introduces or rather enlarges the knowledge about polymers. This will be dealt with in upper secondary level courses.

Discipline(s) involved: Chemistry, biology

Estimated duration:
Each sub-unit is flexible as they are designed to fit into a topic already taught in the curriculum and the material can be used in different ways and combinations.

II. IBSE Character

In all of the three subunits, the following aspects of IBSE are present, with different foci in the different subunits:

- Developing questions
- Developing hypotheses
- Testing hypotheses with experiments
- Documenting experiments
- Searching for information in books, the internet, and on products
- Discussing ideas with peers

Especially sub-unit 3 applies the IBSE steps both for scientific experiments and the idea of technical / industrial processes of the optimization of products.

III. Science Content Knowledge

Sub-Unit 1: Become a Household Detective!
For this sub-unit, only very basic knowledge about simple characteristics of the different substances used in the activities (salt, sugar, water, oil, washing powder, soap) is needed. This knowledge can be found in every science or chemistry textbook for introductory classes. In addition, basic knowledge about where to find bacteria is also needed.

Sub-Unit 2: Chemical Care at Home
As this unit focuses on products and processes related to curriculum units on acids and bases, this is also the knowledge background needed. Teachers must be able to choose household products, e.g. cleaners containing acids or bases. They must have general knowledge on the structures and properties of the substances, such as acidic acid, citric acid, or sodium hydroxide. Most important, they must consider all measures necessary for a safe realisation of students' experiments, as described in the material. However, as this content knowledge is also very basic and can again be found in any chemistry textbook, no further explanations are needed at this point.
Precautionary measures are important for the experiments with bacteria and nutrient agar to prepare it sterile and its disposal.
For further information about hygiene around the home, Dr. Norbert Stelter (Henkel *AG & Co. KGaA, Düsseldorf)* suggests the following website:
http://www.ifh-homehygiene.org/IntegratedCRD.nsf/IFH_Home?OpenForm

Basic knowledge about bacteria, fungi and viruses

Bacteria are microorganisms existing in large numbers. Bacteria live nearly everywhere, for example in the air, on objects, or in the water. People need bacteria as they help them but they may also cause diseases. A lipid membrane and a cell wall surround cytoplasm of the cell of the bacterium. The cell wall type affects major characteristics of bacteria. Bacteria are prokaryotes and do not have a nucleus. They also lack other components compared to other cell types. The cytoplasm carries the bacteria's genetic information in form of a circular chromosome which is to be found in the nucleoid. There are different cell morphologies and arrangements of bacteria, e.g. cocci or bacilli. Mostly, you can find a cell wall of peptidoglycan in bacteria which is essential for them to survive compared with fungi, which are eukaryotes and their cell walls are made up of chitin amongst others.

Sources:
http://de.wikipedia.org/wiki/Bakterien
http://en.wikipedia.org/wiki/Bacteria
Hans G. Schlegel (1992). Allgemeine Mikrobiologie. 7. überarb. Aufl.. Georg Thieme Verlag: Stuttgart. 22-26.

The function of proteins depends on its undisturbed molecular geometry. However, in the people's digestive tract proteins are only degradable after their denaturation. This can happen via cooking or gastric acid. This is an important process for the hygiene of food as it destroys not only bacteria but also fungi. By adding strong acids or bases, organic solvents such as alcohol, heat or concentrated inorganic salts (e.g. NaCl) to proteins they are destroyed as they lose their secondary (local segments in a three-dimensional form with regular repeating patterns) and tertiary structure (three-dimensional structure of greater segments) which are altered but the primary structure (peptide bonds between amino acids) stays intact. The result of denaturation of living cells is disrupted activity of cells (disrupted covalent and Van-der-Waals interactions between side-chains of amino acids), they cannot fulfil its function any longer, or the death of cells.
While heating intra-molecular bonds are released by vibrational excitation. By applying alcohol or inorganic salts to proteins not only their secondary and tertiary structure are destroyed but also their primary and quaternary (protein subunits spatially arranged) structure may be destroyed or disrupted due to the competition of building hydrogen bond. Also surfactants may alter proteins as they disrupt the non-polar bonds which are directed inside the protein. Additionally, surfactants may impair the structure of lipid membranes.

Sources:
http://www.chemieunterricht.de/dc2/wsu-bclm/kap_02a.htm
Wikipedia: http://de.wikipedia.org/wiki/Denaturierung_%28Biochemie%29
http://en.wikipedia.org/wiki/Denaturation_%28biochemistry%29

Fungi are microorganisms that belong to group of eukaryotic organisms. They have cell walls made up of chitin (glucose-derivative, polymer of a N-acetylglucosamine). Fungal cells have a cell nucleus which is bounded by two membranes, the nuclear membrane, and which carries the chromosomal DNA.

Sources:
http://en.wikipedia.org/wiki/Fungus
Hans G. Schlegel (1992). Allgemeine Mikrobiologie. 7. überarb. Aufl.. Georg Thieme Verlag: Stuttgart. 169-172.

Bacteria and fungi are able to spoil materials like food or microbial sensitive products because they may multiply and metabolise substances in such goods. Some bacteria and fungi are known to cause illness either as infectious organisms or due to metabolism products. Thus, it is necessary in selected cases to actively fight microorganisms to prevent illness or spoilage of goods. This covers also the preservation of potentially sensitive goods (e.g. cosmetics, water based cleaners, and detergents, or water based paints). Measures to prevent infectious diseases in the private area are summarised under household hygiene. The correct and targeted application of cleansers and detergents support household hygiene.

Viruses are particles on the borderline between inanimate nature and real organisms. Viruses are characterised by the fact that they do not have their own metabolism and thus, viruses do not spoil materials like food or microbial sensitive products. Viruses are not able to multiply themselves. They capture living cells to force them to produce viruses. This is the reason why viruses cannot be cultivated on ordinary nutrient media. Some of them are highly infective and some of the most severe infectious diseases are caused by viruses.

Source:
http://en.wikipedia.org/wiki/Virus

Sub-Unit 3: Chemical Care for functional products

This subunit focuses on different fibres, their structure, their production and their classification. Consequently, this unit applies more specific knowledge on different fibres such as cotton, silk, wool or nylon.
Materials that are discrete elongated pieces or continuous filaments can be classified as fibres. The manufacture of textiles as well as other industrial branches are using fibres. Fibres play an important role in the biology of plants and animals as they are structural elements stabilising tissues as building materials (spider nets, silk) or keeping the optimum body temperature (animals) as insulators (hairs).
Fibres can be subdivided in natural and synthetic fibres (see Figure 1 in classroom materials).

Fibres produced by animals, plants, or geological processes are called natural fibres. Natural organic fibres are biodegradable over a specific period of time. Classification is possible, based on the fibres' origin such as animal fibres (e.g. spider silk, wool or hair (e.g. angora, cashmere, or mohair)), vegetable fibres (often cellulose-based, e.g. cotton, flax, jute, ramie, or sisal), wood fibres, as well as mineral fibres (e.g. such of the asbestos group). Despite this variety in natural fibres and their availability, the production of synthetic fibres is often cheaper and yields can be obtained in larger amounts in comparison with natural fibres. Synthetic fibres can be specially designed to the area of application which enables the development of functional textiles and specific technical textiles.

Synthetic fibres can be subdivided in cellulose fibres (as such or by regeneration of natural cellulose), polymer fibres (synthetic chemicals-based fibres, e.g. polyamide, polyester, aromatic polyamides etc.), mineral fibres (such as carbon fibres, asbestos or fibreglass), and microfibers made of diverse materials.

Sources:
http://en.wikipedia.org/wiki/Fiber
Rösler, Friedrich. Naturfasern. NiU-Chemie 6 (1995) Nr. 26, Seite 5-8.
Karraß, Sigurd. Chemiefasern: Aufbau-Strukturen-Anwendungen. NiU-Chemie 6 (1995) Nr. 26, Seite 9-15.

Cotton, for example, is a natural fibre. Its fibres consist of about 91 % cellulose, 7.85 % water, 0.56 % protopectin, protoplasm and 0.20 % mineral salts. The spinning of cotton is enabled by a typical coiling of the mature fibre. The cellulose layers that are oriented in different directions to the vertical axis are the reason for the coiling.
Cotton is a fibre often used for textiles as it resists alkali treatment. It is, however, damaged by acids which weaken the fibre. Furthermore, it highly resists organic solvents while it is damaged by microorganisms such as mildew or rot-producing bacteria. Regarding the washing process, the fibre does not decompose before a prolonged exposure to temperatures of > 150˚C. However, exposed to flames, it burns readily.

Sources:
http://www.chemgapedia.de/vsengine/vlu/vsc/de/ch/16/mac/naturfasern/naturfasern.vlu/Page/vsc/de/ch/16/mac/naturfasern/baumwollfaser01.vscml.html
http://en.wikipedia.org/wiki/Cotton

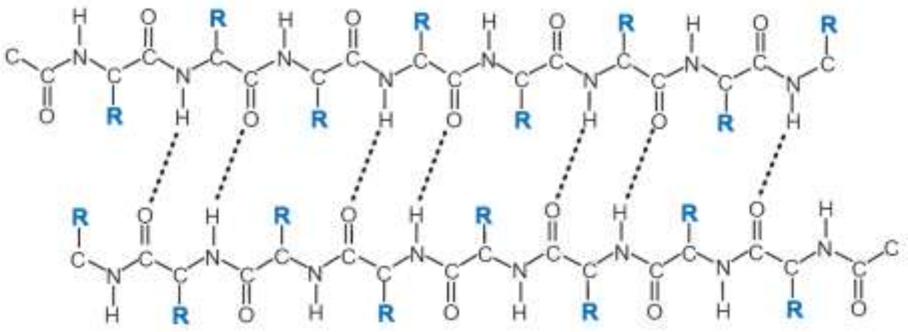
Another example of natural fibres is wool, which is produced as hair by animals. It can be obtained from different animals. Generally, the term wool is used for fibres from sheep but there are also cashmere and mohair from goats or angora from rabbits, among others.
As the fibre is a protein fibre and composed of more than 20 amino acids which form polymers, wool has special characteristics. The crimp formation, elasticity, staple and texture are influenced by the chemical structure of protein polymers. Furthermore, there can also be found calcium, fat, and sodium in the fibre. The fibrous structural protein of wool is keratin. The arrangement of parallel sheets of the outer layers of the polypeptide chains are connected via hydrogen bond. Tiny scales cover the central protein core of the fibre.
To list some important qualities of wool, it is hydrophilic, ready to absorb moisture, hollow, crimped and elastic. Wool grows in staples (clusters). Moreover, the ignition takes place at a higher temperature compared to cotton and it does not melt.

Source: Henkel. Waschen & Pflegen: Spezialratgeber Wolle. http://www.perwoll.de/waschen-pflegen/spezialratgeber/wolle-richtig-waschen.html#content61

Sources:
http://en.wikipedia.org/wiki/Wool
http://www.maxlawsoncarpets.com.au/why_wool.php?11/natural+fibres/163/wool
http://www.medicalsheepskins.com/wool.htm
Rösler, Friedrich. Naturfasern. NiU-Chemie 6 (1995) Nr. 26, Seite 5-8.

Silk is a natural fibre that is made up of proteins. The cocoons of the larvae of the mulberry silkworm are the base raw material of the silk fibre.

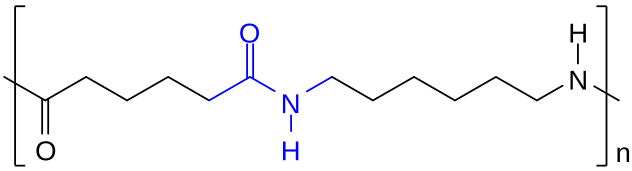
Excerpt from the secondary structure of a general silk protein, containing different amino acids:



Source:
http://en.wikipedia.org/wiki/Silk
Rösler, Friedrich. Naturfasern. NiU-Chemie 6 (1995) Nr. 26, Seite 5-8.

Nylon, first produced in 1935 by Wallace Carothers at DuPont's research facility in the USA, is a thermoplastic condensation polymer. It is a silky material which belongs to synthetic polymers due to its chemical structure. Nylon is polyamide 6.6 and is obtained of a diamine that is hexamethylene diamine (IUPAC name: hexane-1,6-diamine) and a diacid, namely adipic acid (IUPAC name: hexanedioic acid) in a condensation polymerization reaction. By that, repeating units are linked by amide bonds. Important characteristics due to the chemical structure are its high resistance to many chemicals, fungi, insects, mildew, molds, and rot. Besides, it melts instead of burning.

Excerpt from the Nylon structure:



Sources:
http://en.wikipedia.org/wiki/Nylon
Karraß, Sigurd. Chemiefasern: Aufbau-Strukturen-Anwendungen. NiU-Chemie 6 (1995) Nr. 26, Seite 9-15.

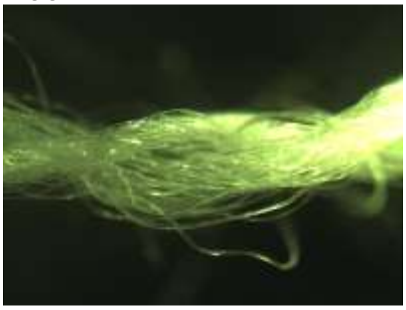
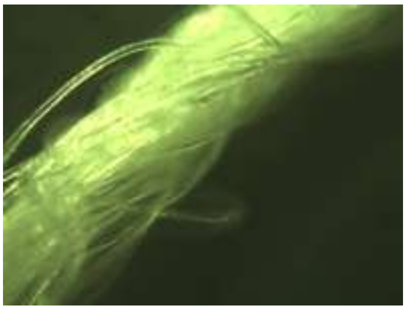
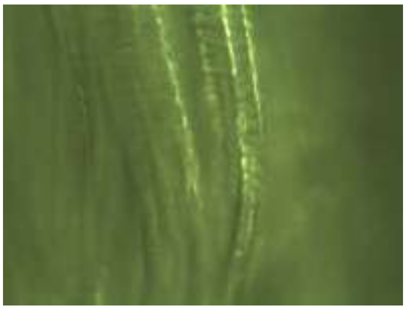
Additionally, **artificial/ viscose silk** is a half-synthetic fibre obtained from cellulose. **Microfibres** are fully synthetic fibres obtained from polyester or other fibres similar to Nylon.

Thickness of fibres

The following pictures of fibres were taken with a Motic BA 400 with different magnification (Source: Kirsten Fischmann, taken at IPN, Kiel, Germany):

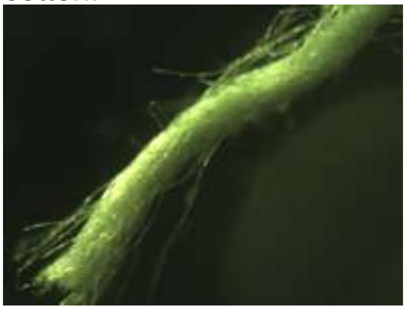
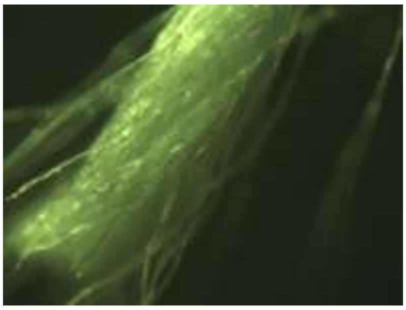
4 x /0.10 10 x /0.25Ph 40 x /0.65Ph

wool:

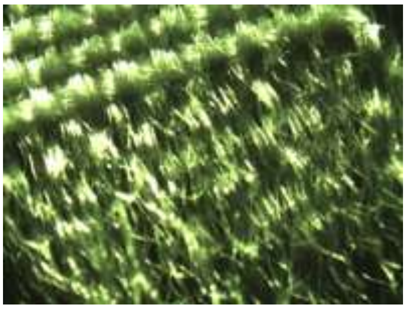
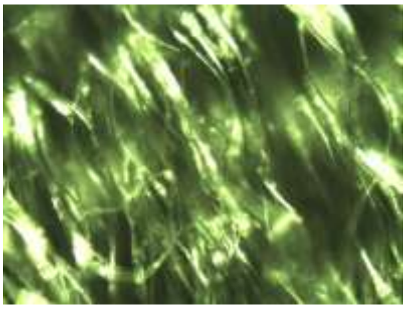
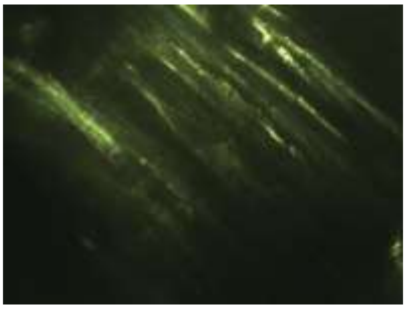
Here you can slightly see the scaly surface of the fibre.

cotton:

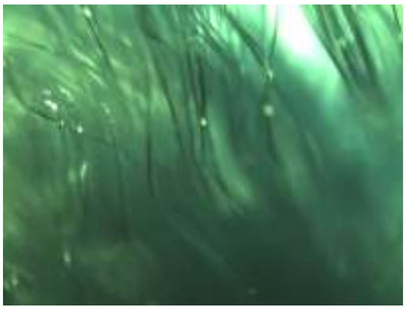
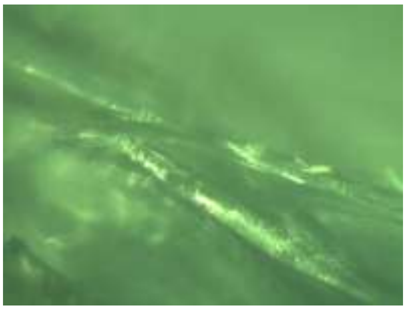
Notice the typical coiling of the fibre.

silk:

Slightly coiled fibre without scales.

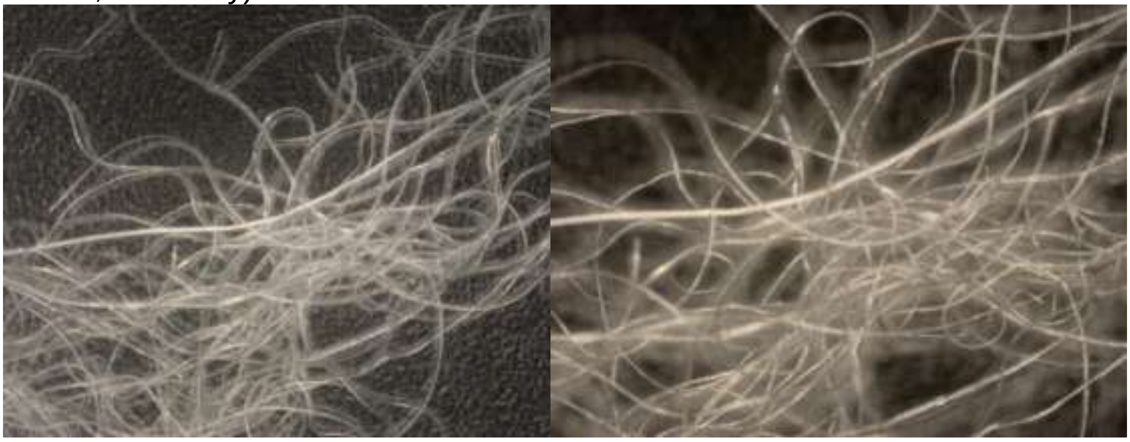
polyester:

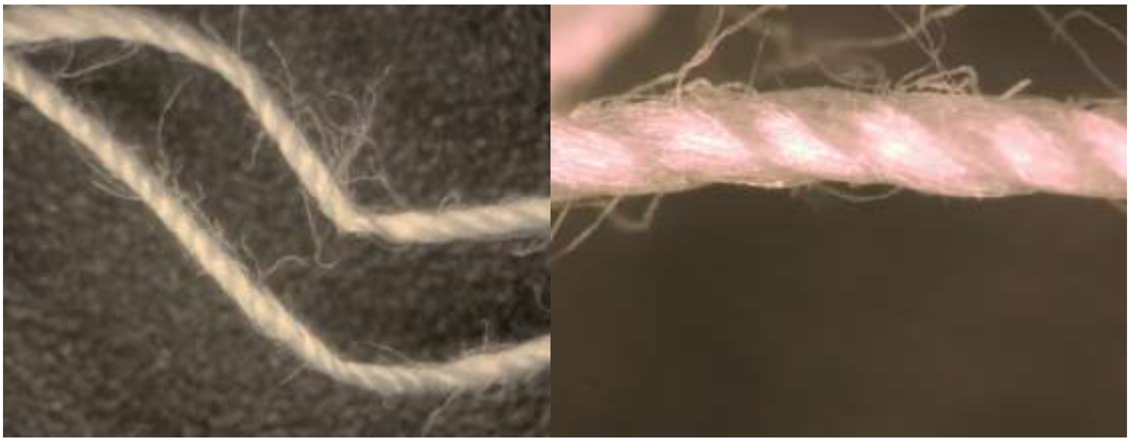
Straight fibre without scales.

The following pictures of fibres were taken with a Keyence Digital Microscope VHX-500F with up to 200x magnification (Source: Kirsten Fischmann, taken at Henkel AG & Co. KGaA, Düsseldorf, Germany):

lamb wool fibres

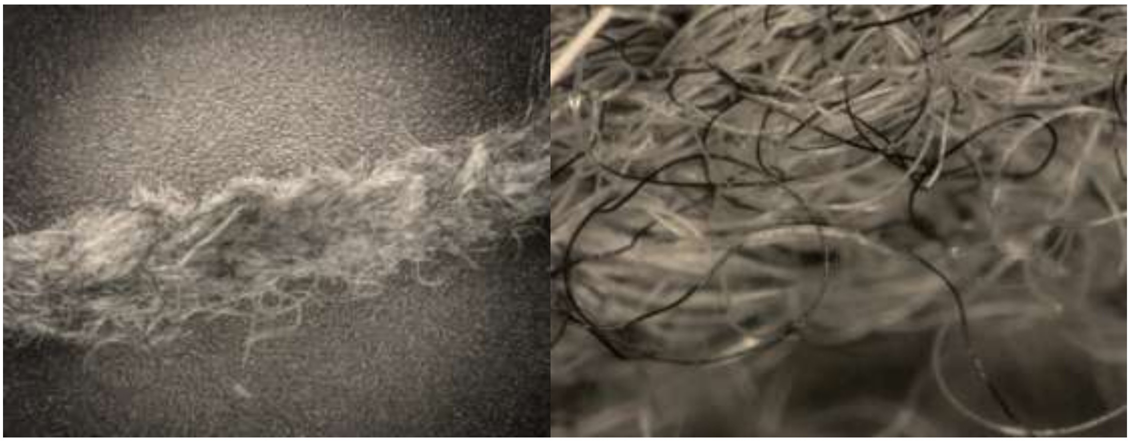


cotton fibres

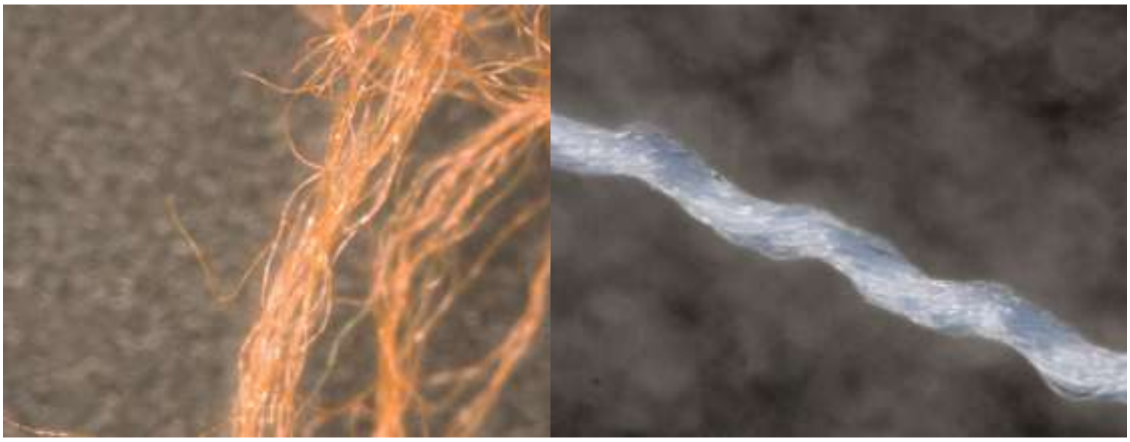


cotton, piece of textile

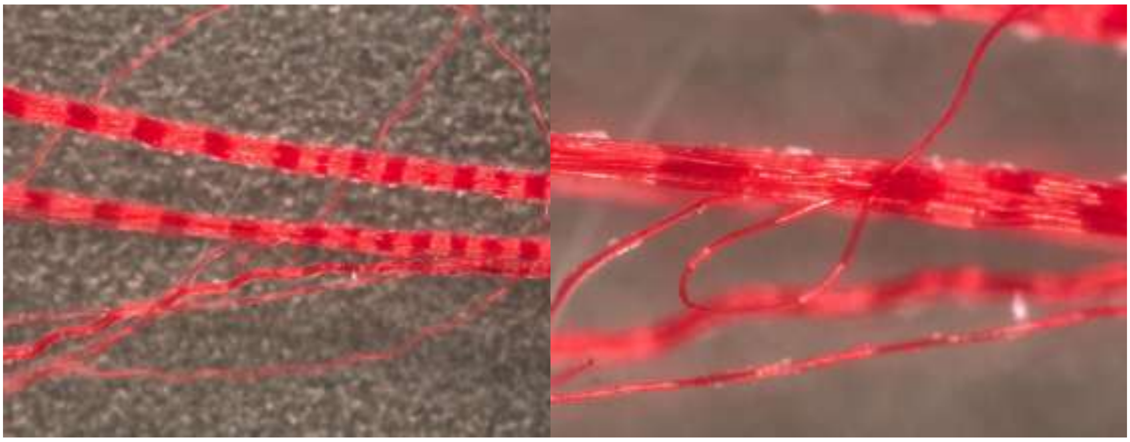
virgin wool fibre



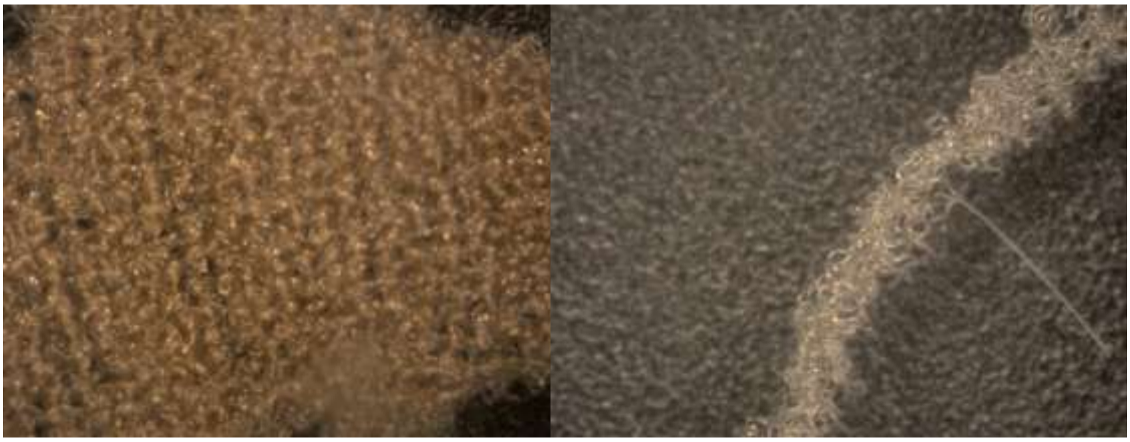
different polyester fibres



polyamide fibres



nylon tights



Methods for making semi-synthetic fibres
There are several methods for making semi-synthetic fibres. Research for example the methods for making acetate silk or rayon, copper yarn or viscose. There exist also several different methods of spinning, i.e. to twist fibres together to make yarn: the dry spinning process, the wet spinning process and the melt spinning process (for more information see: http://www.ivc-ev.de/live/index.php?page_id=58)

Apart from the above mentioned natural and synthetic fibres, there are fabrics with a porous or closed surface. The fabric / surface is characterised by its specific micro-structure which is made up by nodes. The latter exhibit an interconnection between fibrils. These textiles offer special properties such as being waterproof and breathable what hints at their usage. Examples for these special membranes are Gore-Tex®, SympaTex®, or Nomex®.

Gore-Tex® is a membrane of polytetrafluoroethylene. The special characteristics of this fabric are its waterproofness and breathability.

Size of islands about 10µm.
Figure adapted from: http://en.wikipedia.org/wiki/Gore-Tex

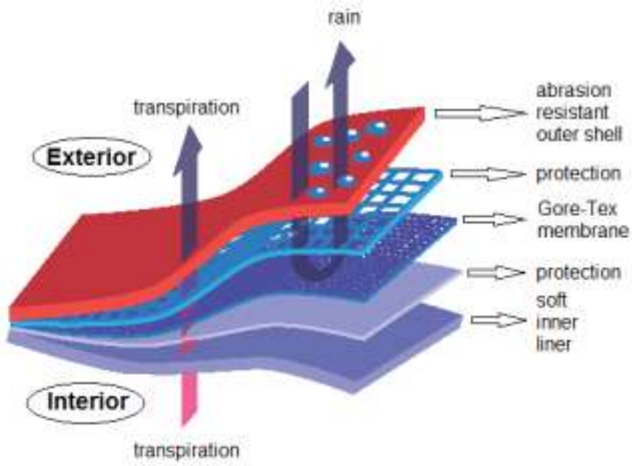
SympaTex® is a non-porous membrane which is a hydrophilic block copolymer made up of polyether-ester. The special characteristics of this fabric are as well its waterproofness and breathability but also its windproofness.

Source: http://en.wikipedia.org/wiki/SympaTex

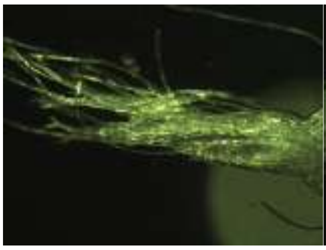
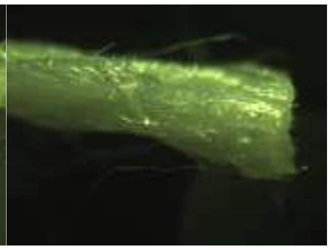
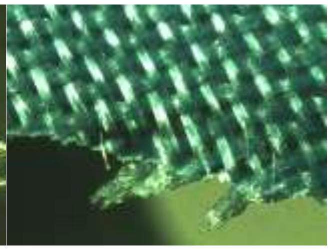
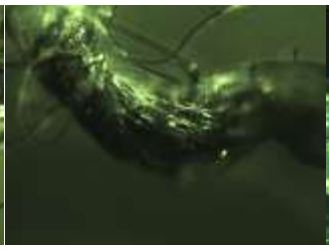
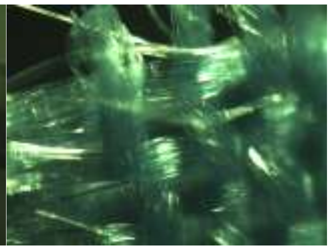
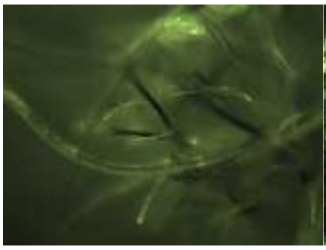
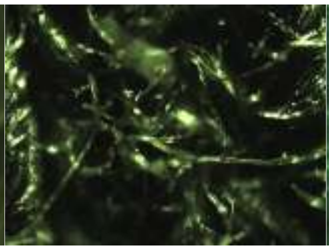
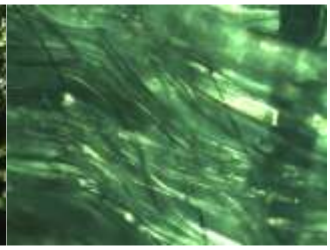
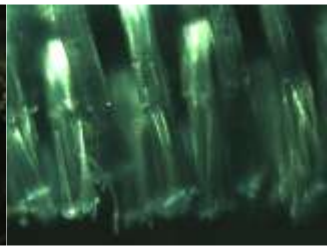
Nomex (styled NOMEX)® is an aromatic polymer of polyamide. Due to its stable molecular structure it is used as a flame resistant fabric.

Source: http://www.mueller-ahlhorn.com/de/Nomex.html

These membranes make up one part of functional clothes, often consisting of several layers. The following picture shows a structure of such a layered textile:



The following pictures were taken after treatment with different detergents.

type of fibre: laundry detergent:	wool	cotton	polyester
All-purpose detergent: Persil-Universal-Powder 5 g in 100 ml H_20, 90 min. at 40°C pH = 10,74			
Mild detergent: Perwoll – care for fine fabrics (liquid) 5 ml in 250 ml H_20, 110 min. at 40°C pH = 7,97			
soapsud: Fa Bar Soap Vitalizing Aqua 3 g in 250 ml H_20, 180 min. at 40°C pH = 9,33			
soapsud: washing soda 2 tablespoons in 250 ml H_20, 180 min. at 40°C pH = 11,26			
acidic solution: vinegar cleaner 5 ml in 250 ml H_20, 180 min. at 40°C pH = 3,75			

Background information on detergents

Solid or powdery all-purpose detergents can be used for washing processes at temperatures between 20°C and 95°C for all white and non-fading textiles of natural (e.g. cotton) and synthetic fibres with the exception of wool and silk but it depends on the textile itself which temperatures are appropriate. Bleaching agents in them are needed to remove bleachable spots as coffee or red wine. During the washing process the bleach system consisting of a peroxide compound and TEAD (Tetraacetylethylenediamine) deliberates peracetic acid which does not only bleach stains but is an effective antimicrobial substance. Thus, solid bleach containing all-purpose detergents are suitable for textiles with significant hygiene relevance (e.g. kitchen textiles) when used with a washing temperature of 40°C or higher. Liquid detergents normally do not contain bleaching agents however, they adhere better to spots. Furthermore, all-purpose detergents are basic. Due to their alkalinity and their content of protease enzymes, all-purpose detergents normally are not suitable for protein fibres like wool or silk.

As **wool and silk** belong to the fibrous structure proteins, a laundry detergent with a neutral pH value is needed. An alkaline pH of all-purpose detergents or detergents for bright colours causes the wool scales to open, they act as barbs, fibres are locked together and this leads to fulling and felting as well as contracting/ shrinking of the wool fibres which cannot be retrieved. Moreover, the detergent must not contain the enzyme protease as it would destroy the fibres as it conducts proteolysis. In this process peptide bonds linking amino acids are hydrolysed. Besides, wool has an effect of natural purification. The core of the wool fibre absorbs water / moisture while washing and soaks which makes the wet fibre sensitive. In the washing process the wool fibres move against one another. Due to that the rotational frequency of washing machines should be reduced as well as the temperature of the washing process (special washing programme for wool, cold – 40°C) and a special detergent for wool and silk (pH ≤ 8, special ingredients for a good foam formation) should be used to gain optimal care for wool. This also applies to silk which loses its resistance to tearing when washed with all-purpose detergents.
Mild detergents are used for the washing of fine coloured fabrics of natural and synthetic fibres (e.g. viscose) with the exception of wool and silk. They can be used at temperatures of 30°C to 60°C. They contain surfactants and are weak basic.
Detergents for bright colours can be used for washing processes at temperatures between 20°C and 60°C for all textiles of natural and synthetic fibres with the exception of wool and silk. They do neither contain bleaching agents nor optical brighteners but enzymes for spot removal. They are basic and gentle to colours.
Detergents for special fabrics e.g. detergent for wool and silk are suitable for textiles of wool and silk and fibre-mixtures of them. They are used at washing temperatures from cold to 40°C. Their pH value is neutral. They do not contain hurtful enzymes to preserve the fibres.
There are some more special laundry detergents as for example detergents for drapes, for journeys (travel detergents) and for sportswear and functional textiles.

Sources:
Richtig Waschen: Informationen rund ums Waschen – Spülen – Reinigen. Jens Gebhard, Christa Wolf, Kerstin Ochs. Henkel AG & Co. KGaA. Redaktion: Consumer Relations. Düsseldorf, 2008. pp. 11-14. http://www.henkel.de/de/content_data/ 95757_richtigwaschen_080723.pdf
Flyer: Textilien richtig waschen – Werte erhalten. Forum Waschen c/o. Industrieverband Körperpflege- und Waschmittel e.V. (IKW). Frankfurt am Main. 2011. http://www.ikw.org/ pdf/ broschueren/IKW_FB_RichtigWaschen_web.pdf

Water containing cleansers and detergents are in principle microbiological sensitive. A microbial attack or spoilage may occur due to bacteria in the environment breaking down biodegradable ingredients, such as e.g. enzymes or surfactants as they are organic. This can typically only be prevented by adding preservatives. Preservatives can function in different ways: they can influence bacterial DNA, their protein synthesis, their cell membrane or cell wall, among other things. Some formulations are resistant against a microbial attack due to their high surfactant concentration or their content of short chain alcohols or the extreme pH. During the product development process new formulas are checked for microbiological stability. In case a sufficient stability can be achieved only by addition of a preservative, the effectiveness and stability of the chosen preservative must be proven by suitable tests. Usually, preservatives approved for cosmetics are also used for laundry detergents and washing additives.

Sources:
Wagner, Günther (2005). Waschmittel: Chemie, Umwelt, Nachhaltigkeit. 3., vollst. überarb. u. erw. Aufl. Weinheim: Wiley-VCH Verlag. p. 116.
Lück, E. & Jager, M. (1995). Chemische Lebensmittelkonservierung: Stoffe, Wirkungen, Methoden. 3.überarb. Auflage. Berlin: Springer Verlag. p. 40-43.
Laundry Detergent Ingredients: Information Sheet. WashWise: A fresh approach to doing the daily laundry. Date of access: July 30, 2012.
< http://www.washwise.org.au/_documents/Laundry%20detergent%20ingredients%20info%20sheet.pdf>.

In the last years some innovations came up regarding the functionality of fabrics. There are different methods that are used to produce for example antimicrobial textiles. These textiles are used in medical areas, such as in infection prophylaxis in medical institutions to control the transmission of pathogenic germ or with people suffering from neurodermatitis as people fear of pathogenic organisms, germs and body-odour (caused by metabolites which are the result of the propagation of bacteria, the silver ions stop the propagation and the bad smell can be stopped as well) which make up the basis for antimicrobial textiles.
Some manufacturers use chemical additives such as quaternary ammonium salts, different kinds of the biopolymer (polysaccharide) Chitosan, or the antibacterial and antifungal as well as preserving agent Triclosan (not used anymore due to possible harmful impact to health). Some other manufacturers use silver which is weaved into the textiles in the form of fine threads or the fibres are interspersed by silver particles. Silver ions kill the bacteria which has an antimicrobial effect. Products may contain small amounts of the metal, in the form of nanoparticles that release ions slowly over time. By these additives antimicrobial textiles should not give bacteria a chance to deposit on textiles. Silver ions have various effects upon bacteria. Silver ions attack the organism's hereditary information of the bacteria and block important enzymes in the microbe/ microorganism. Furthermore, they break through the bacterial capsule and/ or cell wall. Silver ions have an effect upon the bacteria which get into the textiles via sweat/perspiration. So the body-odour is prohibited as well as the settlement/ colonization with pathogenic germs. The precious metal silver is known for its good (skin) tolerance and causes allergies only rarely. Although the textiles could be bought for years, there are only a few studies regarding the effects and impacts on microbial particles. Up to now the question of the building up of resistance, i.e. bacteria learn at regular contact with virtually deadly substances (e.g. silver ions) to resist them, is unclear.

Sources:
Welt Online. Schweissgeruch. “Hightech-Textilien als Geheimwaffe gegen Stinkefüße”. Peggy Freede. 04.03.2011. http://www.welt.de/wissenschaft/article12698561/Hightech-Textilien-als-Geheimwaffe-gegen-Stinkefuesse.html
Bild der Wissenschaft. Materialforschung. „Grün für Silber“ 17.01.2011. http://wissenschaft.de/wissenschaft/news/312728.html
Henry Fountain “Anti-Odor Silver Exits Textiles in the Wash”. The New York Times. Published: November 2, 2009. http://www.nytimes.com/2009/11/03/science/ 03obsox.html

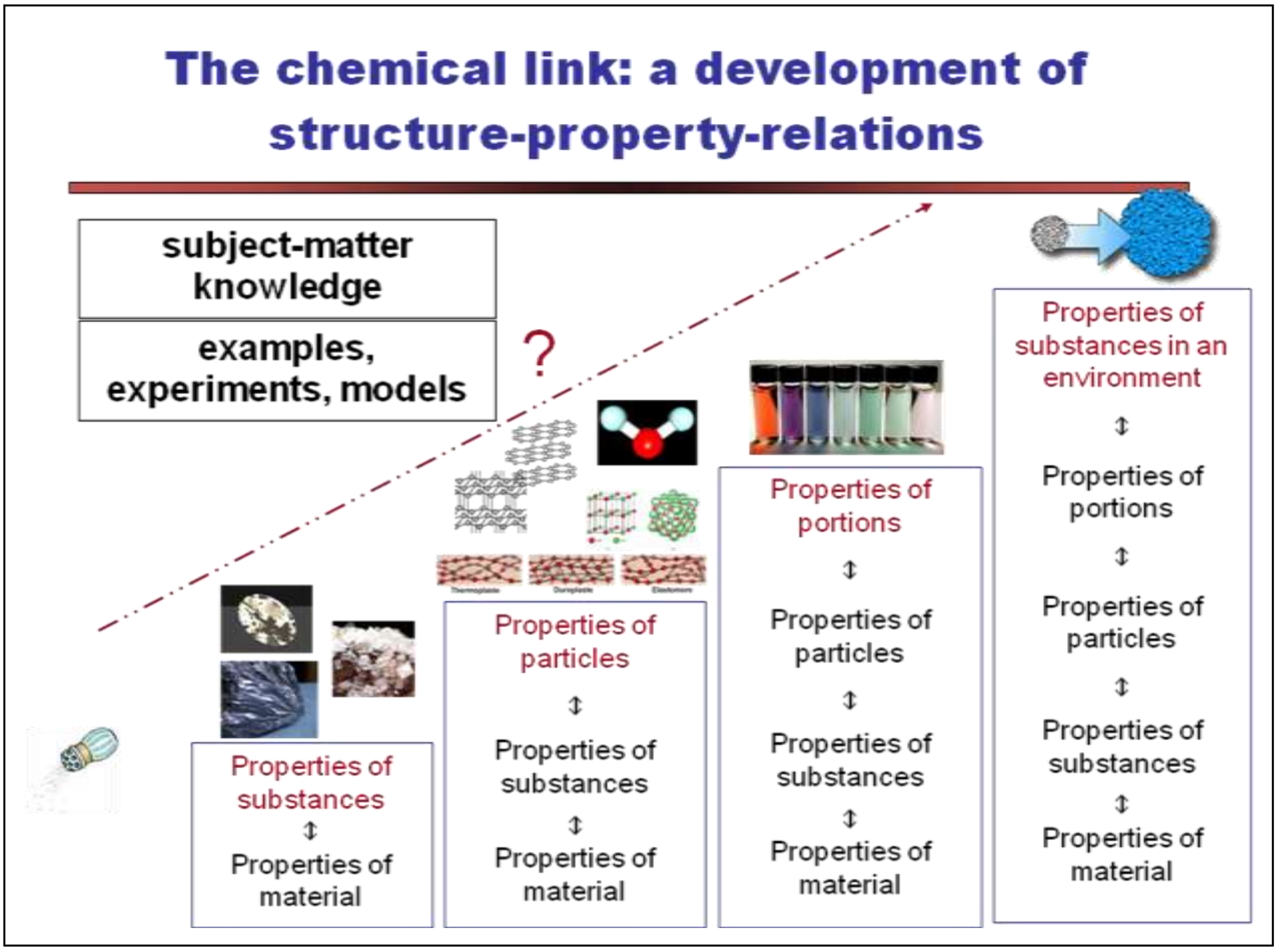
The following table shows a selection of available experiments on fibres, fibre synthesis and functional clothes, as can be found in German textbooks and journal articles.

<u>For adapting this table to the national standards, each partner should research national material.</u>

	Source
1. Syntheses that can be performed in school: a) Nylon® b) Polycaprolactam (Perlon®) c) Artificial silk d) PLA (polylactide)	a) Chemie im Kontext (2006). Berlin, Cornelsen Verlag, Material 7.3 of the student disc c) (s. Chemie heute – AB) d) Remus, L. (2005). PLA aus Milchsäure. PdN-ChiS, 54(4), p. 44-47.
2. Differentiation of types of fibres a) Test for behaviour when felt b) Test for behaviour when wrinkled c) Test for behaviour when burned d) Test for behaviour when smoldered – dry destillation e) Test for behaviour when applying bases f) Test for behaviour when applying acids g) Test for behaviour when applying acetone h) Test for behaviour when applying a drop of water i) Identification of non-dyed fibres with neocarmine-dye	▪ Pfeiffer, B. & Schmidkunz, H. (1995). Unterscheidung von Faserarten und Bestimmung von Fasern – Einfache Verfahren. *Naturwissenschaften im Unterricht - Chemie*, 6 Nr. 26, 21-23. ▪ Schmidkunz, H. (1995). Die Identifizierung von Fasern mit Neocarmin-Farbstofflösungen. *Naturwissenschaften im Unterricht - Chemie*, 6 Nr. 26, 24-25. ▪ Sawal, H.-B. (1997). Identifizierung von Textilfasern durch Experimente. *Praxis der Naturwissenschaften – Chemie*. 5/46. 30-32.
3. Properties of textiles a) Permeability regarding air b) Permeability regarding water c) Permeability regarding steam d) Amount of water absorption e) Insolating properties f) Behaviour when heated	
4. Treatment of fibres a) Dying (material e.g. cotton, linen, silk, wool, cellulose acetate, polyacryl, polyamide, polyester) b) Washing c) Ironing d) Waterproofing e) “Smell“proofing	Lehmann, D. & Pfeifer, P. (1995): Färben von Naturfasern und synthetischen Fasern mit Naturfarbstoffen. *Naturwissenschaften im Unterricht - Chemie*, 6 Nr. 26, 26-29.

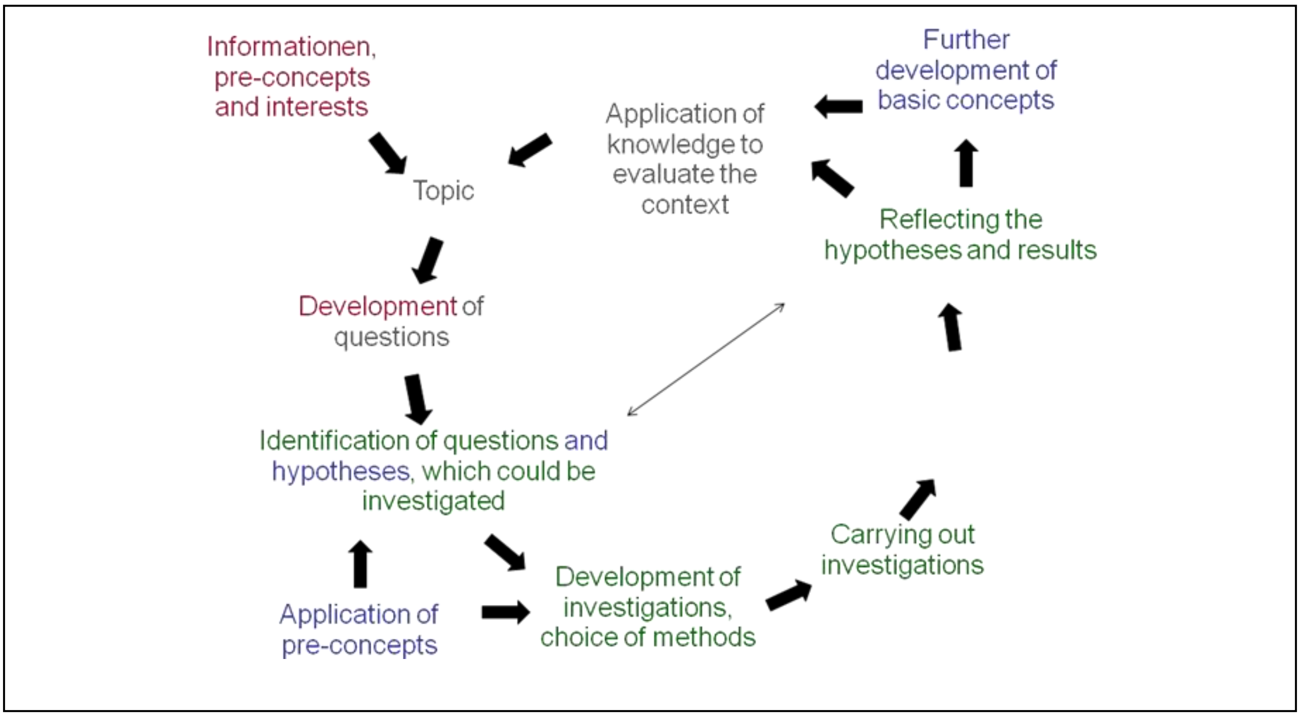
IV. Pedagogical Content Knowledge

The unit on chemical care wants to enhance the students' thinking of substances in interaction with their environment. This is a more complex view than just describing substances and their properties. Research on structure-property-relations (summarised e.g. by Scheffel et al., 2009) points out that students often focus only on one criterion instead of the interaction of different criteria influencing a property or a behaviour. Even in complex structures, properties are sometimes referred to as properties of individual atoms. Additionally, macroscopic properties are sometimes transferred onto sub-microscopic structures in a misleading way, such as giving colours to atoms. The approach of this unit is to avoid this narrow thinking right from the beginning by pointing out the use, the behaviour and the consequences of substances in an environment, not isolated from it. The level of complexity develops from sub-unit to sub-unit, but each new sub-unit should be connected to the knowledge already developed before, as shown in the following figure.



Regarding the method or pedagogical teaching and learning approach, all sub-units allow the students to develop their own ideas for experiments and explanations, of course guided by the material. Next to the guideline of IBSE, context-based learning (see a connection of approaches in Bulte, Pilot & Gilbert, 2006, or in Nentwig & Waddington, 2005) is applied in the design of the units and the material. In sub-unit 1, the students are led through the activities by the story ("storytelling") of becoming a household detective. Sub-unit 2 also situates the activities in the students' home, this time focussing on cleaners and the help of chemical knowledge for a careful treatment of their own and their families' health as well as of objects at home. Sub-unit 3 deals with clothes and fibres, both embedded in daily-life situations, and in industrial contexts.

All sub-units can be structured along the following phases (see Nentwig et al., 2007):



References:

Gilbert, J., Bulte, A. & Pilot, A. (2006). Special Issue on Context-based learning. *International Journal of Science Education (IJSE)* 28/9

Nentwig, P., Demuth, R., Parchmann, I., Gräsel, C., Ralle, B. (2009). Chemie im Kontext: Situating Learning in Relevant Contexts while Systematically Developing Basic Chemical Concepts. Journal of Chemical Education, 84(9), 1439-1444.

Nentwig, P., Waddington, D. (Eds.)(2005). *Making it relevant. Context based learning of science*. Münster: Waxmann.

Scheffel, L., Brockmeier, W., Parchmann, I. (2009). *Historical Material in Macro-Micro Thinking: Conceptual Change in chemistry Education and the History of Chemistry*. IN: Gilbert, J., Treagust, D. (Eds.). Multiple Representations in Chemical Education. Dordrecht: Springer.

V. Industrial Content Knowledge

Sub-unit 1 is not related to industrial processes directly, but it can be connected to especially community plants e.g. by the following activities:

- Students can search for products and how they are described and produced on the internet, connecting the products they have found in their house to producers and selling companies / stores.
- Teachers can decide to connect the “household detective” activities about analyzing substances to a visit in a water plant / wastewater treatment station to compare different ways of chemical analyses.

Sub-units 2 and 3 are already based on co-operations with industry, here with the example of the Henkel Company. Students should not only learn about the chemistry of e.g. cleaners or fibres, they should also learn about how and why they are produced and optimized in certain ways. Industry can provide information on different levels, for example through

- websites or booklets about the historical development of a certain product;
- a real or virtual visit to a plant producing a certain product;
- real or podcasted interviews with experts working in the production or the management, giving information on how and why decisions are taken and a new process is initiated and more.

Background information on the company

Henkel AG & Co. KGaA, a multinational personal care company, was founded in 1876 in Aachen as Henkel & Cie by Fritz Henkel and two other partners. Today the company is headquartered in Düsseldorf, North Rhine-Westphalia, in Germany.

Henkel has three worldwide operating business areas which are Laundry & Home Care, Cosmetics/Toiletries and Adhesive Technologies. The company employs about 48,000 employees worldwide. Globally it holds leading market positions both in the consumer and industrial businesses. Its most famous brand is Persil, the first commercial laundry detergent. Other well-known brands are Schwarzkopf and Loctite, for example.

Henkel products range from household cleaning products (laundry detergents or dishwashing liquid (Persil, Spee, Vernel/Silan, Somat etc.)) over personal care products (shampoo, toothpaste, hair colorants etc. (Schauma, Fa, Diadermine etc.)) to adhesives, sealants and surface treatment products for consumer and industrial purposes.

VI. Learning Path(s)

In all three sub-units, students are introduced into some basic chemical knowledge about structure-property relations, they are enabled to enhance that knowledge based on further investigations, and they are invited to become creative about thinking of new products or ways of presenting ideas to others.

Sub-unit 1 offers basic knowledge on approaches to describe, to structure and to systemize “chemical substances” that students can find at home.
In a second phase, they carry out experiments to deepen their knowledge on properties and behavior of such substances in different environments, e.g. by mixing them or changing conditions such as the temperature. They should develop a deeper knowledge e.g. on systematic tests of solubility (salt / oil / coffee in water), heatability (salt, sugar water), effects on organism (bacteria, skin) etc.
From this, they can draw conclusions about safe treatments which they are invited to present in the third phase.

Sub-unit 2 wants to engage the students in using and enlarging their chemical (and biological) knowledge for the explanation of processes related to cleaning demands in the household. As this might not always be an encouraging topic for 13-14-year-olds, the sub-unit describes several stimulating and sometimes maybe surprising experiments that the students can carry out themselves.
The basic background they should build up throughout the sub-unit is led by the question of how to classify dirt they can see and “dirt” they cannot easily find, such as bacteria. They shall be able to differentiate between hydrophilic and hydrophobic dirt (polarity of structures), living dirt (protein membranes of bacteria), fibre dirt (basic structures and functional groups / reactivity); different cleaning agents such as water / acids / bases / alkanes / acetone (classification).
They should enlarge their knowledge by carrying out experiments to investigate interaction between dirt and cleaning detergents, and they should interpret their findings based on what they had learned about solubility and reactions with focus. On the sub-microscopic level, they should use models about inter- or intramolecular bonding and reactions.
In the third phase, the students are invited to create “the optimal cleaning agent”, designing a product and a strategy to sell it and explain its properties according to its chemical functionality for different situations and environments.

Sub-unit 3 lays or enhances a content knowledge background on fibres used in clothes. The students will analyse structures and properties and will learn how to classify polymers. They investigate different fibres in different products, e.g. the effects of weather (water, temperature), skin (moisture, temperature, skin) and washing detergents (different ingredients, temperature).
The investigations and the discussion of results shall lead to a deeper understanding of structure-property-relations in changing environments, applying model-based explanations and systematic series of experiments along the IBSE structure.
In the closing phase of the sub-unit, the students are invited again to become creative: They should invent “the dream fibre” or “the dream detergent” with argumentations based on structure-property-knowledge, IBSE structure for engineers, and STS arguments.

Student Learning Activities

Activity	***Inquiry type***	***E-emphasis***
1.1 Formulating questions	open inquiry	engagement
1.2 Formulating hypotheses	open inquiry	exploration
1.3 Planning an investigation	bounded inquiry	exploration
1.4 Carrying out experiments	bounded inquiry	exploration / explanation
1.5 Transfer of knowledge	--	explanation / evaluate
1.6 Further applications I	open inquiry	exploration
1.7 & 1.8 Further applications II	bounded inquiry	exploration
1.9 Further applications III	bounded inquiry	explanations
2.1 Which household products contain acids?	guided discovery	engagement / exploration
2.2 How much acid do we find in a household product?	guided discovery	exploration
2.3 Why do companies include acids into cleaning products? – Intended effects	guided discovery	explanation
2.4 Which effects can acids have on different materials and on our health? – Not intended effects	guided discovery	explanation / extend
2.5 Comparison of the effectiveness of different household detergents	guided discovery	explanation / evaluation
3.1 Analyzing fibres	guided discovery	exploration
3.2 The history of fibres	--	engagement
3.3 Production processes of textile fibres	--	engagement
3.4 Characteristics/Properties of fibres	guided inquiry	exploration / explanation
3.5 Membranes – Multifunctional fabrics	guided inquiry	exploration / explanation / extend
3.6 Keeping textiles clean	guided discovery / inquiry	exploration / explanation
3.7 Economic view on textiles	--	evaluation
3.8 Ecological view on textile care	--	evaluation
3.9 Synthesis of bio-fibres	--	extend / evaluation
3.10 The dream fibre/plant	--	extend / evaluation

VII. Assessment

For assessment, both IBSE-steps and content knowledge on structure-property-relations should be taken into consideration.
The students' understanding of important IBSE steps in scientific and in industrial engineering processes can be assessed during the units in a formative way. The usual approach is of course to assess the protocols the students often have to write following an experimental investigation. Making use of modern techniques, an alternative and probably more stimulating method would be a student's documentation by taking photos or producing a little film about an experiment. The latter can include the macroscopic level as well as the sub-microscopic level.

A comparison of an IBSE process carried out to investigate the properties of a detergent (= a scientific approach) and the optimization of a detergent (= an engineering approach) can help to find out how much the students have actually understood about the nature of science. Empirical studies show, for example, that students seem to have difficulties with the formulation and functionality of hypotheses in processes or seem to regard all experiments as approaches to optimise something, not to derive knowledge.

To test content-knowledge, tests should combine basic tasks with context related tasks to assess the students' abilities on application and transfer as well.

Again, formative assessment should be integrated as well.

VIII. Student learning activities

SUB-UNIT 1:

<u>Overall learning aims:</u>

Students learn a simple definition of chemical substances (and chemical reactions, depending on the curriculum). They learn how to characterize substances using different systematic approaches such as observation or experiments. They familiarize themselves with the steps of IBSE using experiments and learn how to document an experiment (protocol schemes).

The students take on the role as “household detectives”, investigating where they can find chemicals in their homes, what chemicals do to certain stains etc.
In order to benefit from this learning process, the following activities should be gone through chronologically by all students. Therefore, the activities are only described in a few words here and can be found in detail in the classroom material.

To start, divide the class into groups of “detective teams”. The following box names activities that can be carried out by those teams. While 1.1. to 1.3 are essential for all, the others can be chosen, arranged or divided by the teachers in different ways. The material describes a storyline that can be given or told to the students to structure their work.

Activity 1.1: Formulating questions

<u>Learning aim:</u>
Here the focus lies on having the students state what they would like to find answers to because it is crucial to involve students’ ideas and (mental) conceptions to make this unit interesting for them. Students learn to think about their environment carefully as it is crucial to raise their awareness about chemistry and dangerous substances.

<u>Material:</u>
see classroom material

<u>Suggestions for use:</u>
The students can think about their questions in their detective team.

Activity 1.2: Formulating hypotheses

<u>Learning aim:</u>
Here the focus lies on having the students state what they expect to find out. In their detective team they learn to formulate hypotheses regarding their research questions of Activity 1.1.

<u>Material:</u>
see classroom material

<u>Suggestions for use:</u>
The students can present their hypotheses to the other teams.

Activity 1.3: Planning an investigation

Learning aim:
Here the focus lies on having the students state how they want to proceed. The aim is to make them think about a structured and logical plan how to conduct experiments. Furthermore, students learn how to define chemical terms.

Material:
Instructions for this activity, paper and pencil, chemistry book, internet
see classroom material

Suggestions for use:
In their detective teams students can research, for example,

- what “chemicals” are;
- safety measures necessary for performing experiments (obligatory!);
- what symbols there are to classify chemicals regarding their hazard (obligatory!);
- what parents/friends think about using chemicals (doing interviews);
- how chemicals can be classified according to their properties (colour, state of matter, ...) etc.

Activity 1.4: Carrying out experiments

Learning aim:
While having a look at the laboratory equipment students learn about the various functions of the different tools. The students learn to plan experiments on their own. The students learn how to responsibly carry out experiments as well as to document them.

Material:
Laboratory equipment
see classroom material
Experiments with white substances

Suggestions for use:
The variety of experiments can be chosen by the teachers. Students should pay special attention to the

- safety regulations;
- control of variables and
- the documentation of their experiments (procedure and observation).

Activity 1.5: Transfer of knowledge

Learning aim:
Here students can deduce from chemical behaviour to household use. They learn to transfer their newly gained knowledge and apply it to daily life.

Material:
see classroom material

Suggestions for use:
The students can solve this activity in team-work.

Activity 1.6: Further applications I

Learning aim:
Here students hypothesize which chemicals they could use to reduce risks in the household.

Material:
see classroom material

Activity 1.7 & 1.8: Further applications II

Learning aim:
Here students investigate which chemicals can be used to remove different stains.

Material:
see classroom material

Experiments (for more guided versions regarding the experiments consider the instructions below)
Worksheet 1: Introduction and safety information
Worksheet 2: How are stains and dirt removed from clothes?
Worksheet 3: The influence of temperature on wash performance
Worksheet 4: Laundry detergents then and now
Worksheet 5: Laundry detergents and the environment
Experiment 1: Finding bacteria

Suggestions for use:
In their detective teams students can cover, for example,
- the differentiation between pure substance and mixture and/or
- what a chemical reaction is (basic level definition).

Activity 1.8 can be complemented with an industrial visit to a sewage treatment plant.

More Guided experimental instructions:

Regarding Worksheet 2:

Apparatus and materials:

- Hotplate
- 2 beakers (500 ml)
- Pieces of cloth
- Glass rod
- Thermometer
- Pipette (1 ml)
- Water
- Pieces of cloth
- Oil (e.g. bicycle oil)
- Liquid laundry detergent

Procedure:

- Take three pieces of cloth and carefully apply a little bicycle oil to each piece, so that a circular stain is formed. Leave the cloth for about 10 minutes, to allow the oil to dry.
- Add about 250 ml water to each of the two beakers.
- Place one of the beakers on a hotplate. Set the temperature control to 30°C and wait while the water heats up. Check the temperature at intervals with the thermometer.
- When the water in the beaker on the hotplate reaches 30°C, drop a piece of cloth into each beaker. Stir the contents of each beaker with the glass rod at intervals over a period of about 10 minutes.
- When the ten minutes have elapsed, use tweezers to take the pieces of cloth out of the water. Examine the cloth pieces to assess the wash result.
- Add 1 ml of the liquid detergent to the beaker containing water at 30°C to create a washing solution. Drop the third piece of cloth into the beaker. Leave it for 10 minutes, stirring occasionally with the glass rod. Remove the piece of cloth after 10 minutes and assess the wash result.

Observation and evaluation:

Piece of cloth washed with …	Wash result
water (cold)	
water (hot)	
wash solution (hot)	

Disposal

- Put the pieces of cloth in the waste bin.
- Empty the beakers (containing water, and detergent) down the sink.
- Put the residual oil into chemical waste.

Source of experiment:
Henkel (2008): Sustainable washing for a clean environment – Chemistry for beginners (11 – 13 year old).

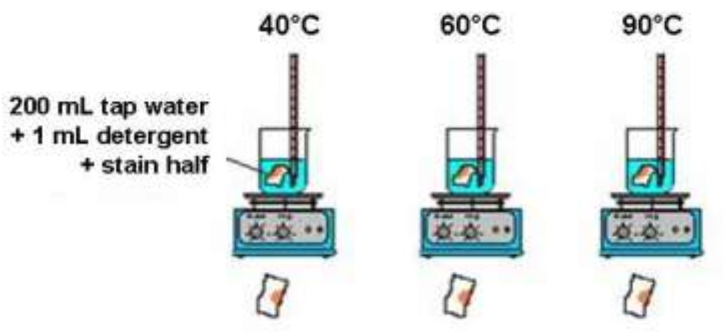
Regarding Worksheet 3:

Apparatus and materials:

- 3 beakers (250 ml)
- graduated cylinder (200 ml)
- 3 hotplates (with stirrer and 3 follower bars or glass rods)
- 3 thermometers
- 3 watch glasses
- Stopwatch
- Tweezers
- Scissors
- graduated pipette (1 ml)
- Pipette filler
- Liquid detergent for colored laundry
- 3 cocoa stains on cotton cloth

Procedure

- Cut out generous pieces of cloth, each with a stain in the center, and cut each stain in two. One stain half will be washed and the other will be used for comparison. Mark the stain halves with a pencil to identify them.
- Add 200 ml tap water to each beaker. Place each beaker on a hotplate and heat one to 40°C, one to 60°C and one to 90°C. Keep the temperatures constant. Cover each beaker with a watch glass.
- After the required temperatures have been reached, pipette 1 ml of the liquid detergent into each beaker. After the detergent has dissolved, drop one stain half into each beaker and start the stopwatch to count down 40 minutes. Stir the liquid in each beaker at intervals or, if stirrers are available, use the stirrers on a medium setting.
- When the 40 minutes have elapsed, take the stain halves out of the wash liquid and dry them. Compare them to each other and to their respective unwashed halves.



Experimental setup

Disposal

- Allow the wash liquid to cool and pour it down the sink.
- Reuse the cloths if possible, or put them in the waste bin

Source of experiment:
Henkel (2008): Sustainable washing for a clean environment – Chemistry for beginners (11 – 13 year old).

Activity 1.9: Further applications III

It depends on the facilities and regulations in each country whether the experiments with bacteria can be carried out.

Learning aim:
Here students investigate where potentially harmful bacteria can be found in the household and how they can be made visible. They transfer their gained knowledge to their household and reflect this topic.

Material:
Experiments: see classroom material

Suggestions for use:

- Students are to select places they want to test for presence of bacteria. Good places to check are light switches, water faucets, pullover sleeves before they go in the wash, ...
- Students should observe that bacteria colonies and fungi are obvious to varying extends after incubation, but that most detergents do not eliminate all bacterial growth.
- Suggest to the students using different concentrations of cleaners.
- Check with biology colleagues for disposal of bacteria cultures or do the following:
  - put in autoclave for min. 20 minutes at 121 °C or in pressure cooker for min. 30 minutes at 116 °C, inactivated material can be given into the dustbin or
  - contact hospitals or hygienic institutes to find out whether they will cover the disposal or
  - burn outside and not in vicinity of people/schools...

SUB-UNIT 2:

Overall learning aims:

The students should learn how to apply and enlarge their chemical knowledge to explain “normal” procedures and products in use at home. The topic of cleaners has been chosen even though it might not be the most interesting one to 13/14-year-olds as it offers a variety of stimulating experiments the students can carry out themselves.

The sub-unit can begin with newspaper articles on accidents in the household and / or advertisements for household products such as detergents and cleaners. The students can be invited to develop and collect explanations in small groups choosing different stories or advertisements. To do so, they have to apply their knowledge on substances and reactions. They are also asked to write down questions for aspects they cannot explain.

Following this broader collection, the students can decide together with the teacher which specific topics they wish to investigate further. One area would be the investigation of different cleaners, regarding general properties (e.g. solubility, pH), and effects on different stains. The result should be a table of substances, properties and suggestions for use, combining results collected from different groups. The process of investigation should follow the IBSE steps, as exemplarily described in sub-unit 1.

Activity 2.1: Which household products contain acids

Learning aim:
Here the focus lies on having the students state what they would like to find answers to.

Material:
Experiment: see classroom material

Suggestions for use:

- Many household substances can be analysed with an indicator in this way. Students can analyse various cleaners based on lemon or vinegar, lemon concentrate, essence of vinegar and decalcifying substances in either solid form (sometimes they consist of pure citric acid) or in liquid form (look for products containing a 50 % citric acid solution).
- The substances colour the dyed filter in different shades of pink. Based on the differences, students can deduce that there are different substances with acidic properties. From the differences in intensities, they can also see that there are variations regarding the intensity of acidic behaviour.

Activity 2.2: How much acid do we find in a household product?

Learning aim:
Here the focus lies on having the students state what they expect to find out.

Material:
Experiment: see classroom material

Suggestions for use:

- Students must be able to calculate volume-concentration-relations.

Activity 2.3: Why do companies include acids into cleaning products? – Intended effects

Learning aim:
Students learn to explain the functionality of acids based on their chemical structure and reactions.

Material:
Experiment: see classroom material

Suggestions for use:
- Since students know that lime scale build-up occurs in water heaters, this experiment can be used as an introduction to the process of calcification.

Activity 2.4: Which effects can acids have on different materials and on our health? – Not intended effects

Learning aim:
Students learn to explain the functionality of acids based on their chemical structure and reactions.

Material:
Experiment: see classroom material, choose some or all experiments from Activity 2.4.1 to 2.4.4

Suggestions for use:
- The experiments show how acids react with different substances, such as bone, meat, marble or metals.

Activity 2.5: Comparison of the effectiveness of different household detergents

It depends on the facilities and regulations in each country whether the experiments with bacteria can be carried out.

Learning aim:
Students learn something about the effectiveness of household detergents because there are differences in their function, as e.g. only some are antibacterial.

Material:
Experimental: see classroom material

Suggestions for use:
- This activity provides an opportunity to combine biological topics with chemistry, e.g. in terms of enzymes and detergents.
- Have students repeat procedure using chemicals at different concentrations (alkaline, neutral, acidic) instead of cleaners.
- Contact plates should be sealed before incubation with Parafilm® tape or something similar to avoid contamination and exposition.
- The plates should be sealed after incubation.
- After working with bacteria, work areas and hands should be disinfected.
- Check with biology colleagues for disposal of bacteria cultures or do the following:
  - put in autoclave for min. 20 minutes at 121 °C or in pressure cooker for min. 30 minutes at 116 °C or
  - contact hospitals or hygienic institutes to find out whether they will cover the disposal or
  - burn outside and not in vicinity of people/schools...

Possible result after incubation: 

Activity 2.6: The optimal cleaning reagent

Learning aim:
Students learn to use the structure-property-knowledge obtained so far. Along the lines of STS approaches, they use logical reasoning skills to argue hypothetically which characteristics should be combined to generate the perfect cleaning reagent.

Material:
Results of Activities 2.1 - 2.5

Suggestions for use:
- Students can assess desirable and problematic properties of cleaners presented so far

SUB-UNIT 3:

Overall learning aims:

In this unit, students shall get to know different types of fibres, both synthetic and natural ones. They are also familiarized with the fibres' synthesis, both in laboratory and in industry. While describing the fibres' use based on their properties, students will learn to differentiate between the macroscopic and the sub-microscopic levels.

III.I Fibres in clothes: analyses of structures and properties

- Basic knowledge: classification of polymers
- Classification and structure (incl. pictures) of fibres (synthetic vs. natural fibres)
- Industrial production of fibres

Activity 3.1: Analyzing fibres

Learning aim:
The pictures present the structure and the composition of fibres. Students work with authentic materials to get to know both natural and synthetic fibres (compare figure 1: classification/synthesis of textile fibres). For several types of fibres, their synthesis is analyzed in regard to polymer mechanisms.

Material:

- Various pictures of different types of fibres, taken with high resolution camera and microscope.
- Experiments: Syntheses of various types of fibres.

Suggestions for use:

- The images of differently scaled fibres are compared. The fibres are looked at more closely at their submicroscopic level. The fibres' properties can be worked out through the existence of functional groups. From the pictures, the composition of the fibres, their size and their chemical structure can be analyzed.
- Students can also collect types of fibres from their own clothes and analyze those.

Activity 3.2: The history of fibres

Learning aim:
This activity is to introduce students to the historical developments of different fibres.

Material:
Books or other resources, internet

Suggestions for use:

- Research activity in which students can gather information on the developments of different fibres
- Can be done in group work
- Students can present their findings to each other
- Activity can be done with or without going into chemical details, depending on focus, time and knowledge of students

Activity 3.3: Production processes of textile fibres

Learning aim:
Students familiarize themselves with the production process of textiles by following the path of the raw material such as cotton through the different production steps.

Material:
internet, informational material, videos or other teaching material
Worksheet 6: The spinning process

Suggestions for use:
- This activity can be complemented with an industrial visit to a fibre production plant.
- This activity can be worked on in groups
- Other processing methods (spinning and weaving methods) can also be covered.

III.II Fibres in products: interaction with weather (water, temperature), skin (moisture, temperature, skin) and washing detergents (different ingredients, temperature)

- Deeper analyses: structure-property-relations in changing environments, model-based explanations and systematic series of experiments
- Characteristics of fibres e.g. behaviour of the fibre in acid/base, water and various washing detergents, in the washing process or while ironing (information on care labels)

Activity 3.4: Properties of different fibres

Learning aim:
Through various experiments, students learn about the properties of different fibres. Here, students are to find out what makes textiles comfortable to wear in certain situations or how certain textiles are to be treated.

Material:
Experiments investigating properties of textiles made of different fibres (e.g. wool, silk, cotton, rayon...; have students collect different clothes samples):

- Permeability regarding air (with pressure)
- Permeability regarding water (jet of water and water drops)
- Permeability regarding steam
- Amount of water absorption
- Insulating properties
- Behaviour when heated

For ideas on experiments, see descriptions below.

Suggestions for use:

- The experiments described in the Classroom Material section can be used as a starting point; encourage students to improve them, however, to make the procedures more standardized and comparable.
- Students should be guided to think about how their findings relate to the everyday use and care of textiles made of different fibres.
- This activity can also be carried out in groups, in which the groups can be divided according to a) each group performing the same experiments but with different textile samples or b) each group performing different experiments with the same material sample.

Activity 3.4: Characteristics/ Qualities of fibres

These are only suggestions. Students will be much more motivated if they can think up their own ways to test these properties, as can be seen by the adaptations made on the photographs (taken by Joachim Borchert):



1) Permeability regarding air

Material:
Plastic syringe (100 ml), stop watch, textile samples (e.g. cotton, polyamide, wool, silk, polyester, PVC)

Chemicals:
air

Procedure:
Fill the plastic syringe with 80 ml of air. Keeping the textile sample pulled firmly over the opening of the syringe, push the air through the textile sample by applying steady force on the plunger. Pay attention to applying the same force with all textile samples. Record the time it takes to push all 80 ml through the textile sample. Sort the textile samples according to their permeability regarding air.

possible questions:

- What is the reason for the difference in permeability regarding air?

2) Permeability regarding water

a) Water drops

Material:
Plastic pipette, small beaker or small (marmalade) jar, textile samples (e.g. cotton, polyamide, wool, silk, polyester, PVC)

Chemicals:
Tap water

Procedure:
Stretch the textile sample over the jar and put a drop of water on the sample.

possible questions:

- What can you observe regarding the water drop on the different textiles?
- How can you explain your observations?

b) Jet of water

Materials:
Plastic syringe (100 ml), stop watch, textile samples (e.g. cotton, polyamide, wool, silk, polyester, PVC)

Chemicals:
Tap water

Procedure:
Fill the plastic syringe with 80 ml of water. Keeping the textile sample pulled firmly over the opening of the syringe, push the water through the textile sample by applying steady force on the plunger. Pay attention to applying the same force with all textile samples. Record the time it takes to push all 80 ml through the textile sample. Sort the textile samples according to their permeability regarding water.

Possible questions:

- What is the reason for the difference in permeability regarding water?

3) Permeability to steam

Materials:
Electric water boiler, test tube, spatula, gas burner, paper towel, marmalade jar with perforated lid or beaker, stop watch, textile samples (e.g. cotton, polyamide, wool, silk, polyester, PVC)

Chemicals:
Copper sulfate pentahydrate, tap water

Procedure:
Heat the blue copper sulfate pentahydrate in a test tube over the gas burner. Pour boiling water in the marmalade jar, stretch the textile sample over the jar and close the lid. Place a paper towel over the lid and some white copper sulfate on the paper towel. Record the time until the copper sulfate indicates a water presence.

Disposal:
Copper sulfate pentahydrate can be collected and reused.

Possible questions:

- What is the reason for the different permeability regarding steam?

4) Amount of water absorption

Materials:
Scale, 5 beakers (100 ml), ring stand and ring, watch, a pair of tongues, textile samples (e.g. cotton, polyamide, wool, silk, polyester, PVC)

Chemicals:
Tap water

Procedure:
Determine the weights of the dry textile samples. Insert each textile sample for 2 minutes into 50 ml of tab water. Let the textile samples hang for 5 minutes to remove the excess water. Weigh the textile samples again.

Possible questions:
- How much water does each textile sample absorb?
- How can you explain your observations?

5) Insulating properties

Materials:
Erlenmeyer flask (100 ml), stop watch, gas burner, rubber band, thermo element, ring stand and ring, cork ring, textile samples (e.g. cotton, polyamide, wool, silk, polyester, PVC)

Chemicals:
Tap water

Procedure:
Heat 40 ml water in an Erlenmeyer flask to 65°C. Wrap the textile sample around the Erlenmeyer flask and fix in place with the rubber band. The flask can be placed on the cork ring. Determine the time it takes for the water to cool from 60°C to 50°C.

Possible questions:
- How can you explain the differences in insulating properties?

6) Behaviour when heated

Materials:
Hot plate, aluminium foil, marker, **small pieces** of textile samples (e.g. cotton, polyamide, wool, silk, polyester, PVC)

Note:
Experiment is to be performed under the exhaust hood!

Procedure:
Place a layer of aluminium foil over the hot plate. Place a textile sample on the aluminium foil and mark its size. Heat the hot plate first to 50°C, then to 100°C, then to 150°C and finally to 200°C, waiting for 1 minute between the heating increments and observing the textile sample. Note how the textile samples change and at which temperature.

Possible questions:
- How can you explain the differences in heating behaviour?

Activity 3.5: Membranes – Multifunctional fabrics

Learning aim:
Students learn that the processing of textiles leads to different membranes which have different properties. Furthermore, membranes can undergo other treatments in order to show specific properties.

Material:
Research pictures of different layers of a membrane used in functional clothes such as Gore-Tex® or similar.
Membrane samples to perform same experiments as in 3.4 (textile samples can either be worn clothes or producers can be asked for defect clothes items that had been returned to them)

Suggestions for use:

- Compare layers of functional clothes with those of TetraPak, have students draw analogies with the functions of the layers and discuss why/why not those layers could also be used in textiles.

Activity 3.5.1: Innovation in the clothing industry

Learning aim:
Students learn that the processing of textiles leads to different membranes which have different properties. Furthermore, membranes can undergo other treatments in order to show specific properties.

Material:
Worksheet 7

Tasks:
1. Find out about the underlying principle. Explain it. You may paint a model to explain the steps. (Search the internet for material and information)
2. List pros and cons regarding the application/ usage of such chemicals or silver. Are there alternatives? Evaluate this new innovation. Take into consideration these various aspects regarding this topic.

Suggestions for use:

- Students should work in teams to compare the statements and work on the two tasks with the given worksheet.
- Students can use their knowledge they gained in biology lessons.
- Finally, students should present their ideas and evaluation.

Activity 3.6: Keeping textiles clean

Learning aim:
Students learn that washing detergents, composed of certain chemicals, interact on a molecular level with certain fibres (and therefore also with textiles made of these fibres). In order to do this, students also analyze detergents in regard to their chemical composition.

Material:

- information material, such as textile care symbols and instructions
- experiments investigating what happens when care instructions are not followed

Experiments:

Worksheet 8: Research project
Worksheet 9: How bleaching agents work
Worksheet 10: The development of laundry detergents – from laboratory to production scale
Worksheet 11: Behaviour of fibres during washing process

Suggestions for use:

- This activity (esp. Worksheet 10) can be complemented with an industrial visit (e.g. Henkel AG & Co. KGaA). There further questions can be researched, such as how the components of laundry powder are evenly mixed or how the powder is kept dry during storage.
- For motivation purposes, in the series of experiments investigating what happens when care instructions are not followed, the students can develop their own ideas how to set up experiments testing those properties taking into account comparability and generalizability of their experiments.
- The experiment in D: Students may bring different detergents from home as well as fibre samples from old clothes they do not need any longer if there are no samples at school. Instead of using beakers, students can use yoghurt cups but they cannot be heated!
- Students may work in teams of two: every team gets every type of sample fibre and tests their interaction with one detergent. They should prepare two differently concentrated solutions of their detergent.
- Finally, students present their observations. They might use a camera to keep records of their findings.
- This activity lends itself to going beyond the visible observations and taking into account the chemical structures of different fibres and the interactions between chemical structure and laundry detergent.

III.III Fibres in society: economic viewpoints and sustainability

Activity 3.7: Economic view on textiles

Learning aims:
Students come into contact with economic perspectives of the textile industry.

Materials:
Information material, internet

Suggestions for use:
- This activity can be compiled together with colleagues from the social sciences department.
- Focus can be laid either on the ratio of current producers (producing countries) of different textiles or on working conditions in different countries, etc.

Activity 3.8: Ecological view on textile care

Learning aims:
Students learn about ecological consequences of detergents used to clean textiles.

Variety of experiments (for detailed experimental descriptions, see below):
Worksheet 12: The influence of temperature on wash performance
Worksheet 13: Improving wash performance by adding stain remover
Worksheet 14: The effect of laundry detergent dosage and water hardness on wash performance
Worksheet 15: The influence of laundry detergents on the growth of cress plants
Worksheet 16: Biodegradability of surfactants – Part 1
Worksheet 17: Biodegradability of surfactants – Part 2
Worksheet 18: Biodegradability of surfactants – Part 3
Worksheet 19: Biodegradability of surfactants – Part 4
Worksheet 20: Ecological impacts of the phosphates previously used in laundry detergents
Worksheet 21: Sustainability in the laundry detergent industry

Suggestions for use:
- This activity includes several experiments that focus on the sustainability of laundry detergents. The experiments can be performed in the form of a learning cycle or different experiments can be selected to be performed by the whole class.

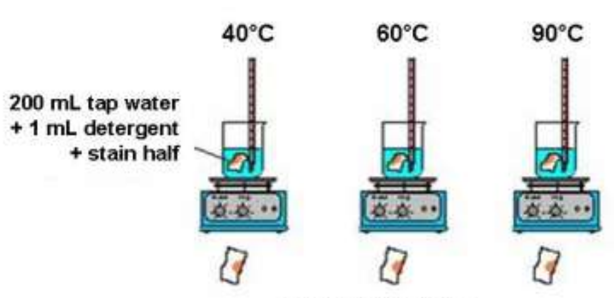
Regarding Worksheet 12:

Apparatus and materials

- 3 beakers (250 ml)
- graduated cylinder (200 ml)
- 3 hotplates (with stirrer and 3 follower bars or glass rods)
- 3 thermometers
- 3 watch glasses
- stopwatch
- tweezers
- scissors
- graduated pipette (1 ml)
- pipette filler
- liquid detergent for colored fabrics
- 3 cocoa stains on cotton cloth

Procedure

- Cut out generous pieces of cloth, each with a stain in the center, and cut each stain in two. One stain half will be washed and the other will be used for comparison. Mark the stain halves with a pencil to identify them.
- Add 200 ml tap water to each beaker. Stand each beaker on a hotplate and heat one to 40°C, one to 60°C and one to 90°C. Keep the temperatures constant. Cover each beaker with a watch glass.
- After the required temperatures have been reached, pipette 1 ml of the liquid detergent into each beaker. After the detergent has dissolved, drop one stain half into each beaker and start the stopwatch to count down 40 minutes. Stir the liquid in each beaker at intervals or, if stirrers are available, use the stirrers on a medium setting.
- When the 40 minutes have elapsed, take the stain halves out of the wash liquid and dry them. Compare them to each other and to their respective unwashed halves.



Experimental setup

Disposal

- Allow the wash liquid to cool and pour it down the sink.
- Reuse the cloths if possible, or put them in the waste bin

Source of experiment:
http://www.henkel.com/com/content_data/106612_4.8.2_Sustainable_washing_for_a_clean_environment_Chemistry_for_Advanced.pdf

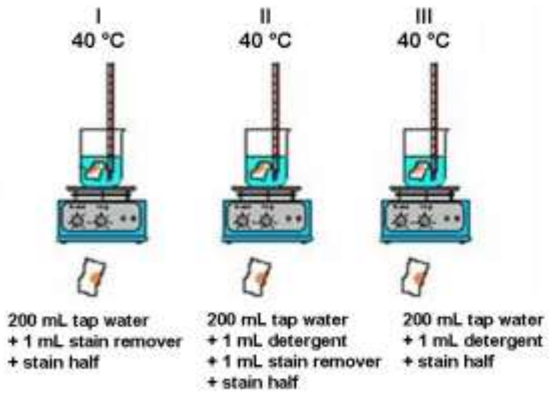
Regarding Worksheet 13:

Apparatus and materials

- *same as in experiment in Worksheet 12 plus*
- graduated cylinder (10 ml)
- stain remover

Procedure

- Cut out generous pieces of cloth, each with a stain in the center, and cut each stain in two. One stain half will be washed and the other will be used for comparison. Mark the stain halves with a pencil to identify them.
- Add 200 ml tap water to each beaker. Heat all three to 40°C and keep this temperature constant. Cover each beaker with a watch glass.
- Use the graduated cylinder to add 1 ml stain remover to beaker I and beaker II, then pipette 1 ml liquid detergent into beaker II and beaker III.
- After the detergent has dissolved, drop one stain half into each beaker and start the stopwatch. Leave beakers I and III for 40 minutes, and leave beaker II until the stain has almost disappeared (this can take between 10 and 20 minutes). Stir the liquid in each beaker at intervals or, if stirrers are available, use the stirrers on a medium setting.
- When the 40 minutes have elapsed, take the stain halves out of the wash liquid and dry them. Compare them to each other and to their respective unwashed halves.



Experimental setup

Disposal

- Allow the wash liquid to cool and pour it down the sink.
- Reuse the cloths if possible, or put them in the waste bin.

Source of experiment:
http://www.henkel.com/com/content_data/106612_4.8.2_Sustainable_washing_for_a_clean_environment_Chemistry_for_Advanced.pdf

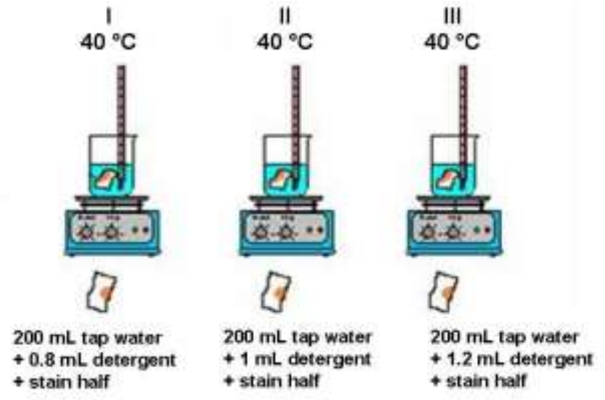
Regarding Worksheet 14:

Apparatus and materials

- same as in Worksheet 12 but:
- graduated pipette (**2 ml**)

Procedure

- Cut out generous pieces of cloth, each with a stain in the center, and cut each stain in two. One stain half will be washed and the other will be used for comparison. Mark the stain halves with a pencil to identify them.
- Add 200 ml tap water to each beaker. Heat all three to 40°C and keep this temperature constant. Cover each beaker with a watch glass.
- Pipette 0.8 ml liquid detergent into beaker I, 1 ml into beaker II, and 1.2 ml into beaker III.
- After the detergent has dissolved, drop one stain half into each beaker and start the stopwatch to count down 40 minutes.
- Stir the liquid in each beaker at intervals or, if stirrers are available, use the stirrers on a medium setting.
- When the 40 minutes have elapsed, take the stain halves out of the wash liquid and dry them. Compare them to each other and to their respective unwashed halves.



Experimental setup

Disposal

- Allow the wash liquid to cool and pour it down the sink.
- Reuse the cloths if possible, or put them in the waste bin.

Source of experiment:
http://www.henkel.com/com/content_data/106612_4.8.2_Sustainable_washing_for_a_clean_environment_Chemistry_for_Advanced.pdf

Regarding Worksheet 15:

Apparatus and materials

- 7 dishes (e.g. crystallizing dishes)
- 1 knife
- beaker (50 ml)
- graduated cylinder (100 ml)
- 2 beakers (500 ml)
- stirring rod
- graduated pipette (20 ml)
- pipette filler
- felt-tip pen
- liquid detergent for colored fabrics
- 4 trays of garden cress

Procedure

- Take the cress out of each tray, together with the mat in which it is growing. Use the knife to cut each mat in two. Place each half in its own dish. One half is left over.
- Place the seven dishes in a row and mark them with the numbers 1 to 7. Add 100 ml tap water to dish 1 and add 100 ml of the liquid detergent to dish 7.
- Prepare the solutions for dishes 2 to 6:
- Mix 180 ml tap water and 20 ml liquid detergent in a beaker. The concentration of the liquid detergent in this beaker is 100 ml/l. Transfer 100 ml of the solution from the beaker to dish 6.
- Pipette 20 ml of the remaining 100 ml to a clean beaker and add 180 ml tap water so that it contains a total of 200 ml. The concentration of the liquid detergent in this beaker is 10 ml/l. Transfer 100 ml of the solution to dish 5.
- Pipette 20 ml of the remaining 100 ml to a clean beaker and add 180 ml tap water so that it contains a total of 200 ml. The concentration of the liquid detergent in this beaker is 1 ml/l. Transfer 100 ml of the solution to dish 4.
- Prepare the solutions for dishes 3 and 2 in the same way.
- **Take care! Always rinse the pipette and beakers with tap water after use so that no higher concentrated solution is transferred to a lower concentrated solution.**
- The concentration of liquid detergent in the series of dishes is now as follows:
  Blank sample; 2. **0.01 ml/l**; 3. **0.1 ml/l**; 4. **1 ml/l**; 5. **10 ml/l**; 6. **100 ml/l**; 7. **1000 ml/l**.
- Leave the cress in the dishes for a period of 5 to 7 days in normal light. Record your observations. Add tap water as necessary to replace any water that evaporates, so that the volume of solution in each dish remains at its original level.

Disposal

- Pour the detergent solution down the sink and put the cress dishes in the waste bin.

Source of experiment:
http://www.henkel.com/com/content_data/106612_4.8.2_Sustainable_washing_for_a_clean_environment_Chemistry_for_Advanced.pdf

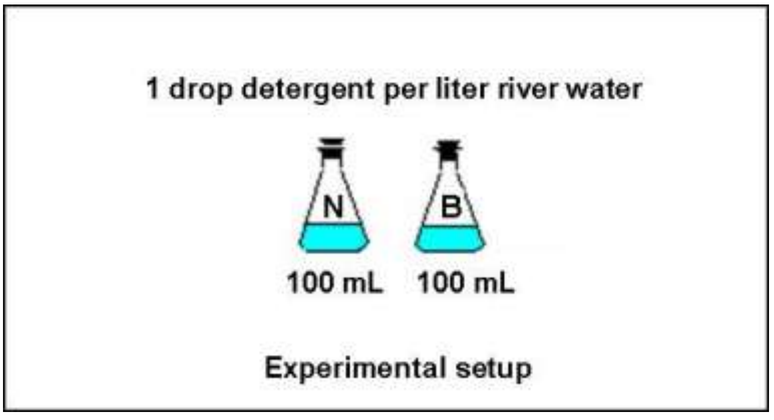
Regarding Worksheet 17, Part 2:

Apparatus and materials

- 2 Erlenmeyer flasks (200 ml) with stoppers
- hotplate
- beaker (500 ml)
- beaker (50 ml; with watch glass as a cover)
- glass rod
- graduated cylinder (100 ml)
- graduated pipette (1 ml)
- graduated pipette (10 ml)
- pipette filler
- felt-tip pen
- liquid detergent for colored fabrics
- river water

Procedure

- Pipette 10 ml river water into a 50 ml beaker and use the glass rod to add 1 drop of the liquid detergent to the beaker. When the drop has dissolved, transfer 1 ml of the solution to an Erlenmeyer flask, add 99 ml river water and label the flask “N” (= non-boiled sample). Stopper the flask firmly.
- Heat a beaker containing 200 ml river water on the hotplate until it boils. Allow the water to cool, then transfer 10 ml to a 50 ml beaker and use the glass rod to add 1 drop of the liquid detergent. When the drop has dissolved, transfer 1 ml of the solution to an Erlenmeyer flask, add 99 ml boiled river water and label the flask “B” (= boiled sample). Stopper the flask firmly.
  Caution! Each time you reuse a piece of apparatus, first rinse it carefully with tap water.
- Observe the foam formation in the flask over a period of 3-7 days. To do this, shake the two flasks simultaneously 10 times, as equally as possible, while holding them upright, then observe and compare the foam covering the two solutions.



Disposal

- Pour the wash liquid down the sink.

Source of experiment:
http://www.henkel.com/com/content_data/106612_4.8.2_Sustainable_washing_for_a_clean_environment_Chemistry_for_Advanced.pdf

Activity 3.9: Synthesis of bio-fibres

Learning aim:
Students familiarize themselves with the biodegradable fibres and discussed the possibility for their uses in textiles.

Material:
Experiments:
A) Synthesis of calcium alginate threads
B) Synthesis of polylactic acid threads

Suggestions for use:
for experiment A):

- make sure the process for preparing the syringe is followed closely, otherwise the needle will clog up with a calcium alginate plug
- a simpler setup can be obtained by pressing the sol into a beaker filled with calcium chloride solution
- calcium alginate threads are used for wound dressing

for experiment B):

- polylactic acid is used as suture material, and will be broken down after a certain time by the body

Activity 3.10: The dream fibre/detergent

Learning aim:
Students learn to use the structure-property-knowledge obtained so far. Along the lines of STS approaches, they use logical reasoning skills to argue hypothetically which characteristics should be combined to generate the perfect fibre/plant.

Material:
Results of activities 3.1 - 3.9

Suggestions for use:

- Students can assess desirable and problematic properties of fibres and textiles presented so far
- They can consider additives and production methods, working conditions and sustainability regarding manufacture and decomposition of different washing detergents and fibres, etc.
- Students should work in a team to exchange ideas and discuss different approaches.
- Finally, the students should present their dream fibre/ dream detergent to the class.

WP3 | Chemical Care Unit

European Science and Technology in Action:
Building Links with Industry, Schools and Home

Work Package 3
UNIT CHEMICAL CARE
B - Classroom Materials

European Science and Technology in Action:
Building Links with Industry, Schools and Home

Lead partner for unit: Leibniz- Institute for Science and Mathematics Education (IPN)

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B: Classroom Materials

SUB UNIT 1:

Become a household detective – use and explore your scientific expertise!
Scientists analyse phenomena in nature and in man-made environments. They carry out experiments to test if their expectations – they call them hypotheses – were correct or false. They can then use their knowledge to optimize processes, for example, or they offer their knowledge to engineers and other experts who can use it to design new techniques and devices.
Of course, scientists have modern equipment in their laboratories to get very good and trustful results, but you can also carry out a lot of such investigations in your own house. Become a scientific household detective!

Activity 1.1

Before you start, you should think about the questions you want to answer, the things you want to find out. Let´s take the example of chemistry, maybe you think about something like…

- Where do we have chemical substances in the house, what do we use them for?
- Which of these substances may be dangerous, how do we have to treat them correctly?
- Where can chemical substances help to avoid natural risks?
- Where do we find and use chemical reactions in the household? Why do we use them?
- ...

See if you can find more questions and discuss them with your detective team!

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Activity 1.2

Let's see how you could proceed to investigate some of your "research questions". Scientists write down what they expect before they start, they call these assumptions "hypotheses". Develop some hypotheses for your questions in your detective team! Use the knowledge you have about products and processes in the house or think about what you have heard on TV or found in the internet.

Our hypotheses for our research questions are:

Activity 1.3

Now you need a good working plan, how do you wish to proceed and what kind of equipment do you need? Who in your group is going to do what?

To investigate where you might find chemical substances or chemical reactions in your household, you first have to define what chemical substances (often just called chemicals) and chemical reactions are. Where can you look for explanations? Of course in the internet, but those explanations might be too advanced as they might have been written for experts. Try your chemistry book as an alternative as well ☺.

Definitions of chemical substances:

Definitions of chemical reactions:

You will have found out that all substances can be called chemicals, did you expect that? Outside the world of chemists, many people think that chemicals are always dangerous and that we better avoid getting in contact with them. You can interview your friends and parents to see what they think about chemicals…

For a chemist, every substance is a chemical with properties he / she can describe and investigate and with a certain structure he can show with the help of models. Why do chemists have to use models to do so? Well, because chemists cannot see the structure of substances, build up by atoms, with their eyes! But this is something you will explore later…
Let´s come back to your search for chemicals in the household. What can you do to find them? You can

- read descriptions of products such as detergents, food, batteries…;
- look for substances in containers like your salt container, a soap container, …

Now you can go look for some chemicals in your household. Write down which chemicals you have found:

Which way might be better for your safety?

To deal with chemicals you have to learn some safety measures before. You will find the necessary symbols and information in your textbook, so develop a poster in your detective team that you can always take out and check before you get in touch with chemicals!

Template for your poster:

Now, when you have found some chemicals in your household, what could you do to find out more about such chemicals? Again, you can

- describe them according to how they look like and develop systems to categorize them;
- read descriptions of products such as detergents, food, batteries… or
- you can carry out experiments, that´s what chemists do!

Start with some simple substances and a simple system of categorization: Look for all white substances in your household and describe them according to what they look like. You can also make pictures. Think about what you could use to see more? Black paper, a microscope, …?

Present your categorization scheme and pictures to your detective team.

Activity 1.4

To carry out an experiment, you need laboratory equipment, of course. Have a look in your book again and copy some of the equipment you find there in your detective investigation book. Think about the different functions of the tools you have found and write them down next to each tool.

Piece of equipment: functions of piece of equipment:

Every experiment is related to a question again, such as:

- Can I burn the substance?
- Is the substance soluble in water?
- …

Think about more questions in your detective team and write them down in your book.

Chemists often also use other substances to test what they have found; they call some of them indicators. Maybe you can use them as well in your school?
Show your ideas to your teacher to see which experiments you can actually carry out without any danger for yourself and others, because this is always rule N^{o}1 for every chemist!

Now take your white substances which you have found in your household and carry out the experiments you have decided on with your teacher.

As a good scientific detective, you have to document what you have done in a good way, of course, to make sure that you can tell your results in a convincing way to others later on. How would you design such a good documentation? Make a suggestion in your detective team and discuss it with other detective teams on a detective conference!

Are you now ready to carry out your experiments? Check all the safety measures again, collect the material you need, talk to the teacher once more and then start! No, stop, think about what you have to consider for being able to compare the different white substances before you start! The following questions might help you to do so:

- Can you just take any amount of a substance to test the burning or to test the solubility, for example?
- Can you just take water from the tab without controlling anything to test solubility?
- …

Okay, now you can start! And don't forget to observe carefully and to document everything as a real scientist detective!

Activity 1.5

After having characterized your substances, think about the use of the different chemicals. Can you explain what you use them for with the knowledge you have now gained from your chemical analyses and observations? Develop a short advertising statement for one of your substances saying why something is good to be used for like

“You can solve XXg of salt in water so every soup will be as salty as you would like to have it!”

“My washing powder is basic with a pH of XX so it will clean your dirty washing well!”

My advertising statement:

Activity 1.6

In the beginning, we also said that some chemicals are used to avoid risks in the household, what could those risks be?

Think about detergents and cleaning agents, why is it necessary to use them in your household? Find some reasons in your team:

Activity 1.7

To get rid of dirt or microorganisms such as bacteria and mold, you can use chemicals. But how can you choose the right chemical substance for the different types of dirt and bacteria? Do you have an idea how to check whether bacteria have been removed?
Again, you have to know more about the chemicals, but also about the processes that start when you give a chemical to a piece of dirt or to bacteria, for example.
Let´s start with dirt… Which properties and characteristics do you know about dirt? Start to write them in the first column of a table!

Properties of dirt			
Colour			
Left overs of salt, sugar, …			
Oil			
…			

Now add some cleaners you know in the first row of the table. Your table might look like this:

Properties of dirt	Water	Citric Acid cleaner	Washing powder
Colour			
Left overs of salt, sugar, …			
Oil			
…			

Now think about properties you have found out about some chemicals, how might they help to decide on the best cleaner? Here comes one example: You learned that some chemicals are soluble in water, which kind of dirt could you delete just with water?
Insert your conclusions in the table as well. Your table might look like this:

Properties of dirt	Water	Citric Acid cleaner	Washing powder
Colour			
Left overs of salt, sugar, …	Salt and sugar are soluble in water, so water can be used to get rid of them.		
Oil	Oil is not soluble in water so we can´t use water for oil stains.		
…			

Activity 1.8

Again, you can also use information you can get on chemicals you cannot easily analyse at school. Washing powders are such an example. While salt is just one chemical substance (the chemist calls it a *pure substance*), washing powder is a mixture of several substances. Why is that the case? Because you need many different chemicals to get rid of different types of dirt! You need the main component which is "basic" to destroy fatty dirt pieces, for example. You need another substance to get rid of unwanted colours, e.g. from juices, this is reached by a chemical reaction taking place in your washing machine which destroys the colour substance. You will probably find some information on washing powder in the internet, add that to your table as well!

Properties of dirt	Water	Citric Acid cleaner	Washing powder
Colour			Contains a chemical that destroys colors.
Left overs of salt, sugar, …	Salt and sugar are soluble in water, so water can be used to get rid of them.		
Oil	Oil is not soluble in water so we can´t use water for oil spots.		
…			

At this point, you can perform several experiments. Some suggestions of experiments are given on the following pages:

Additional worksheets (Source: Henkel (2008): Sustainable washing for a clean environment – Chemistry for beginners (11 – 13 year old).

Worksheet 1: Introduction and safety information[1]

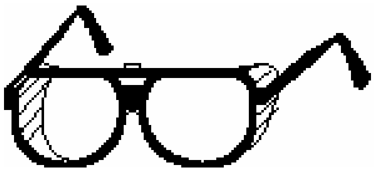
Laundry washing is an everyday activity in modern homes. You might have helped with the washing now and then, or even done it yourself. Perhaps you have even asked yourself one of the following questions:

You can answer these questions with the help of the following worksheets and experiments. However, you should pay careful attention to the following:

- **Before you start, read the worksheet or instructions so that you know what you are going to do.**
- **Then, before you do anything else, check that all the materials and/or chemicals you need are at hand. If anything is missing, inform your teacher.**
- **Communicate quietly with the other members of your work group, so that you don't disturb the other groups.**
- **After an experiment, clear up the tables or benches. Dispose of the used chemicals, clean the apparatus, etc.**

Safety instructions

At the learning stations you will work with substances you are familiar with from everyday life: soap and laundry detergents. Nevertheless, safety instructions have to be complied with during experiments. Naturally this includes wearing protective goggles.



Task

1) Why do people not wear protective goggles at home when working with laundry detergents?
2) Which other basic rules for carrying out experiments can you remember?

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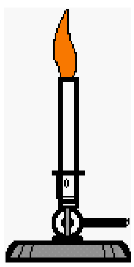
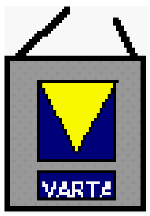
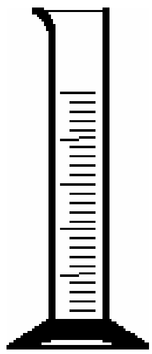
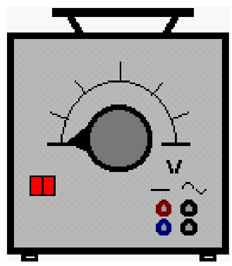
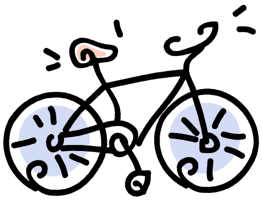





[1] Worksheet taken from:
Henkel (2008): Sustainable washing for a clean environment – Chemistry for beginners (11 – 13 year old).

Worksheet 2: How are stains and dirt removed from clothes?[2]

Imagine the following situation: You are cleaning your bicycle before you go for a ride. When everything is nice and clean, you want to oil the bicycle chain quickly. You hurriedly open the bottle containing the bicycle oil – and some of the oil splashes out onto your new white T-shirt. You want to wash the oil out again immediately, so you go into the kitchen where there is a hot water and a cold water tap. Will you succeed in removing the oil with water?



Tasks

1) Plan an experiment with which you can find out whether the oil stain can be removed with water. Make a sketch of the experiment first, and then briefly write down what you are going to do. Can you vary any of the conditions?
2) Carry out your experiment and write down what you observed. Were you able to remove the stain with water?
3) As a group, discuss what else you could use to remove the oil stain. When you have decided what to do, write it down and then carry out a new experiment to remove the stain. Write down what you observed and the result.

[2] Worksheet taken from:
Henkel (2008): Sustainable washing for a clean environment – Chemistry for beginners (11 – 13 year old).

Worksheet 3: The influence of temperature on wash performance[3]

In this experiment you have to find out whether the wash performance remains the same at different temperatures or whether it changes. To do this, you will be given cocoa-stained cotton cloths, which you will wash at different temperatures.

Tasks

1) Plan an experiment, with which you can test wash performance at different temperatures. Make a sketch of the experiment first, and then briefly write down what you are going to do.
2) Carry out your experiment and record the wash result.
3) At which temperatures did you obtain the best wash result?
4) Give reasons why laundry should or should not always be washed at a low temperature (30°C).

[3] Worksheet taken from:
Henkel (2008): Sustainable washing for a clean environment – Chemistry for beginners (11 – 13 year old).

Worksheet 4: Laundry detergents *then* and now[4]

Anna browses through her grandmother's photo album. On one of the photos she sees a group of women standing behind big wooden tubs. Steam is rising from the tubs. "What are they doing?", asks Anna. "That was the big washday", says Grandmother. "It was hard work then …"

A washday used to take hours, and sometimes even days. The heavy work could scarcely be carried out by one person alone. There were professional washerwomen, who would carry out the family's big wash, as long ago as the 16th century.

Laundry can now be washed easily and quickly, thanks to advanced detergents and washing machines. The following text tells you about the development of laundry washing and laundry detergents, using the laundry detergent Persil® as an example.

Tasks

1) Read the information on the development of the laundry detergent and the technology of laundry washing in **Material 1**. Each member of your group should read one text. Under the text are several illustrations, which you have to arrange in the right sequence. Draw up a timeline, in which you can glue the illustrations and write or glue information about the development of laundry washing and laundry detergents.
2) Some of the text fields in **Material 1** are empty. Ask your parents and/or grandparents what changes they have seen in laundry washing. Compare their answers in your group and write short texts about them in the empty fields. Add these texts to your timeline.
3) **Material 2** shows an advertising poster for Persil®, the **self-acting detergent**. What do you think "self-acting" means? Write your answer in the field under the advertising poster.

[4] Worksheet and Materials 1-2 taken from:
Henkel (2008): Sustainable washing for a clean environment – Chemistry for beginners (11 – 13 year old).

Material 1

The development of the laundry detergent

In **1907**, the Henkel company launched a totally new laundry detergent: Persil. It was the first German washing powder with simultaneous bleaching action, which meant that laundry no longer had to spread out on the grass to be bleached by sunlight.

From the **2nd century AD,** soap was used to wash laundry.

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The first “washing powder” then became available around **1880**. Initially, however, it consisted of powdered soap. Ever new formulations were subsequently developed.

By **about 60 AD** the Romans and Egyptians were using first cold and then hot water for washing their laundry. Aids such as sand, urine or soapwort were often added to the water to enhance the wash performance.

The development of laundry technology

In the late 19th and early 20th century, laundry was spread out on the grass after washing, so that it would bleach in the sun. This made clothes appear clean and fresh.

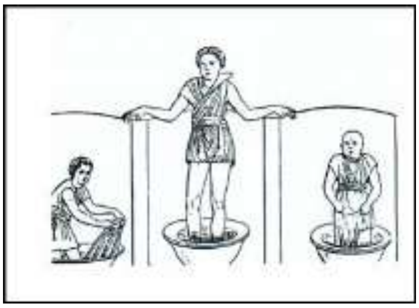
10th century: The first washing device appeared – a bat or paddle, consisting of a wooden board with a handle, with which the laundry was beaten. Laundry was also often beaten on flat stones.

In the **18th century**, a machine was developed for wringing out the wet laundry.

Around 60 AD, laundry was carried out in ancient Egypt and Rome by men, who trampled it in large tubs until it was clean.


SOAP
POWDER


Persil
das selbsttätige Waschmittel



Material 2

The term “self-active” means …

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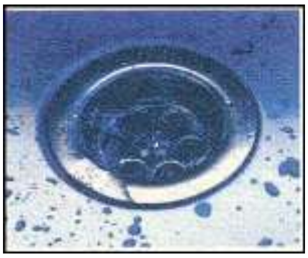
Worksheet 5: Laundry detergents and the environment[5]

After the laundry has been washed, it is clean again – but what about the water that leaves the washing machine? Just as when you shower, take a bath, clean your teeth, wash the dishes, etc., laundry washing generates wastewater. What happens to this wastewater?



You probably know that household wastewater passes through the drains and sewers into a sewage treatment plant. It passes through a number of treatment stages in the sewage plant before it is clean enough to be discharged into surface water.

Tasks

1) Try to treat the wastewater you have been given, using the substance separation methods with which you are already familiar. In **Material 3** you will find the apparatus and materials you are to use. Which substances can and cannot be removed? Write your result in the table.
2) Read **Material 4** to find out about wastewater treatment in sewage treatment plants. Each member of your group should read one information text. Which of the substance separation methods that you used can you find in the text?

[5] Worksheet and Materials 3-4 taken from:
Henkel (2008): Sustainable washing for a clean environment – Chemistry for beginners (11 – 13 year old).

Material 3

You can use the following apparatus and materials

- Beakers
- Glass funnels
- Filter paper
- Coarse sieve
- Fine sieve
- Tweezers

Your wastewater contains:

water, bits of paper handkerchiefs, vegetable scraps, sand, washing powder

Substance	Removed with …
Bits of paper handkerchiefs	
Washing powder	
Sand	
Vegetable scraps	

Disposal

- Put the bits of paper handkerchiefs and the vegetable scraps in the waste bin
- Put the sand in the sand bucket
- Pour the residual wastewater down the sink

Material 4

How does a sewage treatment plant work?

1) First of all the wastewater passes through the mechanical treatment stage. A raked bar screen holds back any relatively large objects in the wastewater, such as pieces of wood, plastic bags or cloths.

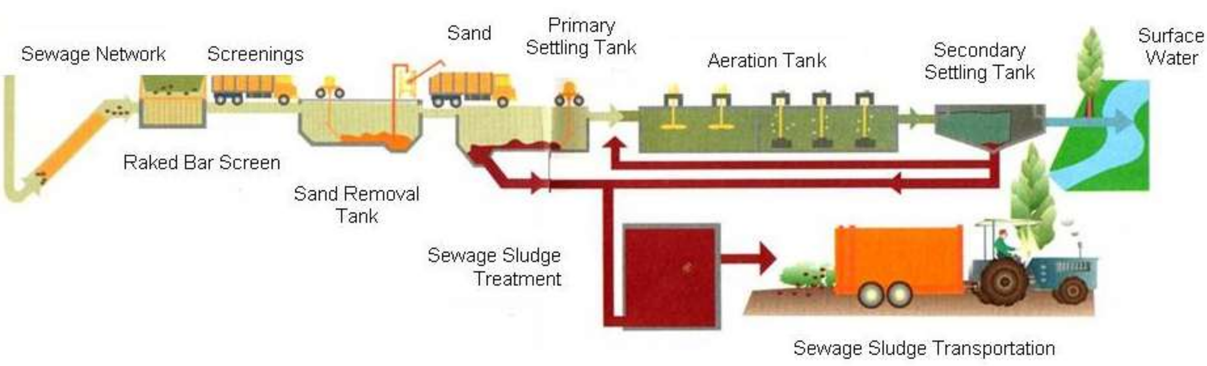
2) The remaining dirty water is then passed through a sand removal tank. Most of the sand settles out there. The water then runs into a primary settling tank, where substances such as food residues can settle on the floor of the tank.

3) The partially cleaned water then flows into an aeration tank, into which air is blown. The bacteria in this tank digest and break down the residual substances in the wastewater. This is referred to as biological treatment.

4) The secondary settling tank is part of the biological treatment stage. Bacteria and residual contaminating substances settle on the bottom of the tank as sludge. After passing through all these stages, the treated water can be discharged into a nearby river.

5) Besides mechanical and biological treatment, there is also chemical treatment. This is the use of chemicals to remove contaminating substances that are still present in the wastewater. This treatment stage is often not present in older sewage treatment plants.

Sketch of a sewage treatment plant



Where are the methods of substance preparation that you already know about?

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Activity 1.9

So far, you needed some chemical knowledge to be a successful household detective. Now we will demand some biology as well! Why? Because you shall be looking for bacteria and other microorganisms or the risk of microbial growth which you do not want in your household!
Of course, not all bacteria are unwanted. You have plenty of them on your skin, in your mouth or in your digestion system. They actually help you, but there are also bacteria that might cause illnesses; and those have to be avoided, of course!
Think again in your detective team: Where would you expect risks for the growth of unwanted bacteria or mold in your household?

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As you cannot see bacteria, you need to set up an experiment again. You can catch bacteria and let them grow in a safe environment when you use agar plates. Talk to your biology teacher about how to prepare them, how to use them in a safe way for yourself and others and plan your experiment – become a bacteria detective this time!

You could perform the following experiment:

Experiment 1: Finding bacteria[6]

Apparatus and chemicals

- 6 petri dishes (with lids) with nutrient agar for usage as contact plates or special contact plates
- overhead marker
- tape (eg. Tesa® film)
- cotton swabs (sterile, new box), sterile moistening liquid (e.g. water)
- hand disinfectant

Safety

Observe all safety measures regarding the handling of bacteria! Wear your safety goggles! After sealing the petri dishes, do not open them again!

Procedure

- Touch the surfaces where you expect bacteria with the nutrient agar in a petri dish or wipe the surface with a moistened cotton swab taken from a newly opened box. Then wipe the cotton swab in zig-zag lines across the agar. Seal the contact plates/ petri dishes immediately with tape. Note on each plate where the sample is from and incubate them for 48 hours at 37°C or 5-7 days at room temperature.
- After incubation, compare the different plates.
- Describe grown colonies with magnifying lens, if available.
- You may examine the bacteria under a microscope.

Note here which surface you tested along with your observation after incubation:

Disposal

- Contact plates should be sterilized / autoclaved.
- All material that has had contact with bacteria should be disinfected.

[6] Source (adapted from):
Wagner, Günter und Blank-Rothenburg, Helga (2001). Bei welcher Temperatur wird Wäsche hygienisch sauber - Wirksamkeit verschiedener Haushaltsreiniger auf ihre antibakterielle Wirkung. *Naturwissenschaften im Unterricht - Chemie,* 12(63), 51-52.

SUB UNIT 2:

Substances in different cleaning agents

The students set up a table of cleaning agents and the substances named as ingredients in those products.
Exemplarily, the content and the effects of acids as ingredients or cleaning agents can be investigated by the following experiments (see material), taken from the German project “Chemie fuers Leben” (also adapted in “Chemie im Kontext”).

Activity 2.1 Which household products contain acids?[7]

Apparatus and materials

- filters, round (Ø minimum of 10 cm)
- large Petri dish
- disposable pipettes
- spatula
- markers for writing on filter
- indicator made from red cabbage
- lemon cleaner
- substance for decalcifying
- lemon juice concentrate
- essence of vinegar
- other cleaners…

Safety

Observe all safety measures regarding the handling of acids as printed on the labels! Wear your safety goggles!

Procedure:

- Soak the round filter in red cabbage indicator and dry (air dry, use hair dryer or put on radiator) in a Petri dish. Based on the indicator’s intensity, the process may have to be repeated several times.
- Use pipette or spatula to apply small sample of the substances to be analysed to filter and mark the spots accordingly.

Disposal:

- After diluting, pour the solutions down the sink. Put the filter in the waste bin.

[7] Source (adapted from):
http://sinus-transfer.uni-bayreuth.de/fileadmin/MaterialienBT/Skript_Flint.pdf

Activity 2.2 Compare the amount of acid in different household products[8]

Apparatus and materials

- beaker (150 ml)
- measuring cylinder (50 ml)
- magnetic stirrer and stir bar
- buret (25 ml)
- funnel
- destilled water
- rinse aid
- sodium hydroxide solution (c = 0.5 mol/l)
- universal indicator

Safety

Observe all safety measures regarding the handling of acids! Wear your safety goggles!

Procedure

- Pour 10 ml of rinse aid into the measuring cylinder and add distilled water to yield 50 ml of solution.
- Pour the solution into a beaker and add a few drops of universal indicator.
- Fill the sodium hydroxide solution into the burette.
- While stirring, titrate in 0.5 ml-steps until the solution reaches its point of change.

Disposal:

- After diluting, pour the solutions down the sink

[8] Source (adapted from):
Freienberg, Julia (2002). „Chemie fürs Leben – ein neuer Ansatz für den Chemieunterricht am Beispiel der Behandlung von Säuren, Laugen und Salzen in der Sekundarstufe I sowie Anknüpfungsmöglichkeiten für die Sekundarstufe II“, Dissertation, University of Rostock 18.12.2002.

Activity 2.3 Why do companies include acids into cleaning products? – Intended effects[9]

Apparatus and materials

- Water heater with lime scale build-up
- Essence of vinegar or decalcifying substance as bought in the store

Safety

Observe all safety measures regarding the handling of acids! Wear your safety goggles!

Procedure

- Dilute some essence of vinegar with water in a ration of 1:5.
- Pour the solution into the water heater and boil it. Rinse afterwards and compare the look of the interior of the water heater.
- For using the decalcifying substance as bought in the store, follow its instructions.
- According to the degree of lime scale build-up, you may have to repeat the process a few times.

Disposal

- After diluting, pour the solutions down the sink.

[9] Source (adapted from):
Freienberg, Julia (2002). „Chemie fürs Leben – ein neuer Ansatz für den Chemieunterricht am Beispiel der Behandlung von Säuren, Laugen und Salzen in der Sekundarstufe I sowie Anknüpfungsmöglichkeiten für die Sekundarstufe II“, Dissertation, University of Rostock 18.12.2002.

Activity 2.4 Which effects can acids have on different materials and on our health? – Not intended effects[10]

2.4.1 Effect of acid on bones

Apparatus and materials

- 1 large test tube (Ø 3 cm)
- decalcifying agent, e.g. citric acid solution or decalcifying substance as bought in the store
- long and thin bone from chicken, duck or goose; cleaned

Safety

Observe all safety measures regarding the handling of acids! Wear your safety goggles!

Procedure

- Put the bone in a test tube and add enough decalcifying solution to completely cover the bone.
- In case the bone does not stay submerged, you can hold it in place by covering the test tube with a (pierced!) stopper.
- Leave the test tube sit for several days according to the bone's thickness, renewing the solution every day.

Disposal

- After diluting, pour the solutions down the sink. Put the solids in the waste bin.

[10] Source (adapted from):
http://sinus-transfer.uni-bayreuth.de/fileadmin/MaterialienBT/Skript_Flint.pdf

2.4.2 Closer investigation of the products of the reaction between marble (chalk) and acids[11]

Apparatus and materials

- 1 test tube for each acidic solution to be analysed
- matching pierced stoppers
- fermentation locks, one for each test tube
- spoon
- glas stirring rod
- crucible tongs
- gas burner
- various acidic solutions to be analysed
- very small pieces of marble (or limestone pieces)
- calcium hydroxide solution
- indicator made from red cabbage

Safety

Observe all safety measures regarding the handling of acids as printed on the labels! Wear your safety goggles!

Procedure

- Fill each test tube up to about a third of its volume with the solutions to be analysed and add several drops of indicator.
- Fill the fermentation locks with the calcium hydroxide solution.
- Add several pieces of marble (or limestone) to each solution (to a heigth of about 1 cm) and close the test tubes quickly with the prepared fermentation locks.
- After a few minutes, remove several drops of each test tube using the glas stirring rod and collect them on the spoon. With the spoon, slowly let the liquid evaporate over the gas burner.

Disposal

- After diluting, pour the solutions down the sink.

[11] Source (adapted from):
http://sinus-transfer.uni-bayreuth.de/fileadmin/MaterialienBT/Skript_Flint.pdf

2.4.3 Reaction between acids and metals[12]

Apparatus and materials

- 4 large and 1 small test tubes for each acidic solution to be analysed
- matching pierced stoppers with a short tube inserted
- stand for test tubes
- watchglas
- crucible tongs
- glass stirring rod
- spoon
- gas burner
- various acidic solutions to be analysed
- magnesium (e.g.pencil sharpener)
- zink (e.g. zinc-plated roofing nails, zinc granules or pieces of a zinc roof gutter)
- iron (e.g. iron nails, iron wool)
- copper (e.g. copper wire)
- indicator

Safety

Observe all safety measures regarding the handling of acids as printed on the labels! Wear your safety goggles!

Procedure

- Fill each of the 4 large test tubes up to about two thirds of its volume with the solutions to be analysed and add several drops of indicator.
- Add one piece of metal to the first test tube and close the test tube with the pierced stopper with a short tube inserted.
- Collect the gas that is generated with a small test tube and perform the test for hydrogen/oxygen gas.
- Proceed accordingly with the other pieces of metal.
- After the reaction subsides, remove several drops of each test tube using the glas stirring rod and collect them on the spoon. With the spoon, slowly let the liquid evaporate over the gas burner.

Diposal

- After diluting, pour the solutions down the sink. Put the solids in the waste bin.

[12] Source (adapted from):
http://sinus-transfer.uni-bayreuth.de/fileadmin/MaterialienBT/Skript_Flint.pdf

2.4.4 Reaction between acid and organic substances[13]

Apparatus and materials

- 1 test tube for each acidic solution to be analyzed
- stand for test tubes
- spatula
- tweezers
- paper towels
- various acidic solutions to be analysed (about 10 ml each)
- several small pieces of raw meat or egg white

Safety

Observe all safety measures regarding the handling of acids as printed on the labels! Wear your safety goggles!

Procedure

- Fill each test tube up to about a third of its volume with the solutions to be analysed and add a piece of raw meat to each.
- Leave the test tube sit for several days, renewing the solution every day.
- Remove the solutions after several days and put the solid remains on a paper towel. Analyse the consistency of the remains by pushing down on them with a spatula.

Disposal

- After diluting, pour the solutions down the sink. Put the solids in the waste bin.

[13] Source (adapted from):
http://sinus-transfer.uni-bayreuth.de/fileadmin/MaterialienBT/Skript_Flint.pdf

Acitivity 2.5: Comparison of the effectiveness of different household detergents[14]

Apparatus and materials

- 5 petri dishes (with lids) with nutrient agar for usage as contact plates
- different household detergents (such as Bref Power®, DER GENERAL®, Sargrotan®; all of these detergents have antimicrobial claim, for reference purposes, other detergents might be investigated also)
- overhead marker
- tape (e.g. Tesa® film)
- cotton swabs (sterile, new box), sterile moistening liquid (e.g. water)
- paper towel
- hand disinfectant

Safety

Observe all safety measures regarding the handling of bacteria and acids/bases as printed on the cleaners' labels! Wear your safety goggles! After sealing the petri dishes, do not open them again!

Procedure

- Divide surface to be tested into five parts.
- Clean the first part with a disinfectant according to its instructions. Clean the second part with an all-purpose cleaner according to its instructions. Clean the third part with an antibacterial all-purpose cleaner according to its instructions and the fourth with warm water. Use part number 5 as a reference, that is leave the surface without any cleaner applied.
- Touch the cleaned surface with a petri dish or wipe the table with a moistened cotton swab taken from a newly opened box. Then wipe the cotton swab in zig-zag lines across the agar.Seal the contact plates immediately with tape. Note on each plate which cleaner has been used on the surface before. Incubate plates for 48 hours at 37°C or 5-7 days at room temperature.
- After incubation, compare the different plates.

Disposal

- Contact plates should be sterilized / autoclaved.
- All material that has had contact with bacteria should be disinfected.

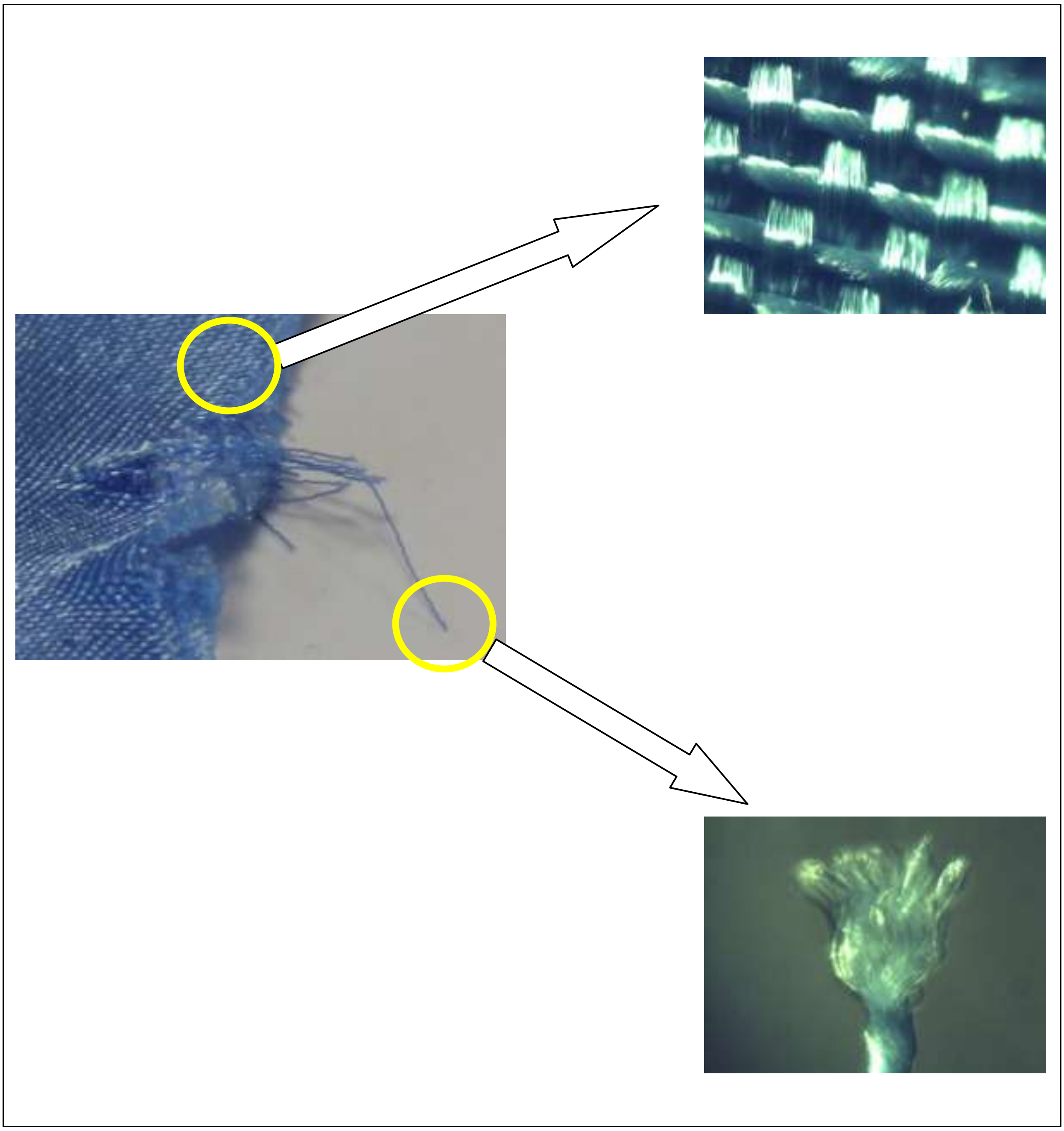
[14] Source (adapted from):
Wagner, Günter und Blank-Rothenburg, Helga (2001). Bei welcher Temperatur wird Wäsche hygienisch sauber - Wirksamkeit verschiedener Haushaltsreiniger auf ihre antibakterielle Wirkung. *Naturwissenschaften im Unterricht - Chemie,* 12(63), 51-52.

SUB UNIT 3:

Activity 3.1: Analyzing fibres

Examine pictures of different fibres made with regular camera and light microscope.

Compare the pictures of a polyester sample:



Compare the pictures of a polyamide jacket sample:

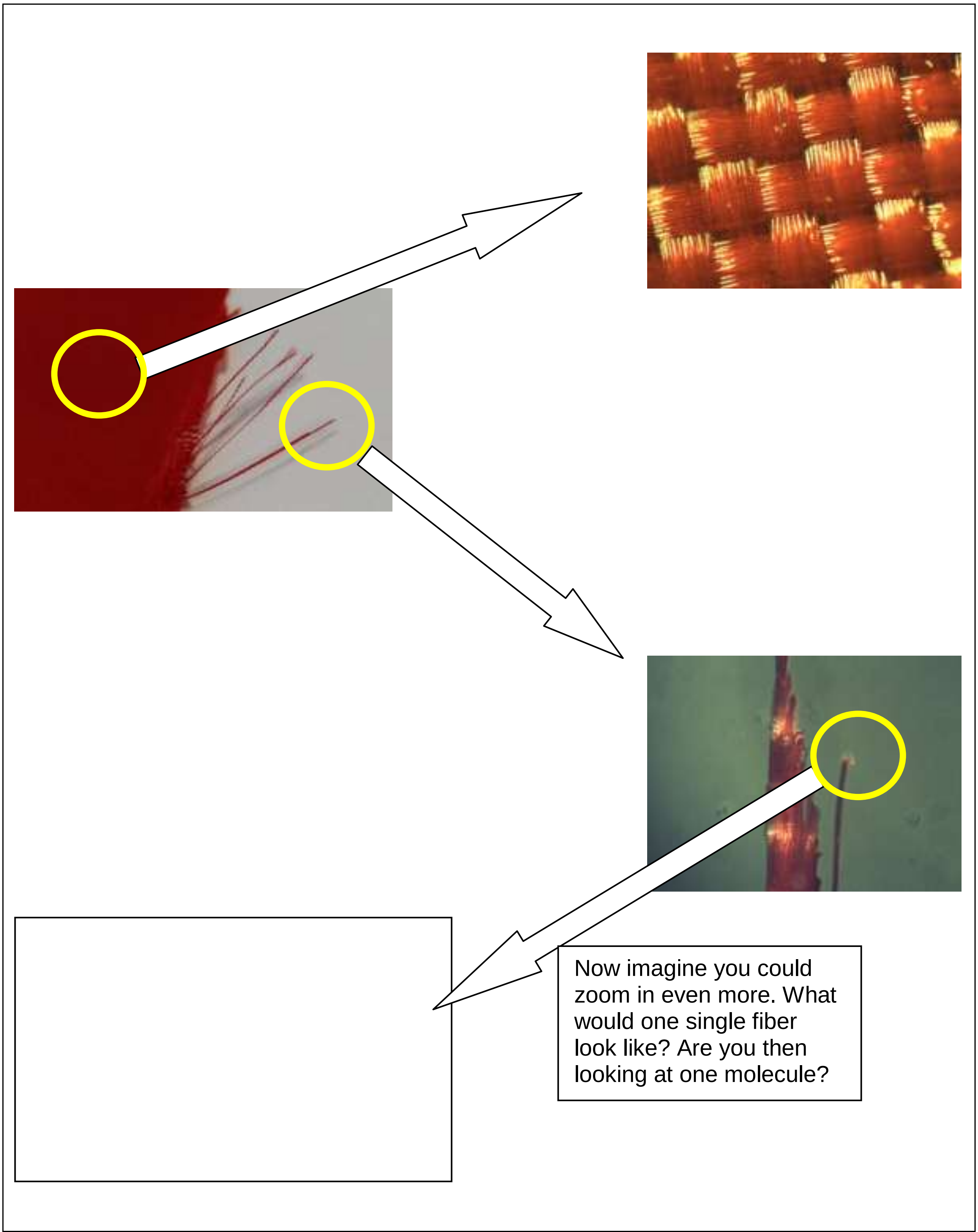
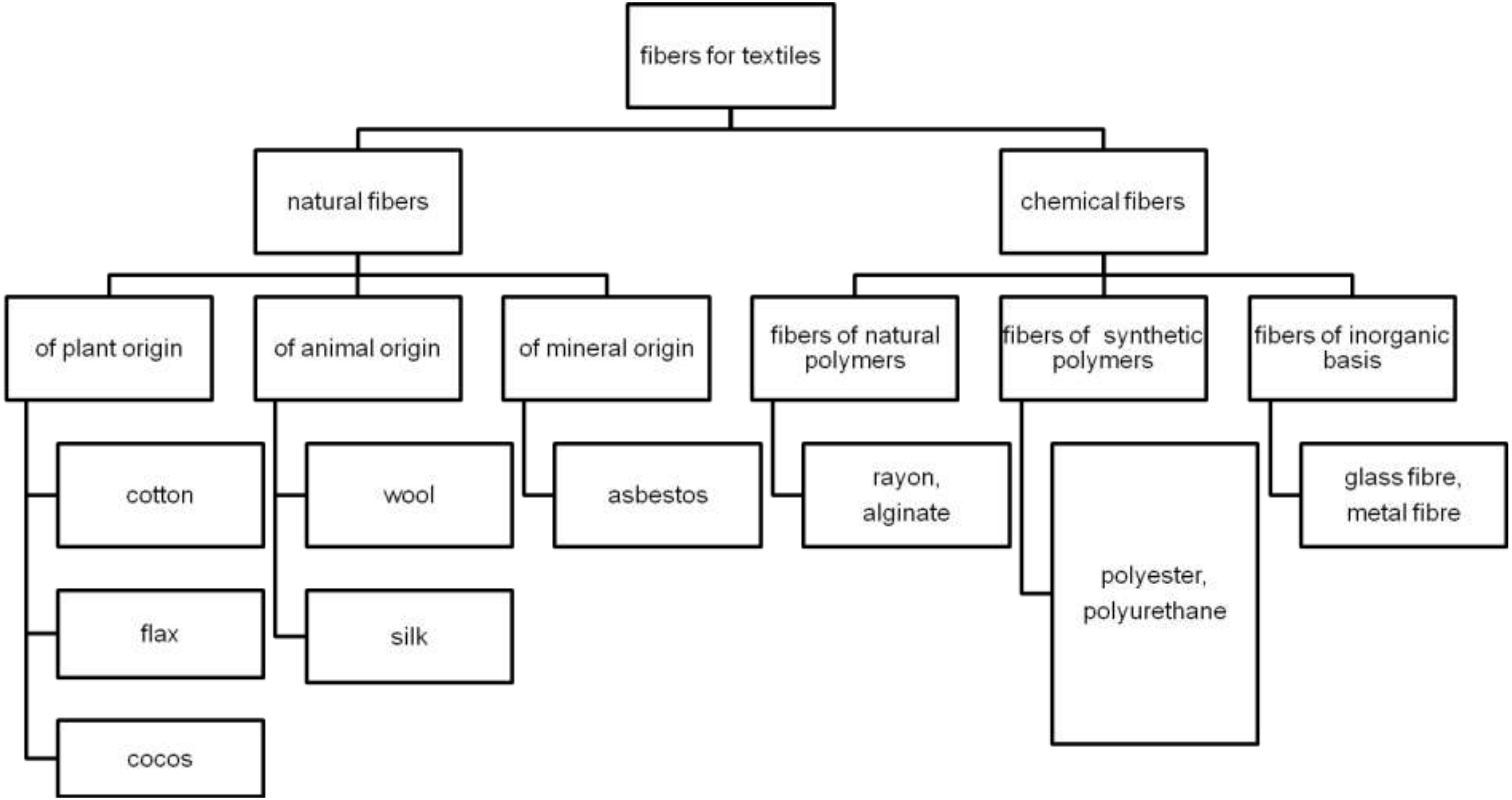


Figure 1: General classification of textile fibres



Activity 3.2: The history of fibres

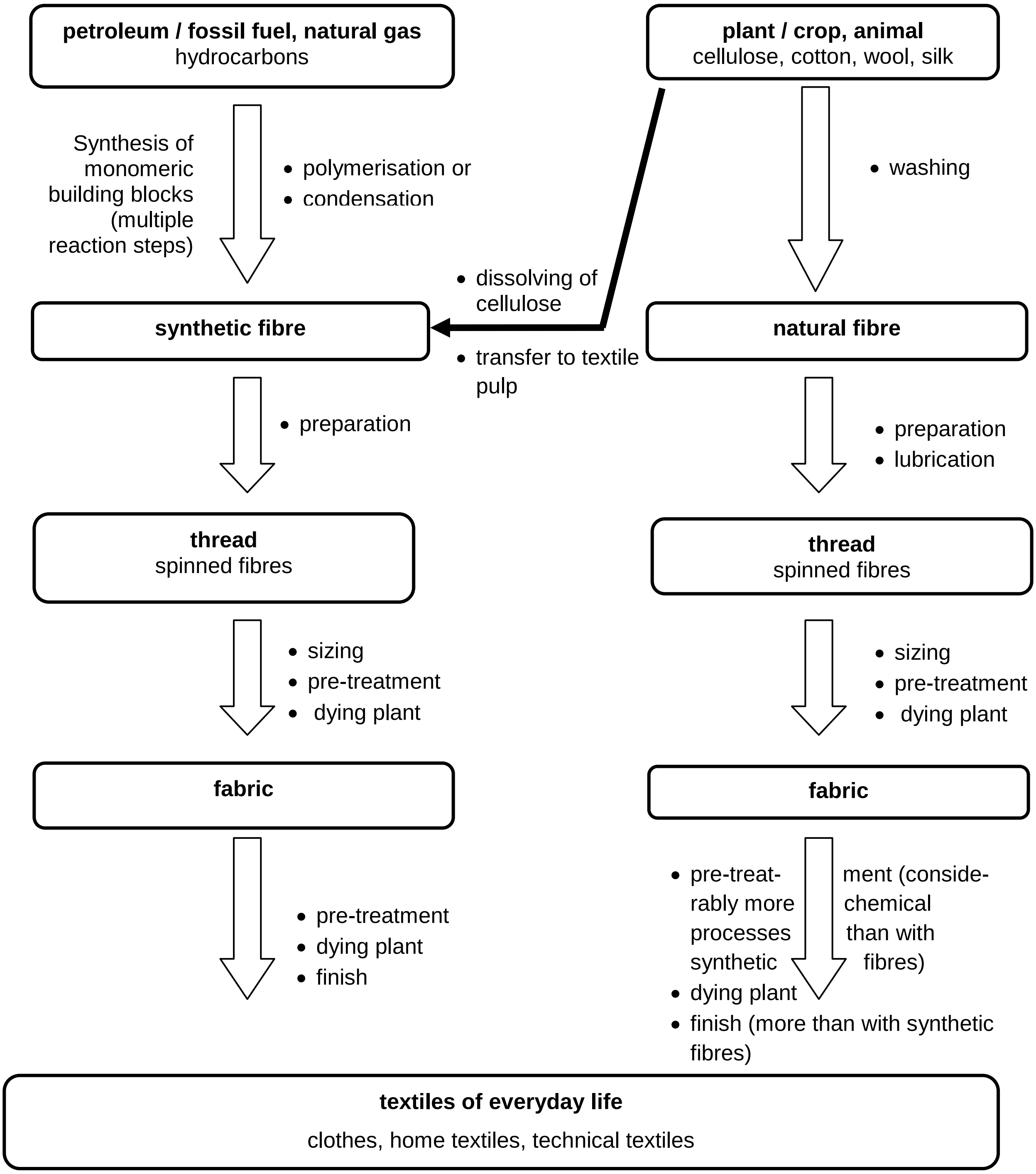
History of the development of synthetic fibres[15]

			Basic patent	
Type of fibre	Inventor	Patent No.	Application date	Start of production
Polyvinyl chloride	F. Klatte	DRP.281877	4.7.1913	1931
Polyvinyl alcohol	W. O. Herrmann and W. Haehnel	DRP.685048	11.3.1931	before 1935
Polyamide (PA 6.6)	W. H. Carothers	U.S.P.2.071.250/1	3.7.1931	1938
Polyethylene	E. W. Fawcett and co-workers	Brit. P. 471590	4.2.1936	1937
Polyvinylidene chloride	R. M. Wiley	U.S.P.2.160.931	1.7.1936	1940
Polyurethane	O. Bayer, H. Rinke and co-workers	DRP.728981	13.11.1937	1939
Polyamide (PA 6)	P. Schlack	DRP.748253	11.6.1938	1939
Polytetrafluoroethylene	R. J. Plunkett	U.S.P.2.230.654	1.7.1939	1954
Polyester	J. R. Whinfield and J. T. Dickson	Brit.P.578079	29.7.1941	1947
Acrylic fibres	H. Rein R. C. Houtz	DBP.915034 U.S.P.2.404.713	14.4.1942 17.6.1942	1943 1942
Polyamide (PA 11)	J. Zeltner and M. Genas	Frz.P.928265	21.4.1944	1948
Polyvinyl acetate	T. Tomonari and co-workers	DBP.932626	17.3.1951	1948
Polypropylene	G. Natta, P. Pino and G. Mazzanti	Ital. P.535712	8.6.1954	1959
Aramid fibres	DuPont	Belg.O.565266/8	1957	1962
Polylactic acid	DuPont	U.S.P.2.668.162	1954	n.a.

[15] Source (adapted from):
P.-A. Koch(2008). Faserstoff-Tabellen; IN Koslowski, Hans-J. (Hrsg). Chemiefaser-Lexikon: Begriffe - Zahlen – Handelsnamen. 12., erweiterte Aufl. Frankfurt am Main: Deutscher Fachverlag GmbH.

Activity 3.3: Research into the process of the production of textiles

General way from raw material to fibre[16]

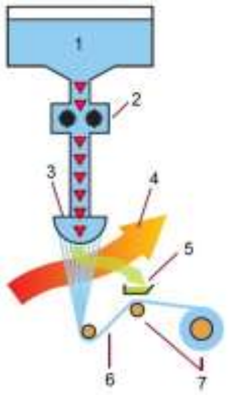


[16] Source (adapted from):
Fonds der Chemischen Industrie im Verband der Chemischen Industrie e.V. “Informationsserie TEXTILCHEMIE“. page 12.

Worksheet 6: The spinning process[17]

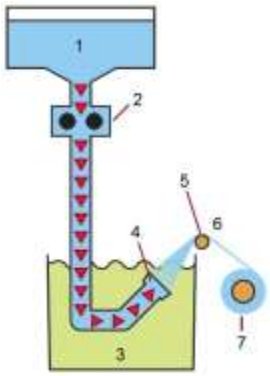
Tasks:

1) Find out about different spinning processes to obtain synthetic fibres.
2) Describe the processes and find out which process can be used for which synthetic fibre.



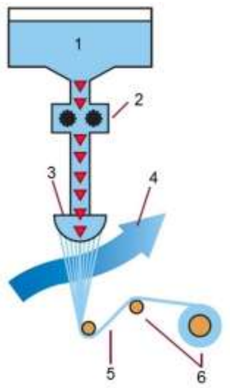
The dry spinning process

1. ______
2. ______
3. ______
4. ______
5. ______
6. ______
7. ______



The wet spinning process

1. ______
2. ______
3. ______
4. ______
5. ______
6. ______
7. ______



The melt spinning process

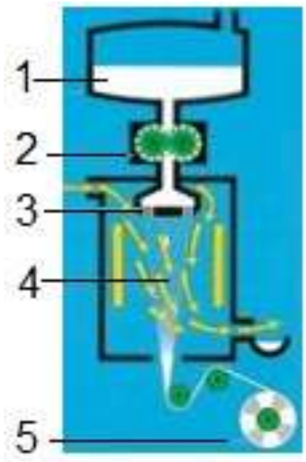
1. ______
2. ______
3. ______
4. ______
5. ______
6. ______
7. ______

[17] Source of figures:
Fonds der Chemischen Industrie im Verband der Chemischen Industrie e.V. “Informationsserie TEXTILCHEMIE: Arbeitsblätter“. page 3.

Solution to Worksheet 6: The spinning process[18]

Production processes of textile fibres – the spinning process
There are several methods for making semi-synthetic fibres. Research for example the methods for making acetate silk or rayon, copper yarn or viscose. There exist also several different methods of spinning, i.e. to twist fibres together to make yarn: the dry spinning process, the wet spinning process and the melt spinning process (for more information see: http://www.ivc-ev.de/live/index.php?page_id=58).

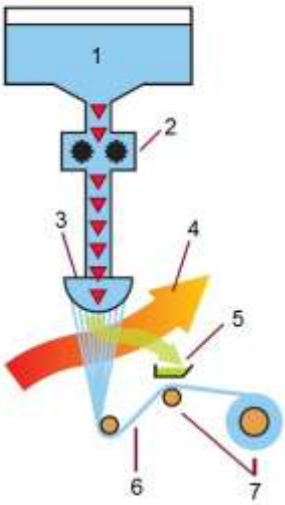
The spinning process
Synthetic fibres can be obtained by different manufacturing processes. Endless yarns called filaments are produced from spin mass. This is pressed through a spinneret. A spinneret can be compared to a bathroom shower head as the spinnable matter (liquid or viscous) must be carefully filtered and is pressed through these from one to several hundred tiny holes or rather openings. When the filaments exit these holes, the liquid polymer is in the spinning process. Then it is first converted to a rubbery state (process of extrusion) and then solidified (process of solidification).
Wet spinning, dry spinning, melt spinning, and gel spinning are the four processes of spinning filaments of manufactured fibres.



The spinning process
(common basic processes)

1. a container holds the spinn mass
2. the spin mass is dosed by a spin pump
3. the spinneret
4. the filament is formed in a medium
   Drawing the filaments may impart strength as drawing pulls the molecular chains together and orients them along the fiber axis which creates a stronger yarn.
5. the filaments are gathered to a filament yarn and spooled by a special device

The dry-spinning process
A container holds the spinn mass (1) which is soluted in an organic solvent. The spin mass is dosed by a spin pump (2) and exits the spinneret (3) into a spinning duct. By evaporating the solvent in a stream of carefully blown in (warm) air or inert gas (4) the solidification of the polymer/filaments is achieved. The filaments are not allowed to touch each other in order not to stick together. The solvent is recaptured (5) and used again. Then the drawing/ stretching of the filaments takes place (6). Finally, they are wound up (7).
This process is applied to produce fibres of acetate, triacetate, acrylic, modacrylic, PBI, spandex, and vinyon.

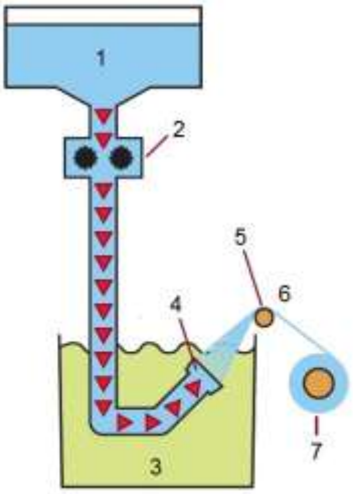


The wet spinning process

In the wet spinning process, which is the oldest used process, the solution is extruded/ pressed directly into the precipitation liquid.

A container holds the fibre-forming substance (spin mass) which is dissolved in a solvent (1). The spin mass is dosed by a spin pump (2). The spinnerets (4) are submerged in a chemical bath (3). When the filaments emerge from the spinnerets, they precipitate from solution and solidify. This is due to a bath which causes the filaments to coagulate. They are pulled towards the top (5). As they are still soft, the drawing/ stretching of the filaments takes place (6). By modifying the stretching, the fibres can be changed according to their specific purpose regarding their stiffness/ resistance and stretching/expanding behaviour. Before they are finally wound up (7) they need to be cleaned from chemicals.

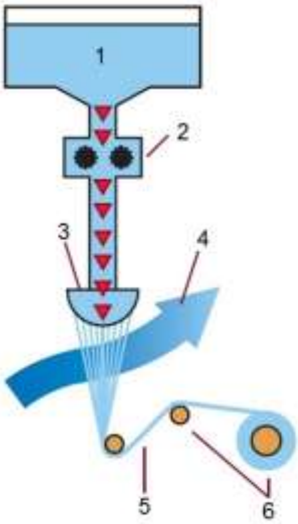
By this process acrylic, aramid, modacrylic, rayon, and spandex can be produced.



The melt spinning process

The melt spinning process is a simple and economic process. In melt spinning, the fibrous raw material needs to be meltable (must not decompose at its melting temperature). The fiber-forming substance is heated and melts (1) before being filtered and dosed by a spin pump (2). Then the extrusion through the spinneret (3) takes place – the melt is pressed through it. The rays of the spin mass flow into a duct several meters high to solidify by cooling via a uniform cold air stream (4). They have to solidify rapidly in order to resist the haul-off speed. Then the drawing/ stretching of the filaments takes place (5). Finally, they are wound up (6).

In this manner, fibres such as nylon, polyester, olefin, saran (polymers made from vinylidene chloride along with other monomers), and polyphenylene sulfide (PPS) (sulfar) are produced.



The gel spinning process

In order to obtain high strength or other special fibre properties this process is used. During the step of extrusion, the fibrous material (polymer) is not in a true liquid state as the polymer chains are bound together at various points in liquid crystal form (in a true solution they would be completely separated). In this process the filaments first pass through air and are then cooled further in a liquid bath. The filaments produced by this method have strong inter-molecular forces which can increase the tensile strength of the fibers. The emerging filaments exhibit a high degree of orientation relative to each other which further enhances strength. In this manner high-strength aramid or polyethylene fibres are produced.

[18] Sources:

- Fonds der Chemischen Industrie im Verband der Chemischen Industrie e.V. "Informationsserie TEXTILCHEMIE: Arbeitsblätter". page 24. http://fonds.vci.de/template_downloads/tmp_fonds.vci.de/119988FCI_Textilchemie_Textheft_20070301.pdf?DokNr=119988&p=111
- Industrievereinigung Chemiefaser e.V. (Herausgeber): Chemiefasern: Von der Herstellung bis zum Einsatz. Frankfurt/Main. Kapitel 6.1 „Fasern nach Maß". English version available see "Man-Made Fibres – The Way From Production To Use" p. 15. http://www.ivc-ev.de/live/index.php?page_id=92
- Manufacturing: Synthetic and Cellulosic Fiber Formation Technology. American Fiber Manufacturers Association / Fiber Economics Bureau. 2012. Zugriff: 28.02.2012. http://www.afma.org/f-tutor/techpag.htm

Activity 3.4: Properties of different fibres

Collect different clothes samples, made of different fibres.

Plan experiments investigating the following properties of your textile samples (e.g. wool, silk, cotton, rayon...):

- Permeability regarding air (with pressure)
- Permeability regarding water (jet of water and water drops)
- Permeability regarding steam
- Amount of water absorption
- Insulating properties
- Behaviour when heated

Activity 3.5.1: Innovation in the clothing industry

Material:
Worksheet 7

Tasks:
1. Rate the arguments into those in favour of using innovations in the clothing industry and those against it.
2. Find out about the underlying principle. Explain it. You may paint a model to explain the steps. (Search the internet for material and information)
3. List further pros and cons regarding the application/ usage of such chemicals or silver. Are there alternatives? Evaluate this new innovation. Take into consideration these various aspects regarding this topic.

Worksheet 7: innovation in the clothing industry

There are different methods that are used to produce antimicrobial textiles. Some manufacturers use chemical additives such as quaternary ammonium salts, different kinds of the biopolymer (polysaccharide) Chitosan, or the antibacterial and antifungal as well as preserving agent Triclosan (not used anymore due to possible harmful impact to health).

New high-tech textiles kill germs. Thus, body-odour is inhibited as the propagation of bacteria is inhibited.

Some manufacturers use silver which is weaved into the textiles in the form of fine threads or the fibres are interspersed by silver particles. Silver ions kill the bacteria which has an antimicrobial effect. Products contain small amounts of the metal, in the form of nanoparticles that release ions slowly over time.

Tests regarding the loss of silver during washing showed large variations in the amount of silver released in the first washing. Most of the silver was in the form of coarse particles of larger than 450 nanometers. This suggests that mechanical stress in the washing machine was responsible for most of the release.

There are concerns about antimicrobial textiles that the additives (e.g. silver ions) may harm the natural skin flora over a longer period of time. It is important to know if the antibacterial silver, e.g. in sportswear, harms the skin of healthy people as there are billions of bacteria and fungi on the skin which play an important role in the body's own infection defence and keep possibly pathogenic germs under control.

Silver can be very effective regarding neurodermatitis as it kills bacteria. Studies showed that by wearing antimicrobial textiles, the skin appearance improved in only a few weeks. The reason for that is that silver ions attack the staphylococcus aureus, a germ typically found with this skin disease.

Activity 3.6: Keeping textiles clean

Worksheet 8: Research project

Task:

find out about the following:

a) What are your clothes made of?
b) What all can you do with your clothes in order to get them clean? Consult the care label for details. For information on what the icons mean, look for information in books or the internet.

For a list of care icons (there are icons for washing, chemical cleaning, ironing, drying and bleaching), see for example:
http://www.textileaffairs.com/docs%5Ccommon-050608.pdf

Worksheet 9: How bleaching agents work[21]

Besides surfactants, which are used as washing active substances, heavy-duty detergents often include bleaching agents. These remove dirt by means of oxidation processes. Bleaching agents were not always present in laundry detergents. At one time, laundry used to be spread out on the grass to be bleached by natural ultraviolet radiation from the sun. During the course of time, as laundry detergents underwent further development, a variety of bleaching agents came to be used.

Tasks

1) Find out about the various bleaching agents and draw up an overview of the bleaching agents you think would be suitable for inclusion in laundry detergents, and the ones which would not. Give reasons for your choices.
2) After consulting your teacher, carry out experiments to show the effects of various bleaching agents.

[21] Worksheet taken from: http://www.henkel.com/com/content_data/106612_4.8.2_Sustainable_washing_for_a_clean_environment_Chemistry_for_Advanced.pdf

Worksheet 10: The development of laundry detergents – from laboratory to production scale[22]

You work in the laboratory of a laundry detergent manufacturer. You would like to develop a new laundry detergent and you have to give your colleagues an overview of the properties your new product should have and what ingredients it should contain.

Tasks

1) Decide first of all which type of laundry detergent you want to produce and what properties it should have (e.g. particularly good environmental compatibility, an attractive price, no fragrances, etc.). You can choose from three detergent types: heavy-duty detergents, detergents for colored fabrics, detergents for wool and silk.
2) **Material 1** contains standard compositions for the three laundry detergent types and **Material 2** contains a choice of laundry detergent ingredients with their corresponding identification numbers (CAS no.). Use this material to gather information on the Internet about the criteria you have drawn up for the ingredients of your laundry detergent type and create a table. The following Internet sites may be helpful:

Wikipedia Encyclopedia	**http://en.wikipedia.org/wiki/Main_Page**
Database on hazardous substances	**http://www.dguv.de/bgia/en/gestis/index.jsp**
Costumer information on cleaning products	**http://uk.cleanright.eu/**
Raw material prices, e.g. Sigma-Aldrich	**www.sigmaaldrich.com** (Registration site)

3) Briefly describe the characteristic ingredients your laundry detergent should have. Remember that industrial production is a very large-scale operation. Give reasons for your decision. Also relate briefly whether there are any ingredients that should NOT be in the laundry detergent you develop.

[22] Worksheet and relating Materials 1-2 are taken from: http://www.henkel.com/com/content_data/106612_4.8.2_Sustainable_washing_for_a_clean_environment_Chemistry_for_Advanced.pdf

Material 1

Standard compositions of laundry detergents

Laundry detergents	Ingredients < 5%	Ingredients 5% to 15%	Ingredients 15% to 30%	Ingredients > 30%	Other ingredients
Heavy-duty laundry detergents	Nonionic surfactants Soap Polycarboxylates Phosphonates Aliphatic hydrocarbons	Anionic surfactants	Oxygen-based bleaching agents Zeolites		Enzymes (cellulase, lipase, protease) Optical brighteners Fragrances
Detergents for colored fabrics	Soap Polycarboxylates Phosphonates	Nonionic surfactants	Anionic surfactants	Zeolites	Enzymes (cellulase, lipase, protease) Fragrances Dye transfer inhibitors
Laundry detergents for wool and silk	Soap Polycarboxylates Nonionic surfactants	Anionic surfactants Zeolites			Care Balsam Fragrances Auxiliaries Dye transfer inhibitors

Material 2

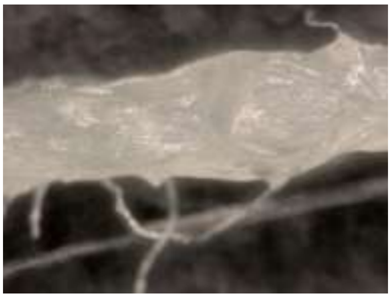
Name of the laundry detergent ingredient	CAS no.
Washing active substances	
Anionic surfactants	
Soap	8052-48-0
Linear alkylbenzene sulfonates (LAS)	27176-87-0
Branched alkylbenzene sulfonates (TPS)	11067-82-6
□-Olefin sulfonates	
Nonionic surfactants	
Alcohol alkoxylates (EO/PO)	69013-18-9
Alkyl polyglycosides (APG)	
Softeners/Builders	
Soda ash (Na_2CO_3)	497-19-8
Nitrilotriacetic acid (NTA)	139-13-9
EDTA	60-00-4
Sodium tripolyphosphate	7758-29-4
Zeolite A	1318-02-1
Polycarboxylates	
Phosphonates, e.g. HEDP	2809-21-4
Bleaching agents	
Sodium hypochlorite	7681-52-9
N,N,N’,N’-Tetraacetylethylene diamine (TAED)	10543-57-4
Sodium perborate	7632-04-4
Sodium percarbonate	15630-89-4
Enzymes, e.g. lipase, protease and cellulase	
Foam regulators	
Fatty acid amides	124-26-5
Cocoamidopropyl betaine	61789-40-0
Optical brighteners	
Stilben derivatives	16090-02-1
Naphthalene benzoxazoles	5089-22-5
Perfumes	
Sandalwood oil	8006-87-9
Linalool	78-70-6
Citronellol	106-22-9
Musk xylene	81-15-2
Dye transfer inhibitors, e.g. polyvinylpyrrolidone PVP	9003-39-8
Antisoiling agents, e.g. PET/POET polymers	
Antiredeposition agents, e.g. carboxymethyl cellulose	9000-11-7
Fillers, e.g. Na_2SO_4	7757-82-6
Colorants	
Corrosion inhibitors, e.g. sodium silicate (Na_2SiO_3)	6834-92-0

Worksheet 11: Behaviour of fibres during washing process

1. Look at the following pictures (same fibre with different enlargements, taken by Kirsten Fischmann at Henkel facility) and comment on them.


Cotton fibre


Cotton fibre with Persil Gold Universal Gel


Cotton fibre with Persil Gold Universal Gel

2. Reserach in school textbooks or on the internet, how dirt is removed from fabric on a submicroscopic level.
3. Carry out the experiment as described in Worksheet 11a.

Worksheet 11a: Behaviour of fibres/textiles in the washing process

Apparatus and materials

- petri dishes and small beakers or yoghurt cup (depends on the number of laundry detergents and the concentration of solutions you like to test)
- pipettes and spatula (one for every detergent, depends on the viscosity)
- pieces of cloth/ threads of different fibres (wool, cotton, polyester, polyamide, viscose); multiplied by the number of detergent (and concentration, if you want to test several)
- tap water
- different laundry detergents (e.g. Persil-Universal-Powder; Persi-Universal-Gel; Perwoll-care for fine fabrics; Persil-Color-Gel; Perwoll-Powder for Wool and Silk; citric acid; washing soap)
- beakers to mix detergent and water
- pH meter
- stop watch
- scissors
- pair of tweezers
- microscope
- heating panel
- glass rod for stirring

Safety

- Wear your safety goggles!

Procedure

- Measure the pH value of tap water and each laundry detergent and solution.
- Prepare solutions of water and laundry detergent in beakers. Prepare solutions of different concentrations for each detergent. (for example, in one beaker add 50 g or 50 ml of the laundry detergent and about 250 ml of tap water and in another beaker prepare a higher concentration the laundry detergent) Label the beakers with name of detergent and concentration.
- Measure the pH value of each laundry detergent solution.
- Fill each solution in X (X = number of textile samples) petri dishes or small beakers.
- Then add a tiny piece of cloth and/or some fibres in one petri dish.
- Heat the solution up to 60°C on heating panels and stir the solution to simulate the washing process.
- Analyse the fibres after 5, 30, and 60 minutes under the microscope.

Disposal

- Take the pieces of cloth/ some fibres/threads out of the petri dishes with a pair of tweezers and put them into the dustbin.
- As these are solutions of laundry detergents, pour them down the sink.

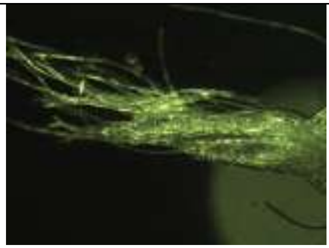
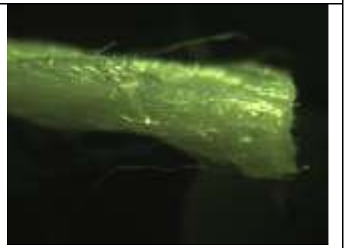
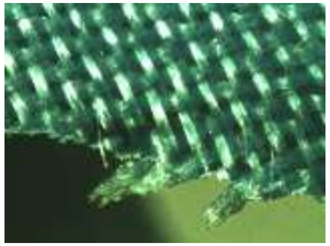
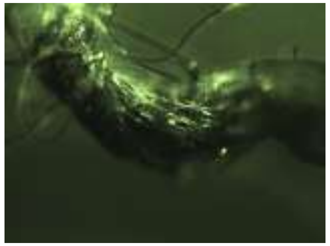
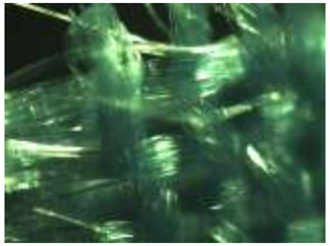
Tasks:

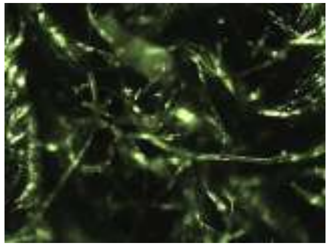
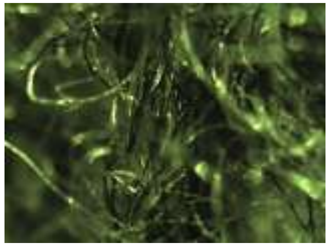
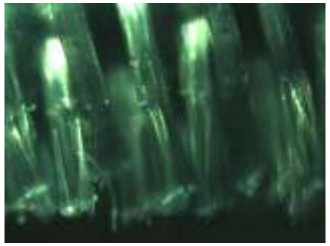
1. Carry out the experiments in teams.
2. Fill in the table in Material 3 with a description of how the fibres look under the microscope.

Material 3: Analysis of cloth/fibre samples in different washing solutions

Detergent	soaking time and temperature	concentration		pH value		natural fibres				synthetic fibres					
						wool		cotton		polyester		polyamide		viscose	
		I	II	I	II	I	II	I	II	I	II	I	II	I	II
all-purpose detergent	5 min.														
	30 min.														
	60 min.														
mild detergent	5 min.														
	30 min.														
	60 min.														
detergent for bright colors	5 min.														
	30 min.														
	60 min.														
special detergent: for woollen fabrics	5 min.														
	30 min.														
	60 min.														
washing soap	5 min.														
	30 min.														
	60 min.														
citric acid	5 min.														
	30 min.														
	60 min.														

Material 3: Possible solution - Analysis of the fibre samples in different washing solutions

				Describe how the fibre look like under the microscope:		
				natural fibres		**synthetic fibre**
Laundry detergent	**soaking time and temperature**	**concentration (detergent in g or ml / H_20 in ml)**	**pH value**	**wool**	**cotton**	**polyester**
All-purpose detergent • Persil-Universal-Powder	90 min. 40°C	5 g in 100 ml H_20	10,74			
Mild detergent • Perwoll – care for fine fabrics (liquid)	110 min. 40°C	5 ml in 250 ml H_20	**7,97**			
soapsuds • e.g. Fa Bar Soap Vitalizing Aqua	180 min. 40°C	**3 g in** 250 ml H_20	**9,33**			

• washing soda	180 min. 40°C	**2 EL in 250** ml H_20	**11,26**			
acidic solution • vinegar cleaner	180 min. 40°C	**5 ml in 250** ml H_20	**3,75**			

Material 4: Differences between laundry detergents

	all-purpose detergent (solid/ powder)	all-purpose detergent (liquid)	mild detergent	detergent for bright colors	detergent for special fabrics e.g. detergent for wool and silk	fabric softener
examples of Henkel AG & Co. KGaA products	Persil Universal, Weißer Riese, Spee als Pulver, Megaperls®, Tabs		Persil, Weißer Riese, Spee als Gel, Spee Feinwäsche, Perwoll Black für Schwarzes und Dunkles, Perwoll Sport für Synthetics	Persil Color, Weißer Riese Color, Spee Color als Pulver, Megaperls®, Tabs, Gel	Perwoll Wolle & Seide Perwoll Pflege für Feines (liquid)*	Vernel
anionic surfactants	✓	✓	✗	✓	✓	✗
non-ionic surfactants	✓	✓	✓	✓	✓	✗
cationic surfactants	✗	✗	✗	✗ (✓)	✗	✓
softener	✓	✓	✓	✓	✓	✗
bleaching agent	✓	✗	✗	✗	✗	✗
enzymes	✓	✓	✓	✓	✗	✗
optical brighteners	✓	✓	✗	✗	✗	✗

[23] Sources:

- http://dblay.de/einblicke/wasch/arten
- Richtig Waschen: Informationen rund ums Waschen – Spülen – Reinigen. Jens Gebhard, Christa Wolf, Kerstin Ochs. Henkel AG & Co. KGaA. Redaktion: Consumer Relations. Düsseldorf, 2008. http://www.henkel.de/de/content_data/95757_richtigwaschen_080723.pdf
- (Flyer) Textilien richtig waschen – Werte erhalten. Forum Waschen c/o. Industrieverband Körperpflege- und Waschmittel e.V. (IKW). Frankfurt am Main. 2011. http://www.ikw.org/pdf/broschueren/IKW_FB_RichtigWaschen_web.pdf

Activity 3.7: Economic view on textiles

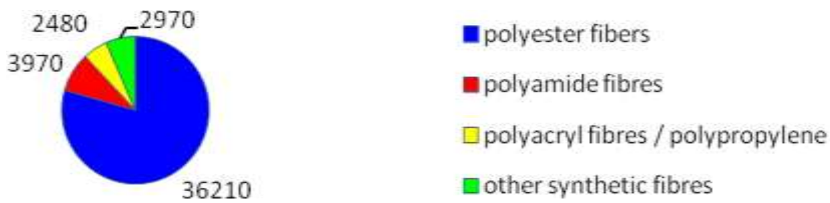
Production of chemical fibres in Germany 2010[24]

in 1000 tons

synthetic fibres, total	550
cellulose fibres	201
chemical fibres, total	751

World production of chemical fibres 2010

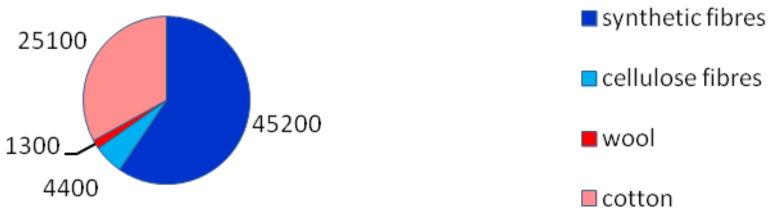
in 1000 tons



synthetic fibres, total	45.630
cellulose fibres	3.970
chemical fibres, total	49.600

World production of textile fibres 2010

in 1000 tons



[24] Source:
Industrievereinigung Chemiefaser e.V. http://www.ivc-ev.de/live/index.php?page_id=43

Activity 3.8: Ecological view on textile care

Worksheet 12: The influence of temperature on wash performance[25]

Imagine you have a cocoa stain on your white T-shirt! Is it true that the higher the wash temperature is, the more easily the stain can be removed? To find out, you will be given cocoa-stained cotton cloths to wash at different temperatures.

Tasks

1) Plan an experiment, with which you can test wash performance at different temperatures. Make a sketch of the experiment first, and then briefly write down what you are going to do.
2) Carry out your experiment and record the wash result.
3) At which temperatures did you obtain the best wash result? Why is this?
4) Investigate how much energy you could save by washing at 30°C or 40°C instead of 60°C. Calculate the saving in electricity costs. Which other electrical appliances could you run with the saved energy?

[25] Worksheet taken from: http://www.henkel.com/com/content_data/106612_4.8.2_Sustainable_washing_for_a_clean_environment_Chemistry_for_Advanced.pdf

Worksheet 13: Improving wash performance by adding stain remover[26]

The chosen wash temperature is one of the factors that influence how good the wash performance is. In this experiment you will now investigate how the addition of stain remover affects the wash performance. To do this you will be given cocoa-stained cotton cloths, which you will wash with laundry detergent, stain remover and a combination of laundry detergent and stain remover.

Tasks

1) Plan a series of experiments with which you can investigate the effect of stain remover on wash performance. Make a sketch of the experiment first, and then briefly write down what you are going to do.
2) Carry out your experiment and record the wash result.
3) With which experiment did you obtain the best wash result? Why is this?

[26] Worksheet taken from: http://www.henkel.com/com/content_data/106612_4.8.2_Sustainable_washing_for_a_clean_environment_Chemistry_for_Advanced.pdf

Worksheet 14: The effect of laundry detergent dosage and water hardness on wash performance[27]

You have probably seen the advice shown below on a packet of laundry detergent at home:

4/5 Kg	SOFT WATER	80ml	120ml	200ml
	MEDIUM WATER	120ml	160ml	240ml
	HARD WATER	160ml	200ml	280ml

This shows the recommended dosage of laundry detergent for different degrees of soiling and water hardness. The experiment investigates the effect of the detergent dosage and the hardness of the water on the wash performance. This is done by washing pieces of cocoa-stained cloth using different dosages of laundry detergent.

Tasks

1) Plan a series of experiments with which you can investigate the effect of the laundry detergent dosage and the hardness of the water on the wash performance. Make a sketch of the experiment first, and then briefly write down what you are going to do.
2) Carry out your experiment and record the wash result.
3) With which dosage did you obtain the best wash result? Why is this? Take the hardness of the water into account.
   (Note: You can find an overview of water hardness on the Internet, e.g. by looking up the region's waterworks.)

[27] Worksheet taken from: http://www.henkel.com/com/content_data/106612_4.8.2_Sustainable_washing_for_a_clean_environment_Chemistry_for_Advanced.pdf

Worksheet 15: The influence of laundry detergents on the growth of cress plants[28]

Wastewater from households (for example from the washing machine) is thoroughly cleaned in sewage treatment plants so that it can be discharged into surface water. What would happen if we discharged our wastewater into the environment without subjecting it to any sort of treatment beforehand? This experiment shows the influence of a laundry detergent on the growth of cress plants. The wash water represents the wastewater, and the cress plants represent the environment.

Tasks

1) Devise a series of experiments with which you can investigate the effect of the laundry detergent on the growth of cress plants. Use different concentrations of the laundry detergent. Make a sketch of the experiment first, and then briefly write down what you are going to do.
2) Carry out your experiment and record your observations. How did the cress change under the influence of the laundry detergent?
3) Plot your results on a graph.

[28] Worksheet taken from: http://www.henkel.com/com/content_data/106612_4.8.2_Sustainable_washing_for_a_clean_environment_Chemistry_for_Advanced.pdf

Worksheet 16: Biodegradability of surfactants – Part 1[29]

Each year, about **250,000 metric tons** of surfactants are used in households, trade and industry in the Federal Republic of Germany. Most of them – about 64 percent – are ingredients of laundry detergents and household cleaners. They are also used in cosmetics and pharmaceuticals, textile and leather auxiliaries and in numerous other sectors. Anionic surfactants are the most widely used (136,000 metric tons each year), followed by the nonionic surfactants (approximately 97,000 metric tons).

The surfactants used in households, e.g. to wash laundry, enter the drains unchanged in the wash liquid. High concentrations of surfactants are toxic to many aquatic life forms (e.g. fish and algae). For reasons of environmental compatibility, it is therefore very important that these surfactants are rapidly removed from the environment, e.g. by undergoing **biodegradation**.

There are two stages of surfactant biodegradation: **primary** and **ultimate**.

When primary biodegradation occurs, the basic chemical structure of the surfactants remains largely unchanged, but they lose their characteristic ability to dislodge dirt. They also become less toxic to organisms that live in water, and form less foam.

As biodegradation proceeds, the surfactants are broken down into ever smaller and simpler units. These changes are caused by the metabolic processes that take place in microorganisms that use organic substances as food. Finally the surfactants are converted into mineralization products such as carbon dioxide (CO_2), water (H_2O) and salts, together with biomass (bacterial cell material). The biomass is formed from small C-H units, and its formation is the reason why, strictly speaking, substances never undergo 100% ultimate biodegradation.

In 1973, Europe's first piece of legislation regulating the ingredients of laundry detergents and household cleaners came into force. This was the Detergent Directive. It stipulated that anionic and nonionic surfactants in laundry detergents and household cleaners would have to have a primary biodegradability of at least 80%. During the following years, however, the consumption of laundry detergents and household cleaners continued to increase and the required primary biodegradability proved to be no longer adequate. The new so called EU Detergent Regulation of 2004 therefore stipulated that all washing-active surfactants in laundry detergents and household cleaners must be ultimately biodegradable.

Tests of primary biodegradability include the **OECD Confirmatory Test** and the **OECD Screening Test**. Tests of the ultimate biodegradability of organic compounds include the **Closed Bottle Test (OECD 301 D)** and the **Coupled Units Test (OECD 303 A)**.

Tasks

1) Explain the difference between primary and ultimate biodegradation of surfactants. Why is it not possible to achieve 100% ultimate biodegradation?
2) In the late 1950s, mountains of foam could be observed on surface waters. These were caused by the surfactants in the laundry detergents that were in use at that time. Explain how foam came to be formed on surface waters.
3) Search the Internet for information about OECD test methods. Briefly describe one test for primary biodegradation and one for ultimate biodegradation.

[29] Worksheet taken from: http://www.henkel.com/com/content_data/106612_4.8.2_Sustainable_washing_for_a_clean_environment_Chemistry_for_Advanced.pdf

Worksheet 17: Biodegradability of surfactants – Part 2[30]

Most of the ingredients of laundry detergents pass into sewage treatment plants with the wastewater. There they either undergo biodegradation or are removed by other processes before the cleaned wastewater is discharged into surface waters. If small amounts of ingredients, e.g. surfactants, do manage to enter the environment, nature is not completely defenseless, as some natural organisms are able to break down surfactants and other chemicals. This experiment shows what happens when small amounts of laundry detergents enter a river or lake.

Tasks

1) Plan an experiment, with which you can investigate the biodegradability of surfactants in rivers and lakes. Make a sketch of the experiment first, and then briefly write down what you are going to do.
2) Carry out your experiment and record your observations. Find explanations for what you observed.

[30] Worksheet taken from: http://www.henkel.com/com/content_data/106612_4.8.2_Sustainable_washing_for_a_clean_environment_Chemistry_for_Advanced.pdf

Worksheet 18: Biodegradability of surfactants – Part 3[31]

Since the mid-1950s, modern surfactants were used in large quantities in laundry detergents and household cleaners. Tetrapropylenebenzene sulfonate (TPS) was the first poorly biodegradable surfactant to be used. A visible sign of this was the mountains of foam on watercourses (Fig. 1).

Fig. 1: Mountains of foam on surface waters – caused by poorly biodegradable surfactants in detergents

The detergent industry responded by starting to develop and introduce readily biodegradable surfactants. Between 1961 and 1964, TPS was gradually replaced in the West Germany by linear alkylbenzene sulfonates (LAS). Moreover, the Henkel company measured the surfactant load in the river Rhine at two-weekly intervals. The results were made available to scientists, politicians and supervisory bodies, and were published annually. In the 1970s, the municipal sewage plants were also upgraded.

Tasks

Material 5 shows an overview of laundry detergent consumption in Germany from 1960 onward, and an overview of the surfactant loads in the river Rhine near Düsseldorf from 1958 to 2007.

1) Describe the course of the two graphs.
2) How can the graph of the surfactant load over time be explained in relation to the use of surfactants in laundry detergents?

[31] Worksheet and relating Material 5 are taken from: http://www.henkel.com/com/content_data/106612_4.8.2_Sustainable_washing_for_a_clean_environment_Chemistry_for_Advanced.pdf

Material 5

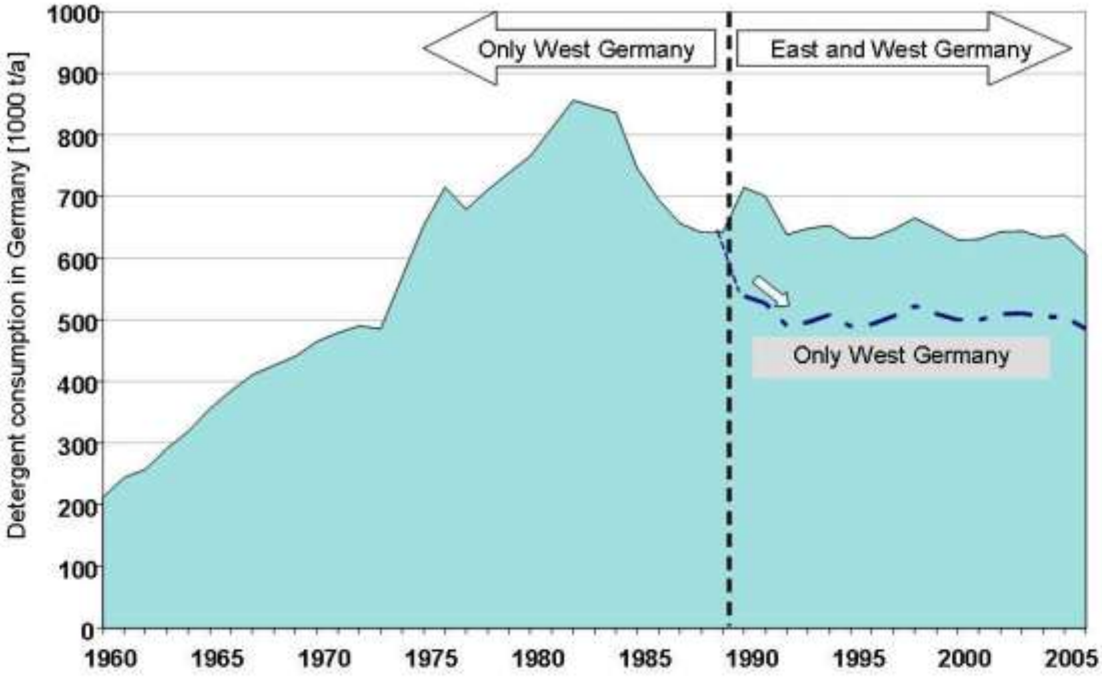


Fig. 1: Laundry detergent consumption in Germany

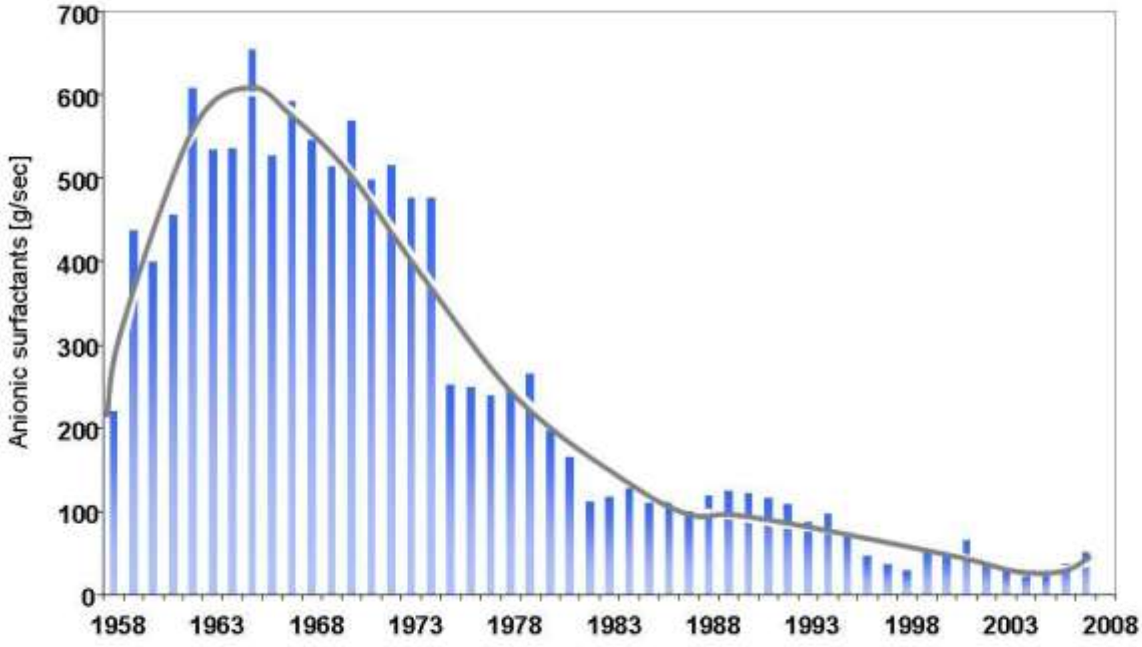


Fig. 2: Surfactant loads (median values) in the river Rhine near Düsseldorf (1958 – 2007)

Worksheet 19: Biodegradability of surfactants – Part 4[32]

The surfactant tetrapropylenebenzene sulfonate (TPS), which is poorly biodegradable, was phased out in West Germany between 1961 and 1964, and was replaced by surfactants known as linear alkylbenzene sulfonates (LAS).

The following diagrams show the structural formulas of TPS and a LAS:

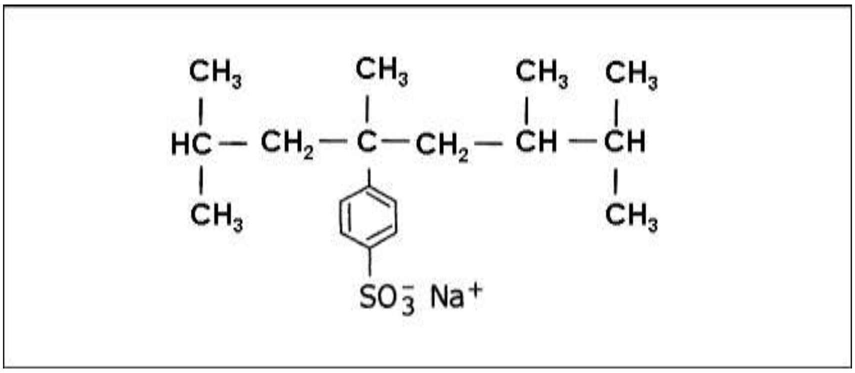


Figure 1: Tetrapropylenebenzene sulfonate (TPS)

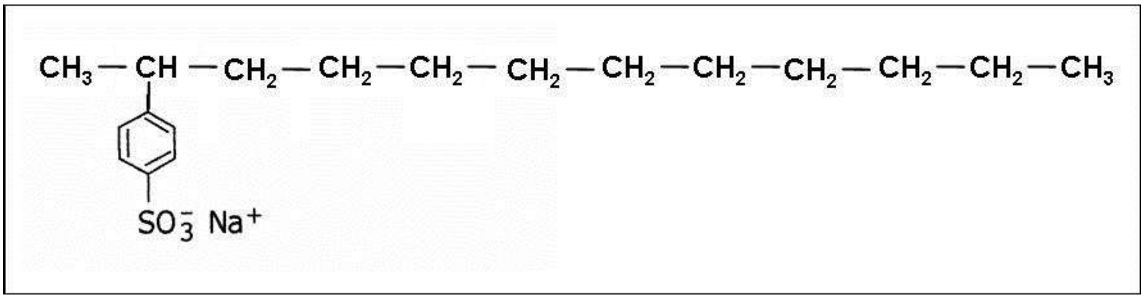


Figure 2: 2-Dodecylbenzene sulfonate (a LAS)

Task

What might the reason be for the poorer biodegradability of TPS relative to LAS?

Remember that the surfactants are broken down in surface waters by microorganisms.

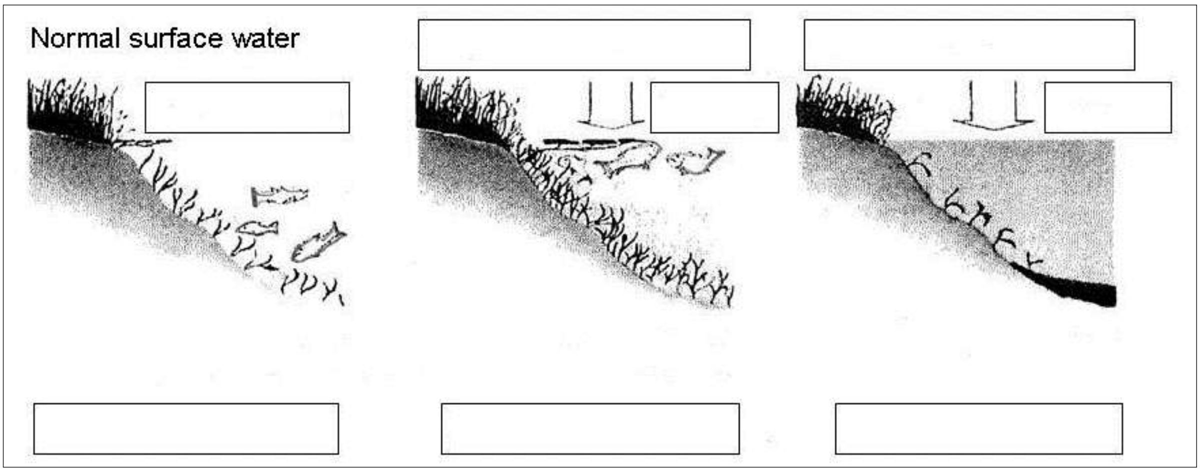
[32] Worksheet taken from: http://www.henkel.com/com/content_data/106612_4.8.2_Sustainable_washing_for_a_clean_environment_Chemistry_for_Advanced.pdf

Worksheet 20: Ecological impacts of the phosphates previously used in laundry detergents[33]

Phosphates are all around us in the natural world. The metabolism of every organism, including humans, needs compounds that contain phosphate groups. If excessive amounts of phosphate enter lakes, however, as they did in the days when detergents contained phosphates, a surplus of plant nutrients can accumulate in the lake. This stimulates the growth of algae, which constitute most of the biomass in the water. The organisms that live on algae can therefore also multiply, and there is a knock-on effect at the next highest levels of the food chain. More algae means more photosynthetic activity, releasing oxygen, so that a surplus of oxygen accumulates in the upper layers of the lake. And because there is more biomass, more organisms die. The dead biomass sinks to the bottom of the lake, where microorganisms break it down aerobically, i.e. consuming oxygen as they do so. This results in a shortage of oxygen in the deeper water layers. In the absence of oxygen, anaerobic bacteria multiply, releasing toxic metabolic products as they do so. These toxic products cause many forms of life in the lake to die. The oxygen-depleted lake can no longer be used as a source of drinking water. Over-enrichment of aquatic systems with plant nutrients (C, N, P) is referred to as eutrophication.

Task

Add captions to the following diagram to illustrate the process of eutrophication. Use the following terms: *Phosphates, anaerobic digested sludge, strong plant growth, oxygen-rich, nutrient-rich, oxygen-depleted, nutrient-depleted*



The phosphate content of Lake Constance – Germany's biggest inland body of water – has been studied for many years. The knowledge gained can be applied to other bodies of water such as the North Sea and the Baltic. The diagram below shows the phosphate concentration in Lake Constance from 1950 to 2004.

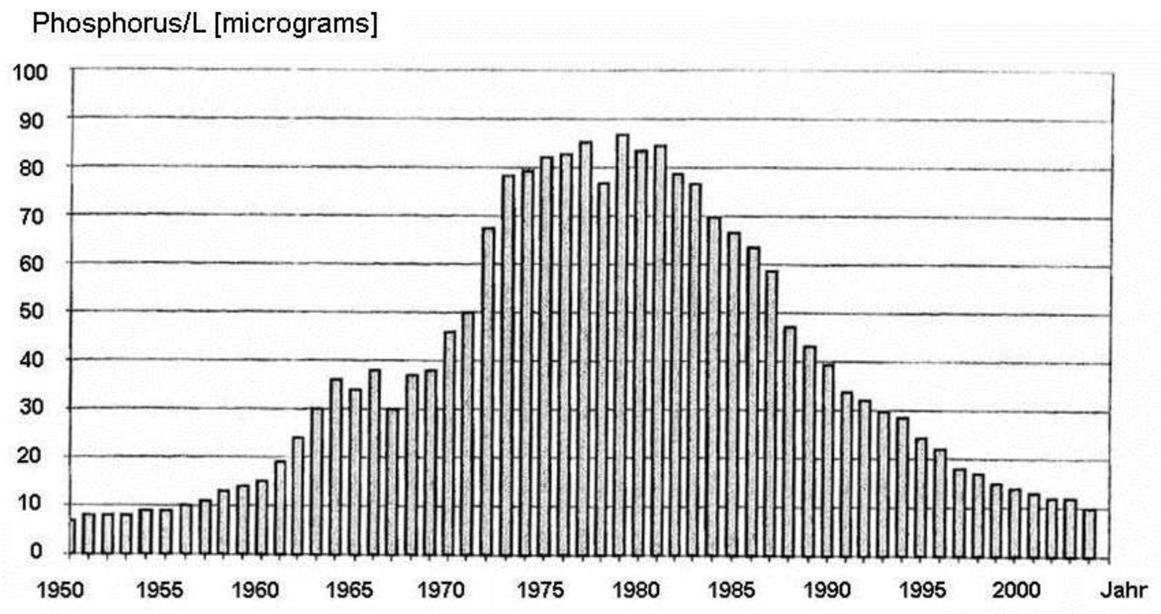


Fig. 1: Phosphate concentration in Lake Constance from 1950 to 2004

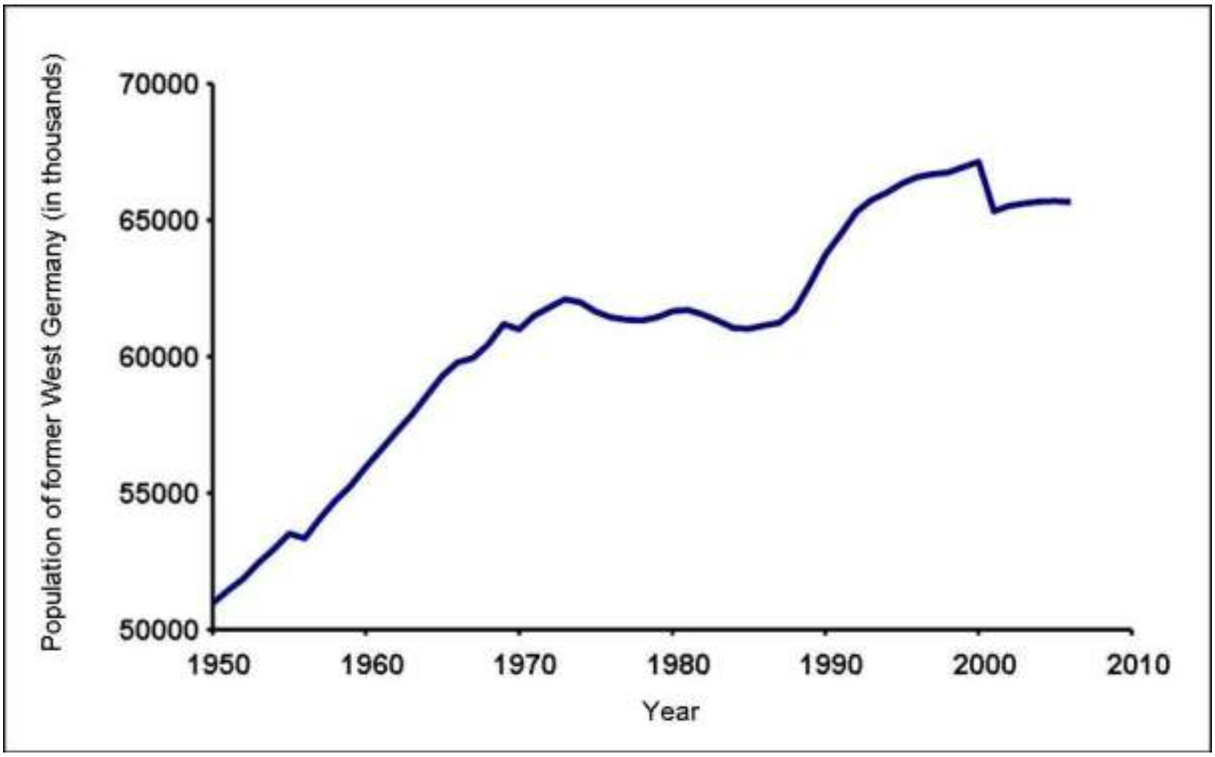
Task

Explain the curve of the phosphate concentration in Lake Constance. Draw on **Materials 6, 7 and 8** in your explanation.

[33] Worksheet and relating Materials 6-8 are taken from: http://www.henkel.com/com/content_data/106612_4.8.2_Sustainable_washing_for_a_clean_environment_Chemistry_for_Advanced.pdf

Material 6

Population of the former West Germany from 1950 to 2006:



Source: German Federal Statistical Office (*www.destatis.de*).

Material 7

The history of phosphate-free laundry detergents

Year	Event
From 1930	Phosphates present in laundry detergents
1950 – 1959	New raw materials such as the water softener sodium tripolyphosphate used in laundry detergents.
1966	Phosphates in laundry detergents are recognized as playing a key role in the eutrophication of lakes. The search for phosphate substitutes starts.
From 1970	Increasing emphasis on biochemical wastewater treatment
1973	Filing of patent application for phosphate substitute Zeolite A (brand name Sasil®).
1975	Environmental safety assessment of phosphate substitute Zeolite A in laundry detergents
1977	Successful trial of the first low-phosphate laundry detergent containing Zeolite A.
1983	The first completely phosphate-free laundry detergent is launched on the market. In the following years, phosphate-free laundry detergents become established in Western Europe.

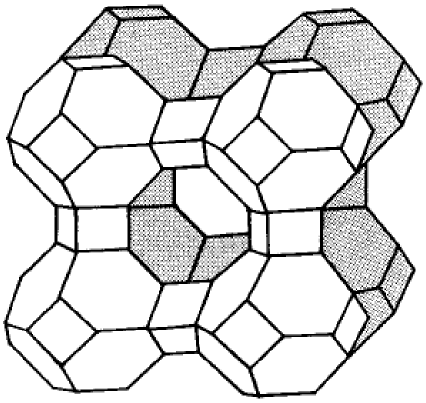
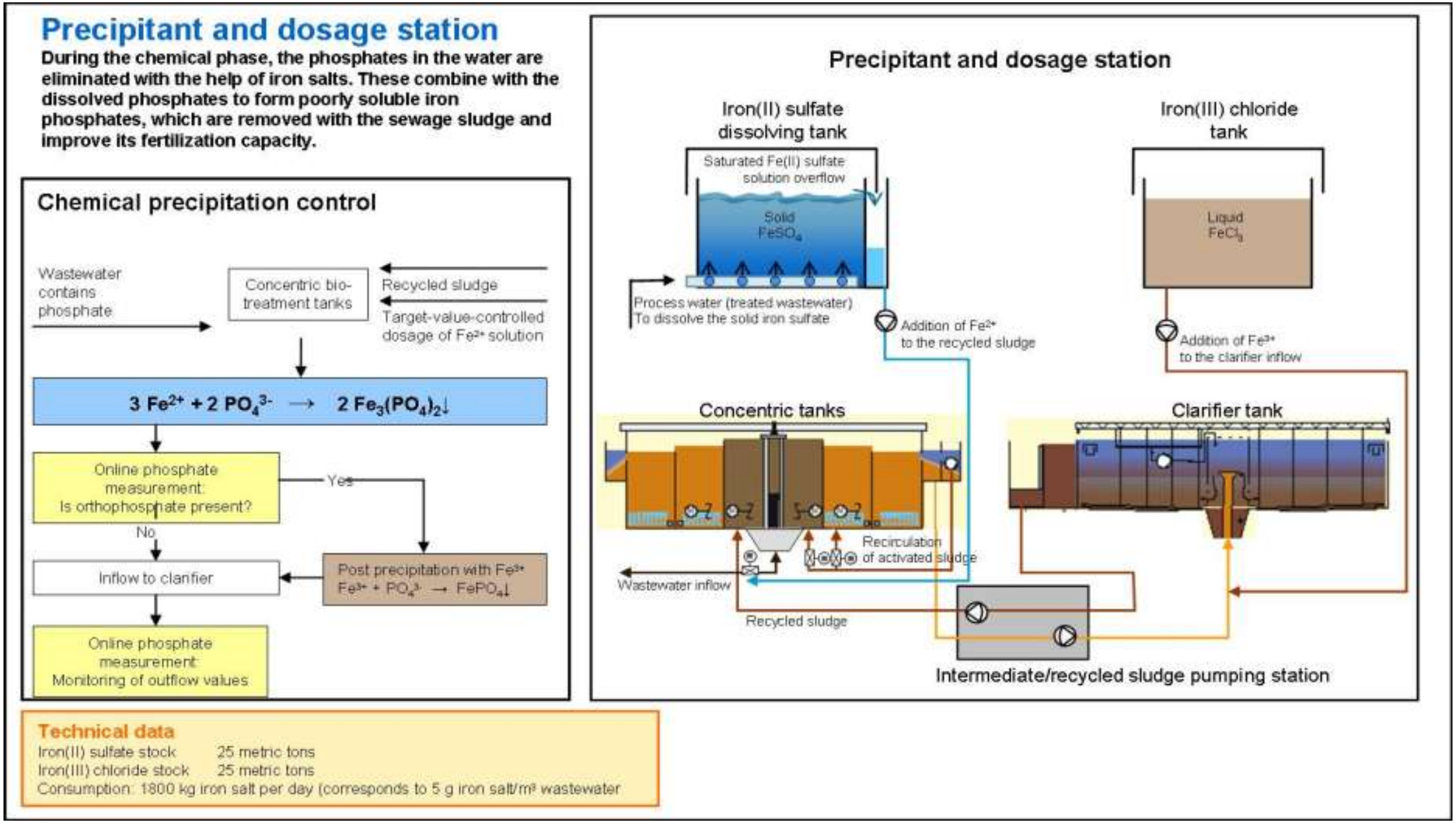


Figure: Sasil® crystal

Material 8

The central sewage treatment plant of the city of Constance is designed for a population equivalent of 215,000 and is the largest on Lake Constance. Each day, up to 40 million liters of wastewater are treated. This is equivalent to the content of about 2000 road tankers. The plant's precipitant and dispensing unit is shown in the diagram. (Source: Entsorgungsbetriebe Stadt Konstanz, *www.konstanz.de/imperia/md/content/ebk/89.pdf*)



Worksheet 21: Sustainability in the laundry detergent industry[34]

Climate change and the limited availability of water and energy are two major themes that affect us all. For this reason, many companies have undertaken to embrace the principles of sustainable development and social responsibility in the conduct of their business.

Many revolutionary advances of days gone by, such as the “self-acting detergent” and phosphate-free products are now established in our everyday lives. However, laundry detergent developers cannot afford to bask in the glow of yesterday’s successes – today, ideas for improved and new products are in continuous demand. Responsible companies know that sustainability has three dimensions, all of which must be taken into account in their business practices:

Tasks

1) In Henkel’s Sustainability Report 2007, you can find examples of innovations in the laundry detergent industry from the beginnings down to the present day. Read pages 3–7 of the Sustainability Report. You can find the report on the Internet at:
   http://www.henkel.com/cps/rde/xchg/henkel_com/hs.xsl/12152_COE_HTML.htm
2) Find examples of innovations and assign them to the above dimensions.
3) What are the advantages of these innovations?

[34] Worksheet taken from:
http://www.henkel.com/com/content_data/106612_4.8.2_Sustainable_washing_for_a_clean_environment_Chemistry_for_Advanced.pdf

Activity 3.9: Synthesis of bio-fibers

A) Synthesis of calcium alginate threads[35]

Apparatus and materials

- sodium alginate sol (ρ = 20 g/l)
- calcium chloride solution (c = 1 mol/l)
- deionised water
- beaker (250 ml)
- reaction tube (diameter: 2 cm, length: 25 cm)
- measuring cylinder (100 ml)
- rubber stopper to fit the reaction tube
- heatable magnetic stirrer and magnetic stirring bar
- glass rod
- syringe (2 ml) with injection needles (diameter: 0.45 mm, length: 12 mm)
- tweezers
- paper towels
- scale
- sieve

Procedure

- For preparing 100 ml of the sodium alginate sol, warm 80 ml of deionised water in the beaker to 70°C. Turn of the heat and increase stirring speed to a maximum so that a vortex forms. Sift 2 g of sodium alginale to the upper vortex wall and keep stirring until the sodium alginate dissolves (help out with a glass rod if needed, after turning off the stirrer).
- After the sol has cooled to room temperature, remove the stirring bar and clean it and the glass rod with deionised water over the beaker. Add deionised water to yield 100 ml and mix stir the sol again with the glass rod.
- Mount the reaction tube vertically, close the bottom with a rubber stopper and add 50 ml of calcium chloride solution.
- Fill the syringe (without needle) with 1 ml of the sodium alginate sol and clean the outside of the syringe with a paper towel. Let air bubbles in the sol rise to the tip of the syringe and then attach the needle.
- Pierce the rubber stopper of the reaction tube carefully and dress the sol into the calcium chloride solution carefully and evenly. After the syringe is empty, it is removed with the needle. Refill the syringe and repeat the above-described process of attaching a **NEW** needle.
- The thread will rise to the top and can be removed after 1 minute from the solution. Hang it up to dry and weigh the gained fibre.

Disposal

- Pour the calcium chloride solution and any remaining sodium alginate sol down the sink. Put the calcium alginate threads in the waste bin.

Further ideas

- Research what calcium alginate threads are used for.

[35] Source of experiment:
Marburger, A. (2002). Alginate in der Medizin: Anwendung in Wundauflagen, Dentalabdruckmassen und Medikamenten gegen Sodbrennen. *Praxis der Naturwissenschaften - Chemie in der Schule*, 51(5), 27-35.

B) Synthesis of polylactic acid fibres[36]

Apparatus and materials

- test tube
- test tube stand
- gas burner
- plastic weighing dishes (chilled)
- tin(II) chloride
- lactic acid
- beaker (small)
- anhydrous copper sulfate
- boiling chips
- pipette (5 ml)
- tweezers
- glass rod

Procedure

- Fill 3 ml of lactic acid, several crystals of tin(II) chloride and some boiling chips into a test tube.
- Heat for 10 minutes while constantly agitating it gently.
- During the heating, hold a small beaker over the test tube to collect the emitted steam. Test for water using the anhydrous copper sulfate.
- As soon as the content in the test tube turns orange to brownish, pour the hot and liquid contents onto a chilled plastic weighing dish.
- At the transition from liquid to solid, use the tweezers and glass rod to pull threads from the material.

Disposal

- Put the threads in the waste bin.

Further ideas

- Research what polylactic acid threads are used for.

[36] Source of experiment:
Huntemann, H., Parchmann, I. (2000). Biologisch abbaubare Kunststoffe: Einordnung in ein neues Konzept für den Chemieunterricht. *CHEMKON*, 7(1), 15-21.

WP3
Unit Title

European Science and Technology in Action Building Links with Industry, Schools and Home

Work Package 3
Plastic and plastic waste

European Science and Technology in Action:
Building Links with Industry, Schools and Home

Lead partner for deliverable: **Hana Čtrnáctová, Mária Ganajová, Peter Šmejkal**

Version: 1

The ESTABLISH project has received funding form the European Community's Seventh Programme [FP7/2007-2013] under grant agreement n^{o} 244749
Start Date: 1st January 2010 Duration: 48 months

The research leading to these results has received funding from the European Community's Seventh Framework Programme [FP7/2007-2013]

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PU	Public	
PP	Restricted to other programme participants (including the Commission Services)	
RE	Restricted to a group specified by the consortium (including the Commission Services)	
CO	Confidential, only for members of the consortium (including the Commission Services)	√

I. Unit description

The unit is focused on studying plastic and plastic waste. It is divided into three subunits.

The first subunit deals with getting to know plastic, its marking, separation and recycling. Due to its properties, plastic has a wide range of use in all spheres of human activities. In competition with classical materials, mainly metals, polymers have succeeded mostly because of their easy processing, low density and a convenient ratio of utility qualities and price. Pupils acquire knowledge of plastic from everyday life and they will deepen it in this subunit. They will learn to identify symbols used to mark plastic and those on plastic packing and they will verify different properties of plastic by experiment.

Using plastic is closely connected with the issue of plastic waste disposal. Plastic does not decompose itself, therefore it accumulates in the environment.

Subunit 2 deals with plastic waste. Within different activities pupils have to think about the issue of waste disposal, discuss it with classmates and propose possible solutions. Pupils should work out that recycling is an effective solution to the problem of plastic waste disposal. They should understand why it is necessary to recycle and realize that every individual can contribute to the improvement of the environment by correct and regular separation.

In the subunit 3 pupils/students will study various polymers, their physical and chemical properties and then, on the basis of acquired experience, they will estimate their practical and industrial exploitation and they will seek their both existing and possible applications. They will think of polymers occurring in their surroundings, reasons for application of the given polymer (why PVC was used for the particular toy), further they will analyse them by several tests (flame test, polymer density, etc.) and propose the applications of polymers.

Subunit	**Student's level**	**Topic**
Subunit 1:	11-17 years	Plastic
Subunit 2:	11- 17 years	Plastic waste
Subunit 3:	11-17 years	Polymers around us

Involved disciplines:
Chemistry

II. IBSE character

The lesson develops pupils' ability to look up information on the Internet, identify problems, create mind models, discuss, communicate with peers, propose hypotheses, distinguish alternatives.

By carrying out activities and work with worksheets pupils understand the substance of scientific research. The activities are designed in such a way that pupils work in groups, discuss, reason and propose solutions to the problems. Problems are stated either by a teacher or by pupils themselves. Thus mainly managed and restricted research is used in the activities.

For example, in activities 1.2 Plastic Properties and 3.5 Properties of polymers, problems are stated by a teacher while the experiment which will enable to solve the problem is proposed either by the teacher or pupils. Pupils should determine combustibility of plastic, its thermal and electrical conductivity, reaction with acids, alkalis or with solutions of salts. Pupils write the results into tables by which way they improve the following skills necessary for research – data collecting and recording, data processing, carrying out experiments, stating hypotheses. In groups, pupils discuss conditions for conductivity of plastic, compare the conditions with conductivity of other substances.

While working on the activity Decomposing of plastic and different materials in soil, pupils acquire the basis of scientific research by reading books and information sources on the time of decomposition of organic substances, metals and plastic in soil, they explain prognoses, compare results, etc.

Activities 2.4 Recycling plastics – using project-based method, 3.1 Materials around us and what plastics and polymers and 3.13 Pointing out the importance of polymers in everyday life give space to communication, reasoning and stating explanations. Pupils tackle tasks focused on properties of plastic, its recycling, processing, separation of waste. A project-based method is used in this activity.

Pupils/students create their own hypotheses and verify them using their own critical considerations (e.g. which polymer can be used for the given application, why the polymer is used for the given product), experimental exploration of substances (polymer analysis, study of their properties, preparation of some polymers), critical discussion with classmates (price, design of product, appropriateness of the polymer for the given purpose), identification and differentiation of alternatives and evaluation of their advantages and disadvantages.

A basis of the unit is the research conducted by the teacher, supported by discussion; this all is based on the exploration of substances and items around us and on the related questions, (properties and resulting applications of some polymers for the given purpose).

III. Scientific knowledge

Plastic materials (from Greek plassein - to shape) are synthetic polymers. They belong to macromolecular substances because they are compounds made of a big amount of atoms. The atoms join together by chemical bonding to make long chains in which basic structure units are repeated. One macromolecule can contain several hundred, thousand or even more basic structure units called monomers.

The number of monomers in a polymer molecule is expressed by polymerization degree. Compounds with a low polymerization degree are called oligomers, the ones with a higher polymerization degree are polymers. In a polymer, monomers represent a construction or a structure unit with the same chemical composition which is regularly repeated.

According to the origin the following polymers are distinguished:

a) natural – eg. polysaccharines, proteins, nucleic acids,

b) synthetic – eg. polyethylene, polyesters, polyvinyl chloride, Teflon,

c) modified – chemically modified natural substances, eg. celluloid, viscose.

Synthetic polymers (plastic) are divided into:

1. According to the type of chemical reactions by which they are created:

a) Polymers prepared by polymerization,

b) polymers prepared by polycondensation,

2. According to the shape of macromolecule polymers are divided into:

a) linear,

b) branched,

c) reticular,

d) spatially reticular.

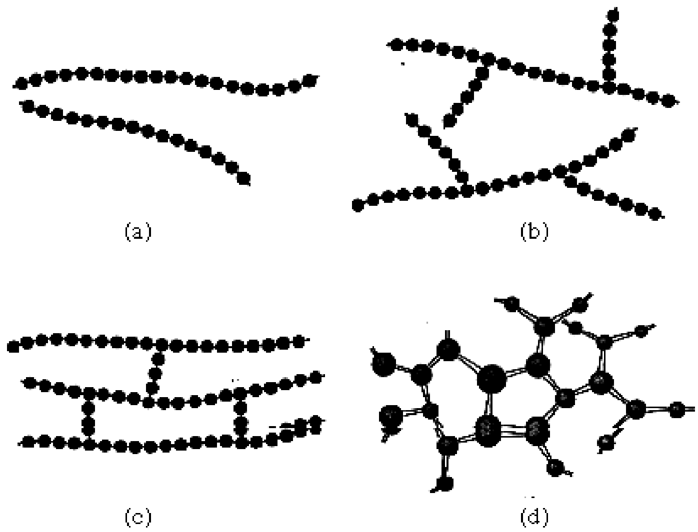


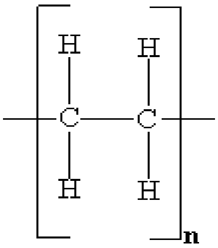
Fig. Different structures of macromolecules according to shapes

Characteristics of selected plastic capable of recycling

We will focus on polyethylene, polypropylene, polyvinyl chloride and polystyrene. All these types of plastic are made by polymerization. It is a polyreaction in which two identical monomers with multiple bondings react. If different monomers with multiple bondings react, it is called copolymerization.

Polyethylene (PE)

It consists of atoms of carbon and hydrogen exclusively, therefore it does not represent a serious environmental problem in incineration of waste. It burns down into CO_2 a H_2O. In figure a) there is a structural model of polyethylene and in figure b) there is a spatial chain of polyethylene.



a) b)

Polyethylene, a well-known polymer, is produced by polymerization of ethene (fig.).

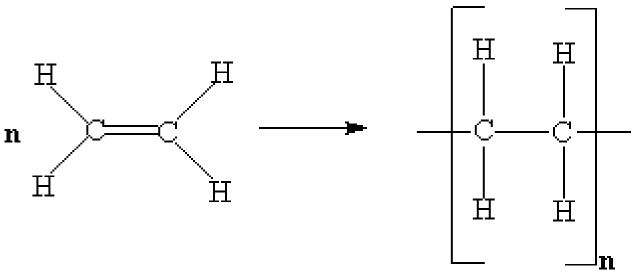


Fig. Polymerization of ethylene

According to the way of production, type of initiation agent, and catalyst, polyethylene with different properties is produced:

- HDPE – high density PE from English high density polyethylene
- LDPE – low density PE from English low density polyethylene

Use of HDPE

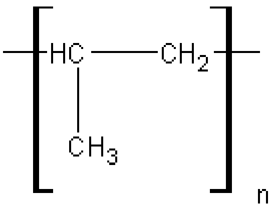
- Hollow objects in moulds, eg. different high volume vessels,
- crates
- bottles for detergents
- bottles for mineral water,
- bottle lids.

Use of LDPE

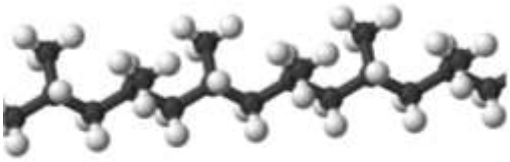
- production of foils, eg. foils for agriculture,
- used as packing material, or applied on paper or aluminium foils,
- production of rubbish bags,
- production of bags,
- production of tetrapack,
- production of cables, pipes, etc.

Polypropylene (PP)

In figure a) there is a chemical formula of polypropylene and in figure b) there is a spatial chain of polypropylene.



a)



b)

Polypropylene is produced by polymerization of propylene.

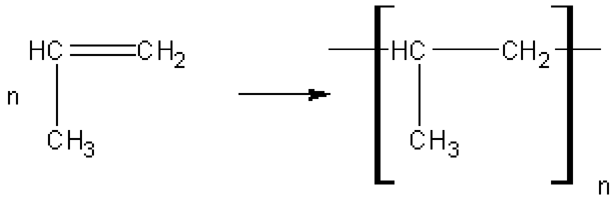


Fig. Polymerization of propylene

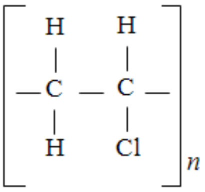
Use of polypropylene

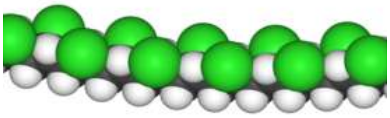
- it is used as a part of machines and equipment, eg. in car making industry (parts of dashboards and fans, bumpers) and in consumer industry (parts of vacuum cleaners, kitchen appliances) because polypropylene has outstanding mechanical properties,
- it is used for making syringes and other medical aids because it is resistant to sterilizing temperatures,
- production of packing foils,
- production of toys because it can be easily coloured by adding appropriate colouring agents,
- production of buckets and wash-basins,
- production of blenders, suitcases,

- in the form of fibres it is used for production of carpets, decoration cloths, knits (stockings).

Polyvinyl chloride (PVC)

Polyvinyl chloride belongs to the most important plastic. Together with polyethylene a polypropylene it belongs to most widely produced synthetic plastic. The structural model of polyvinyl chloride and its spatial chain are in the pictures.





Preparing polyvinyl chloride

Polyvinyl chloride is synthetized based on polymerization of vinyl chloride monomer. Vinyl chloride is synthetized from natural gas, petroleum and sea water salt. Polyvinyl chloride is processed either without softeners, with stabilizers, lubricants and modifiers only, into hard products (pipes, boards, etc) or with softeners into semi-solid to elastic products (foils, vessels, toys, protective gloves, etc.).

Non-softened, hard polyvinyl chloride is known under a general trade name *novodur; softened*, soft polyvinyl chloride is known under the name *novoplast.*.

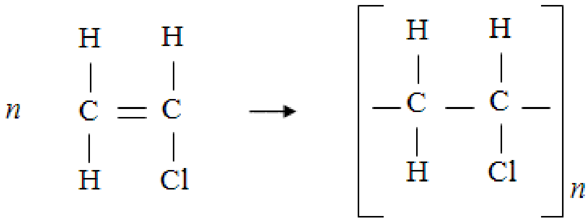


Fig. Polymerization of vinyl chloride

Use of polyvinyl chloride

Products made of polyvinyl chloride are used in electronics, chemical industry, light industry and packing technologies.

Polyvinyl chloride is used in two forms:

a) **novoplast** (flexible – softened

- production of floor covering,
- food foils,

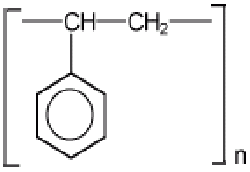
- toys,
- protective gloves, raincoats,
- hoses, bottles, tablecloths,

b) **novodur** (fragile) – non-softened

- production of bars, pipes,
- in making furniture,
- production of leatherette products (jackets, handbags, purses, wallets, etc.),
- production of compact discs ,
- covers for everyday use products, eg. covers for books and exercise books.

Polystyrene (PS)

Polystyrene is one of the oldest synthetic polymers. The chemical formula and spatial shape of polystyrene are in the pictures.



Preparing polystyrene

Polystyrene is made by polymerization of styrene.

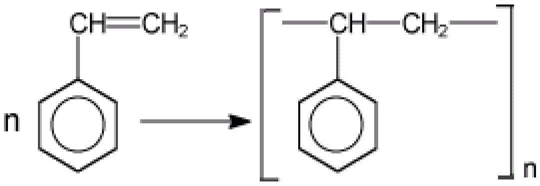


Fig. Polymerization of styrene

Use of polystyrene

- it is mainly used for production of simple consumption products such as jars, bowls, trays, children's toys and other products of consumption industry

Use of foam polystyrene

Foam polystyrene is a white soft material with outstanding thermo-insulating properties due to a huge number of empty bubbles caught in the polymer.

It is used:

- in construction industry as an insulation material,
- for insulation of cables,
- in production of switches and reels,
- in transporting different products as a protective cover,
- it is also basis of combat substance Napalm B.

Advantages and disadvantages of plastic

Advantages of plastic

- objects made of plastic are very light
- they show high solidity and consistency,
- reduce noise well,
- their density is half of that of aluminium, glass or porcelain, therefore they are increasingly used in production of cars, gliders, parachutes, etc.,
- they are nonconductors,

- they are good electrical and thermal insulators. Conductors of electric current are coated with a layer of plastic, walls of buildings are protected from cold by plastic siding boards,
- they do not corrode or decay, eg. outside building sidings, garden furniture, boats,
- many types of plastic are even resistant to chemical substances such as acids and hydroxides,
- they can be easily shaped, coloured or treated. These qualities are important in developing aerodynamic shapes of cars, airplanes and boats,
- as a consequence of these advantages, plastic is called “material of wish“.

Disadvantages of plastic

- they are toxic,
- they are not very hard, therefore they must be protected from mechanical damage,
- a lot of plastic is not thermally stable. It manifests in unqualified treating of textiles containing synthetic fibres, for example,
- some plastic becomes soft when exposed to heat so that it can be shaped, some decomposes when exposed to heat,
- many types of plastic are combustible,
- is damaged by some organic compounds,
- does not conduct electricity, therefore it gets charged with static electricity by friction,
- can become fragile when exposed to light and breaks easily then. Cheap products made of plastic are not worth repairing, they become objects for throwing away,
- some chemicals from plastic get into food. An example of food contaminated by different plastic is an evidence of styrene released from polystyrene, an evidence of softeners from polyvinyl chloride, acetyladehyde released from PET bottles (polyetylene terephtalate),

- disposal of polyvinyl chloride by incineration is complicated by the presence of chlorine in the structure of macromolecules (from 1 kg of PVC as much as 600 g of HCl is produced); by incineration of polyvinyl chloride carcinogenic products of incineration– dioxins – are produced as well. Scientists consider dioxins most poisonous chemicals a man has ever produced. There are about 210 kinds of them. They are produced as useless side products of industrial activities in which chlorine is used in incineration,
- plastic is one of the worst materials for recycling and it pollutes the environment most.

Plastic and environment

Plastic is made of petroleum by rather simple chemical procedures. In spite of the fact that production of plastic is a simple process, the same cannot be said about its disposal. Polymers produced by man cannot be decomposed by organisms naturally present in the environment as they do not have enzymes needed for the decomposition of the polymers. It can be said that plastic in the environment does not undergo any decomposition. Therefore biodegradable plastic representing less burden to the environment is searched for.

Production of new kinds of plastic decomposition process of which is accelerated, eg. plastic enriched with starch, has started. Along with this development of biogradable (capable of composting) plastic which is nontoxical, has nice appearance and is less combustible has also started.

Plastic waste

Plastic waste is a serious problem as each of us produces several kilos of it weekly. A huge amount of plastic waste is produced in households daily and a problem with its disposal arises.

Ways of plastic waste disposal

1. **Landfilling** is the easiest and cheapest way of waste disposal. About half the plastic waste is disposed of this way. Plastic similarly to glass and porcelain unlike other materials do not undergo significant chemical changes. This way

of treating waste is not efficient at all, it is only the last resort solution which has to be further enhanced.

2. **Incineration** is a radical way of plastic waste disposal. It is easily feasible and quite common because all plastic materials can be incinerated easily. This way of plastic waste disposal has not, however, been generally accepted the most convenient solution because part of exhalation may be aggressive (eg. in polyvinyl chloride incineration toxic emissions, e.i. polychloro dibenzo-p-dioxins, polychloro dibenzofurans are released).
3. **Recycling** is the best way today how to avoid surplus of plastic waste in the environment. It is not, however, an easy task because there are a lot of plastic materials to be tackled. The first step towards recycling is separation of waste by a consumer into categories of metals, paper and glass. A different method done in special facilities is magnetic separation and separation based on density. Physical properties of plastic are used here as magnets do not effect it, though they effect steel objects, and plastic has lower density than aluminium and glass objects. To ensure its repeated use, recycled plastic is usually all melted and at the same time a mixture of plastic of a low class is produced. The mixture can be used in production of cheap plastic products such as rubbish bags or tiles used for pavements or roads. Not all plastic, however, can be recycled.

Products from recycled plastic:

flowerpots

sandpits

boards on benches

Advantages of plastic recycling

- used plastic is used so that it does not end up in landfil sites and incineration plants,
- natural resources are conserved (petroleum)
- not used material is repeatedly minced and melted,
- products are resistant to water, wind, ice,
- products do not require maintenance, can be cleaned easily,
- products have a wide range of use.


- **Disadvantages of plastic recycling**
- high costs,
- quality of recycled material many times cannot reach that of the primary one as materials are degraded in processing
- big weight (difficult to carry), eg. a plastic bench costs €150 and weighs 65 kg.

IV. Pedagogical Content Knowledge

Discussion methods – discussion, managed discussion

Pupils discuss, eg. the issue of produced waste from the point of view of the environment. A teacher together with pupils discusses recycling of different materials as well as plastic and its use. Pupils discuss the results of the experiment and conclusions drawn from it.

Problem-based teaching

A teacher consistently gets pupils involved in the process of looking for and finding solutions to problems – eg. pupils look for possibilities of waste disposal. A model task: Compare the life cycle of a glass and plastic bottle and try to produce a graph of the two cycles.

Group and co-operative teaching

A group is made up of two to seven pupils. A task for the group: How is plastic made? Find at least two ways of its production. Pupils present conclusions they arrived at in groups. They can use the information they have looked up on the Internet.

Why do people produce such an amount of waste? What reasons do we have to separate it? Can you separate waste correctly? Why don't some people separate waste?

Project-based teaching

The basis of the method is tackling a task of a complex character. The whole activity 5 is focused on project-based teaching. The results of pupils' work are not only answers to the questions in the worksheet but also their presentation either by PowerPoint presentation or poster in front of the class, eg. Draw a simple comics "From the life of PET bottles".

Practical methods

They include carrying out chemical trials by which pupils not only observe phenomena but also effect them in an active way – they prepare, manage and evaluate chemical process themselves. Based on carried out experiments pupils acquire knowledge on properties of plastic in the lesson.

V. Industrial Content Knowledge

The industry in the Czech Republic offers, as for production and processing of plastics, a wide range of applications. In 2009, 42 companies were involved in the production of plastics while secondary processing of plastics was carried out in more than 2300 rather smaller companies. There are six major players in the production of plastics; the others are mainly processors of secondary raw materials. The most important manufacturer of plastics in CR is Unipetrol Litvínov (http://www.plasticportal.eu/cs/podla-cinnosti/ci/833/sub-ci/868/unipetrol-rpa-sro/f/510), where mainly PE and PP are produced. The present capacity of these two plastics reaches 600 000 tons. The youngest manufacturer is Monetive Sokolov (http://ww2.momentive.com/home.aspx), where acrylic polymers and copolymers are produced. The present capacity is less than 90 000 tons. Silon Planá (http://www.silon.eu/) produces 40 000 tons of polyolefin-based filled mixtures and also polyester fibres from PET waste with a capacity of 450 kg/h. The major subscriber of this company is a car industry (more than ¾ of production); the produced plastics terminate as textiles in cars (rugs, upholstery of seats, etc). The only large-scale manufacturer of synthetic rubber in CR is the company Synthos (former Kaučuk) Kralupy nad Vltavou (http://www.synthosgroup.com/cz/synthos-kralupy-a.s/about-the-company/basic-info), whose production achieves roughly 100 000 tons/year. The company Spolana Neratovice is known for its production of PVC; unfortunately, due to a negative (partly undeserved) media picture of the company and ongoing financial crisis, a termination of production is expected.

Smaller manufacturers offer mainly the production of moulded, injection moulded, and pressed products from primary materials and these companies are based countrywide. A number of them is worth mentioning, e.g. the company Kronospan Jihlava (http://www.kronospan.cz/) is one of the largest manufacturers of large-scale wood-based materials in Europe, in particular chipboards, which are further processed into laminate chipboards and worktops. The other companies to mention are e.g. Plaston CR, s.r.o. Šluknov, which uses the injection-pressing technology of plastics processing based on the customer's order and further it also produces technical pressed parts including their surface finish. The company FV plast, a.s., in turn, produces PPR pipes, plastic fittings and armature for water distribution and also plastic systems for pressure distribution of drinking water and hot water, central and floor heating, etc. Megat – production of plastics Zlín, s.r.o. is involved in the production of plastic profiles using the technology of extrusion, i.e. it produces plastic pipes for different purposes, e.g. furniture plastic profiles, plastic strips, plastic edges, plastic cover plates, swimming pool roofing, plastic tubing, etc. Other companies can be found in various industrial catalogues, e.g. ABC of Czech economy http://firmy.abc.cz/plast/zpracovani-plastu/?stat_id=38). The cause of existence of a large number of companies is a relatively easy technology of plastics processing. For this reason, even the companies from other industries have their smaller production lines for plastics processing, e.g. in food industry. For example the company Coca Cola ČR (http://www.cocacola.cz/) realises the production of plastic bottles on its own production line from prefabricated parts resembling test tubes. It saves a lot of transportation costs, which would mean a transportation of whole bottles because considering their large volume it would be possible to transport a considerably smaller amount of bottles than prefabricated parts.

The main application areas of plastics consumption are packaging items - 37 %, building industry - 21 %, car industry - 8 % and electro technology - 6 %.

Source:

http://www.schp.cz/prilohy/305d535b/11_01_07%20POLYMERY%20VE%20SVETE%20A%20V%20CR%202.pdf?PHPSESSID=mubkwubn

http://www.enviweb.cz/clanek/obecne/71585/evropsky-trh-plastu-roste-prioritou-se-stava-ekologie

VI. Learning path

Subunit 3:

Students try to select at least any ten items occurring in their surroundings. They themselves try, or with the teacher's assistance, to guess what a majority of these items have in common and to infer that all of them are made from materials. Further they infer that for a large group of these items and products, a basic or highly used material is polymer (or synthetic polymer, plastic). They try to evaluate why it is so (low cost of material and then also of the product, ease of processing, formability, or - with some materials - it is incombustibility, ideal density, etc.), next they try to more exactly define (and discuss using the Internet and literature sources) the concept of polymer and polymer material, synthetic polymer and plastic.

After that the students will experimentally explore some of the properties of the selected synthetic polymers and systematise the acquired knowledge. On this basis, they will next try to identify an unknown sample of polymer on the basis of their own considerations and predetermined procedure /on the basis of the Internet search and findings from the previous activity).

The students will try to apply the acquired knowledge during the consequent activity, within the framework of which they will propose an appropriate polymer to be applied (used) in the given product. They should not consider only technical but also economical and aesthetic parameters. These considerations can also contain the students' ideas about the product concerning e.g. the endurance under extreme conditions or the design and to justify them in the follow up discussion.

The consequent activities include the two experiments, from which the students have to draw conclusions and which should demonstrate the properties and the relation to the structure of polymers, in particular how the structure and the properties are

influenced by the conditions through the preparation of polymer and next also the properties and reactions of polymer under mechanical loading.
Using the acquired knowledge, the students will write a short essay entitled “ Life with polymers“ or “ Life without polymers“, which will reflect and consequently discuss with other students their opinions on the world of polymers and the importance of polymers in the life of man and society. It is important that the students write the essay on the basis of the knowledge acquired (experiments, literature, the Internet) within the previous activities; their opinions can therefore be robust and superimposed on real experience. In this case, when performing the task, interlink is formed between the disciplines, interdisciplinary bonds occur and more competencies are developed.

VII. Assesment

It is desirable to ask the students to write their hypotheses in a paper or an electronic form. Though the students can work in groups, it is desirable to ask them to record their hypotheses individually. These records together with students’ activity can be later taken into consideration when evaluating the students. Other evidence can be the results of students from some of their activities, e.g. the results of plastics analysis (correctness of determination of plastics sample).

VIII. Student learning activities

SUBUNIT 1. Plastic

Activity 1.1 Kinds of packaging plastic materials and their labelling

Teacher's notes

Learning aims:

- get to know different kinds of plastic
- learn about symbols of different plastic used to label plastic products

Materials:

- worksheet, samples of different plastic packaging

Suggestions for use:

A teacher brings different kinds of plastic waste to the class. They are pieces of the following plastic: linoleum, pipes, plastic bags, fitting foil, polystyrene, plastic containers, pens, covers of books and exercise books, packages of chemicals, milk, juice, plastic bottles. Pupils recognise different kinds of plastic. Their either look up the necessary information on the Internet or ask the teacher. In the second part of the lesson, pupils can work with worksheets in which they will look for answers to important questions concerning labelling plastic packages.

Kinds of plastic packages and their labelling

Student's worksheet

You can come across plastic packages at every place. Producers label products packages with names and symbols of used kind of plastic or the information is stamped (most frequently in the bottom part of a package). The following materials are used, for example: polyethylene terephthalate, polyethylene, polypropylene, polyvinyl chloride, polystyrene.

Written labelling of plastic materials:

Material	*Number labelling*	*Letter labelling*
Polyethylene terephthalate	1	PET
High density Polyethylene	2	HDPE
Polyvinyl chloride	3	PVC
Low density Polyethylene	4	LDPE
Polypropylene	5	PP
Polystyrene	6	PS

Graphic labelling of plastic materials:

Task 1

1. There are plastic packages made of four different kinds of plastic in the pictures. Below each of the pictures write the name of the plastic the package is made of.

1).. 2) ....

3) .... 4) ....

5)

.... 6)

....

Task 2

Answer the following questions:

What is the significance of packaging plastic?

....

....

Compare different properties of natural and plastic materials.

....

....

Activity 1.2 Properties of plastic materials

The activity is focused on studying properties of plastic materials (weight, density, thermal and electrical conductivity, combustibility, solubility, reacting with acids, alkalis and firmness) by means of chemical experiments. Pupils formulate hypotheses about expected properties based on their previous knowledge and verify them consequently by experiments.

Learning aims:

- acquire knowledge of plastic materials properties based on the carried out experiments,
- apply the acquired knowledge of plastic materials properties in practice

Materials:

- See worksheet

Procedures:

- See worksheet

Properties of plastic materials

Student's worksheet

Plastic is a material one comes across every day. In the following experiments you will examine properties of different plastic materials. Before carrying out the experiments think about the fact which properties are important in producing and using plastic materials.



Discuss in groups:

Is plastic useful? Which are the properties that have enabled their widespread use? Do all plastic materials have the same properties? Does plastic undergo changes with time? Which properties of plastic would you like to study in more detail? Does plastic have negative properties as well?

Carry out the following experiments and record your findings step by step. Finally, complete the table in which you will summarize different properties of the examined plastic materials (PE, PP, PS, PVC). Next to each plastic write where in everyday life its qualities could be used.

List of activities:

1.2.1 Weight of plastic materials
1.2.2 Determining density of plastic materials by comparing with water density
1.2.3 Combustion of plastic materials
1.2.4 Thermal stability of plastic materials
1.2.5 Verifying thermal conductivity of plastic materials
1.2.6 Electrical conductivity of plastic materials
1.2.7 Solubility of plastic materials
1.2.8 Reacting with acids, alkalis and solutions of salts
1.2.9 Tensile strength of plastic materials

<u>Activity 1.2.1 Weight of plastic materials</u>

<u>Materials:</u>

scales, objects of plastic, metal, wood, glass....

<u>Procedure:</u>

Compare density of plastic materials with that of other materials. Before carrying out the experiment, state your hypotheses.

<u>Hypotheses:</u>

....

....

Weight plastic, metallic, wooden, and glass objects of comparable sizes. Write the results into the table and make comparisons.

<u>Findings:</u>

m_p=m(plastic object)	g
m_k=m(metallic object)	g
m_d=m(wooden object)	g
m_s=m(glass object)	g

Weight comparisons: m_p m_k m_d m_s

The smallest weight was that of the object made of ________________________

How would you characterize density of plastic in comparison with that of other materials?

....

Can it be used in practice? Give examples.

....

....

Activity 1.2.2 Determining density of plastic materials polyethylene (PE), polypropylene (PP), polystyrene(PS), polyvinyl chloride (PVC) by comparing with water density.

Materials:

Glass beaker of 250 cm^3, samples of different plastic materials (PE, PP, PS, PVC)

Procedure:

Study the plastic objects and formulate hypotheses about their density in comparison with that of water. Write down your hypotheses.

PE

PP

PS

PVC

Hypotheses:

....

....

Propose a procedure by which you can verify and compare the density of the above plastic materials with that of water. You can look up water density in the chemical tables. Describe the procedure in words.

Procedure:

....

....

Problem solving task:

Devise a procedure for exact setting the density of selected plastic materials.

....

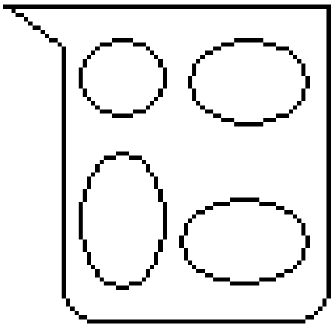
....

....

Findings:

1. In the picture, there is the result of the experiment to determine density of different plastic materials of PE, PP, PVC, PS. Write the names of the materials into the bubbles in such a way that it complies with the findings of the experiment.

Picture:



2. Complete the text with the following expressions:

„floats on water“; „falls to the bottom of the beaker“ „bigger, smaller“

The density of water is ________ g/cm^3

Polyethylene _____________, therefore its density is __________________ than that of water. Polystyrene _______________, therefore its density is _________________ than that of water. Polyvinyl chloride ______________________, therefore its density is ______________ than that of water. Polypropylene _______________________, therefore its density is ____________ than that of water.

Complete:

Which formula can be used for exact determining the density of plastic materials?

$\rho = \frac{\quad}{\quad}$

Activity 1.2.3 Combustion of plastic materials

Materials:

burner, scissors, incombustible mat, tongs, copper wire, samples of different plastic materials (PE, PP, PS, PVC)

a) Combustion of plastic materials polyethylene (PE), polypropylene (PP), polystyrene (PS), polyvinyl chloride (PVC).

You know from your everyday life that paper and wood will burn down. In groups, discuss properties of plastic materials. Are they combustible? Do they produce any odour when burning?

Write down your hypotheses.

Hypotheses:

....

....

Procedure:

Carry out an experiment to test combustibility of plastic materials. Observe and describe the changes in phases of the materials during the process of burning, describe the flame – its colour, smoke production, odour. Identify the character of fumes by means of universal indicator paper at the end of the test.

Describe the experiment in words.

Findings:

1. The findings can be summed up in the following table:

Tab. Summary of plastic materials properties

Type of plastic	Polyethylene	Polypropylene	Polystyrene	Polyvinyl chloride
Burning of plastic				
Odour of plastic during burning				
Beilstein's test of halogens				

2. Match the plastic materials on the left with the properties on the right (eg. 2A).

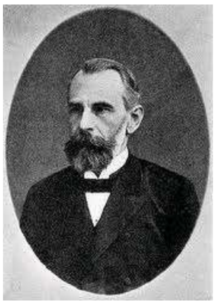
1. polypropylene	A. drops when burning
2. polyethylene	B. does not drop when burning
3. polystyrene	C. burns without soot
4. polyvinyl chloride	D. burns with yellow flame
	E. produces soot when burning
	F burns with green flame

G. gases smell of paraffin

H. gases have sweet odour

I. gases have acrid odour

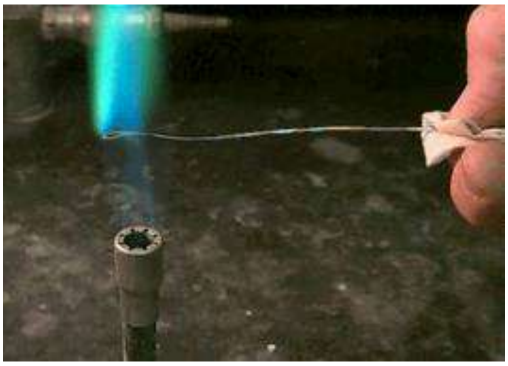
b) Beilstein's test of halogens.



Friedrich Konrad Beilstein (1838 – 1906)

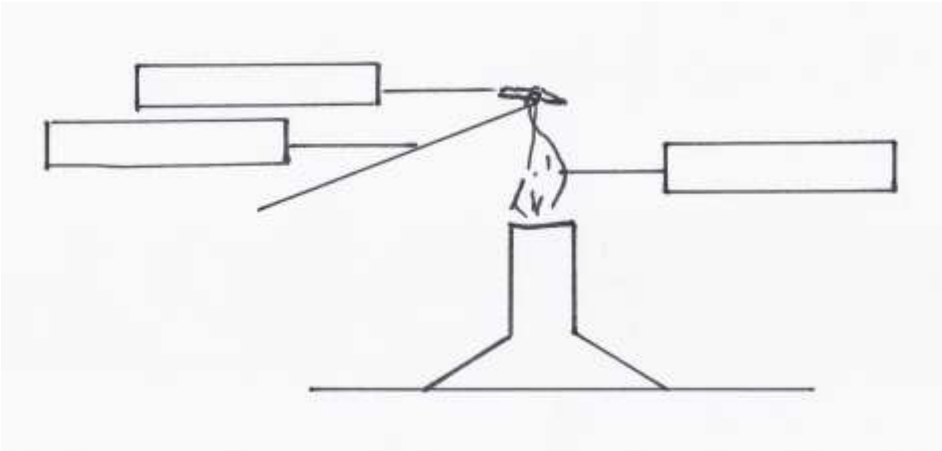
Procedure:

Ignite a copper wire in the flame of the burner. Use the wire to take a sample of a plastic and put it again into the flame of the burner. If halogens are present, the flame will become green. The essence of Beilstein's test is the fact that molten copper in the presence of halogens produces easily volatile cupric halides that cause the green colour of a flame.



Describe the following picture to describe the essence of Beilstein's test.

Picture:



Notes:

The test must be carried out in the presence of fresh air because of the production of poisonous dioxin.

Dioxins ($C_{12}H_4Cl_4O_2$) are currently considered the most toxic chemical compounds accumulating in tissues of organisms. They comprise 210 chemical substances of the groups polychloro dibenzo-p-dioxins (PCDD) and dibenzofurans (PCDF).

The test of combustibility of plastic materials requires skillfulness and carefulness. Do not carry out the test of combustibility of PVC plastic in closed rooms!

Disposal of waste:

Collect the used plastic in collecting receptacles.

Findings:

Write them into the last line of the table for activity 3.2 a).

Activity 1.2.4 Thermal stability of plastic materials

Thermoplastic (plastomers) are plastic materials which become soft and plastic (soluble by heat) when exposed to heat. Polyethylene (PE), polypropylene (PP), polyvinylchloride (PVC), polystyrene (PS) belong to this group.

Materials:

Beaker, burner, matches, above mentioned types of plastic, cotton, metal and wood

Procedure:

Carry out an experiment in which you will observe the change of shape of thermoplastic in boiling water. Compare the change with that of selected natural materials.

Put the appropriate plastic, cotton, metal and wood into boiling water and close the container. Take them out of water some minutes later and write your findings into the table.

Findings:

1. Complete the table:

Plastic	Change of structure in 100 °C water	Natural materials	Change of structure in 100 °C water
PVC		Cotton	
Polyethylene		Metal	
Polypropylene		Wood	
Polystyrene			

2. Which plastic materials used in everyday life cannot be exposed to high temperatures? Justify your answers.

....

....

3. Have you come across „melting „ of a plastic product in everyday life?

....

Activity 1.2.5 Verifying thermal conductivity of plastic materials

Imagine the following situation. Your mum was cooking soup in two pots. She stirred the soup in one pot with a metallic ladle and the one in the other pot with a plastic ladle. She left both ladles in the hot soup and left. She returned half an hour later and wanted to take the ladles out of the pots. Something went wrong, however. She got burnt by one of the ladles. Do you know which by? Carry out an experiment using a beaker, burner, metallic and plastic spoon. Compare chemical composition of metals and plastic materials and based on that prove or contradict your hypothesis on the thermal conductivity of the materials.

Hypothesis:

....

....

....

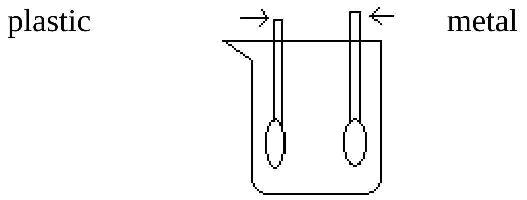
Materials:

Beaker, burner, plastic and metallic spoon

Procedure:

Devise and carry out an experiment to test thermal conductivity of plastic materials.

The picture below may help you with that:



Findings:

State 1 minute later:______________________

State 2 minutes later:______________________

State 3 minutes later:______________________

State 5 minutes later:______________________

What could you say about thermal conductivity of plastic materials?

....

....

<u>Activity 1.2.6 Electrical conductivity of plastic materials</u>

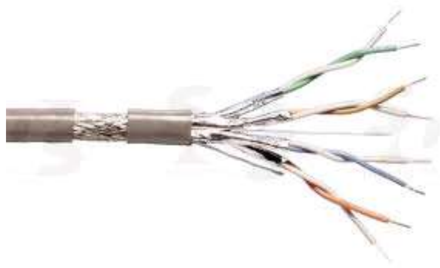
a) Comparing electrical conductivity of plastic materials with that of other materials

<u>Materials:</u>

Source of electricity, electric bulb, different kinds of plastic, cotton, metal and wood

<u>Procedure:</u>

In groups discuss electrical conductivity of plastic materials and that of natural substances (cotton, wood, metal). Write down your hypotheses and compare them with the results of the experiment afterwards.



<u>Hypotheses:</u>

....

....

Carry out the following experiment:

Prepare a simple electrical circuit and connect into it a particular kind of plastic, cotton, metal and wood, respectively.

Write your findings into the table

<u>Findings:</u>

Tab. Conductivity of plastic materials

Plastic	Conductivity	Natural substances	Conductivity
PVC		Cotton	
Polyethylene		Wood	
Polypropylene		Metal	
Polystyrene			

What could you say about electrical conductivity of plastic materials?

....

Homework:

Look up on the Internet information about using plastic materials as electrical conductors / insulators.

....

....

....

....

....

....

b) Static electricity and plastic materials

Materials:

Plastic spoon, cotton cloth, polystyrene balls

Procedure:

In groups discuss and tackle the following problem: When Ann came home, she took off her nylon stockings. When she then touched a metallic door handle, she screamed and jumped out of horror.

What happened to Ann? What is the substance of the phenomenon?

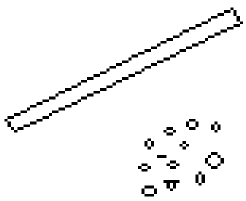
What caused the electric shock?

Hypotheses:

....

....

Try to simulate the situation using a plastic bar, cotton cloth and polystyrene balls. Write down the test procedure and findings.



plastic bar

PS

Procedure:

....

....

....

....

....

Findings:

....

....

Activity 1.2.7 Solubility of plastic materials

Materials:

Test tubes, clap stand , different kinds of plastic, cotton, metal and wood, different solvents (acetone, benzene, ethanol ...)

Procedure:

Fill the test tubes with different solvents and into each tube put a particular kind of plastic, cotton, metal and wood. Write your findings into the table:

Tab. Solubility of plastic materials

Plastic	Time of action	Solvents				
		1.	2.	3.	4.	5.
PVC	5 minutes					
	two hours					
	week					
Polyethylene	5 minutes					
	two hours					
	week					
Polypropylene	5 minutes					
	two hours					
	week					
Polystyrene	5 minutes					
	two hours					
	week					

Natural substances	Time of action	Solvents				
		1.	2.	3.	4.	5.
Cotton	5 minutes					
	two hours					
	week					
Metal	5 minutes					
	two hours					
	week					
Wood	5 minutes					
	two hours					
	week					

Activity 1.2.8 Reacting with acids, alkalis and solutions of salts

Materials:

Test tubes, clap stand , different kinds of plastic, cotton, metal and wood

Procedure:

Before the experiment, formulate your hypotheses about action of acids, alkalis and solutions of salts on plastic materials and natural substances.

Hypotheses:

....

....

Carry out an experiment in which you will study the resistance of the above-mentioned substances to the action of acids, alkalis and solutions of salts.

Fill the test tubes with different acids, alkalis and solutions of salts. Put a particular kind of plastic, cotton, metal and wood into each test tube. Write your findings into the table:

Findings:

1. Complete the table:

Plastic	**Time of action**	**Acids**		**Alkalis**		**Solutions of salts**	
PVC	5 minutes						
	Two hours						
	week						
Polyethylene	5 minutes						
	Two hours						
	week						
Polypropylene	5 minutes						
	Two hours						
	week						
Polystyrene	5 minutes						
	Two hours						
	week						
Natural substances	**Time of action**	**Acids**		**Alkalis**		**Solutions of salts**	
Cotton	5 minutes						
	Two hours						
	week						
Metal	5 minutes						
	Two hours						
	week						
Wood	5 minutes						
	Two hours						
	week						

2. Compare the resistance of organic substances (cotton, wood) with that of plastic materials (resistance to the action of acids, alkalis and solutions of salts).

....

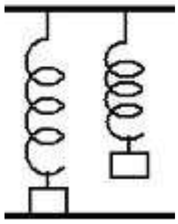
....

3. A lot of chemicals are kept in plastic receptacles.

How is it possible?

....

Activity 1.2.9 Tensile strength of plastic materials



Materials:

Set of weights, different kinds of plastic, cotton, metal and wood

Procedure:

Before the experiment, formulate your hypotheses about tensile strength of plastic materials and natural substances. Look at the above-mentioned materials and discuss their firmness. Carry out the following experiment afterwards:

Hang different weights on a particular kind of plastic, cotton, metal and wood and note the length of their stretch. Write your findings into the table:

Findings:

1. Complete the table:

Plastic	**WEIGHT**		
PVC			
Polyethylene			
Polypropylene			
Polystyrene			
Natural substances	**WEIGHT**		
Cotton			
Metal			
Wood			

2. Do all plastic materials have the same tensile strength? If no, compare the firmness and resistance of the above materials.

....

....

Homework:

Look up on the Internet information about plastic materials with outstanding mechanical properties and read about their use in practice.

Conclusion:

Complete the table based on the acquired knowledge:

Plastic	FOUND PROPERTIES	USE IN PRACTICE
PVC 		
Polyethylene 		
Polypropylene 		
Polystyrene 		

SUBUNIT 2. Plastic waste

Activity 2.1 Resolubility of waste in the environment

Teacher’s notes

Learning aims:

- get pupils interested in waste-related issues,
- discuss the issue of produced waste from environmental point of view,
- look for possibilities of waste disposal,
- think about resolubility of waste,
- try to understand the significance of recycling as the only and effective alternative of waste disposal.

Activity 2.1A Tracing waste

Materials:

- one worksheet per group

Suggestions for use:

Pupils work in groups and use worksheets in their research. They look up the information on the Internet.

In the first part, the worksheet uses the method of comparing the length of human life with that of decomposition of some materials. Pupils find out that during their lives about half the materials would decompose.

The tasks in the second part of the worksheet do not concern the time of decomposition but study the influence of the substances released in the process of decomposition on soil. In the last task pupils try to write all the things that could influence the length of decomposition of different materials.

Tracing waste

Student's worksheet

In the following tasks try to find out what happens to different kinds of waste in the environment and how long they decompose. There is a wood in your neighbourhood where you like walking in, cycling, you go to pick mushrooms or rest in some other ways. You discover on one of your walks someone has started an illegal dump:

When investigating the rubbish more closely, you found:

- juice box
- cigarette end
- used tissue
- invalid credit card
- used chewing gum
- banana skin
- flat mobile phone battery
- marmalade jar made of glass
- perforated bicycle tyre
- plastic mineral water bottle
- apple core
- old magazine
- aluminium tin

You decide to watch how nature will cope with them itself.

Here begins your investigation.

Task 1

You will come back to the dump in the following time intervals. Next to each of them write which of the things should have decomposed.

- One month later
  ……………………………………………………………………..
- Three months later
  ……………………………………………………………………….
- Two years later
  ………………………………………………………………………
- Five years later
  ………………………………………………………………………
- Ten years later
  ……………………………………………………………………….

Task 2

You are 100 years old and in perfect health. Which objects will still be at the dump? Next to each object write its time of decomposition.

.... ……… years

.... ……… years

.... ……… years

.... ……… years

.... ……… years

Task 3

Which objects from the dump could be recycled?

……………………………………………………………………………………………….

Task 4

Which of the objects the environment can cope with itself without polluting the environment?

……………………………………………………………………………………………..

....

Task 5

On one occasion you will find a beautiful edible mushroom growing near the dump. Will you take it home and make scrambled eggs with it? Justify your answer.

……………………………………………………………………………………………………….

……………………………………………………………………………………………………….

Task 6

You have been watching the dump for a long time. Try to name everything that can influence the speed of decomposition of objects on it.

……

……

……

……………………………………………………………………………

Homework

- ***Find out how much waste you produce (municipal waste, or only plastic waste, alternatively) in your household during one year.***

  Procedure: collect waste (municipal waste, or only plastic waste, alternatively) during the whole weekend , weigh it and multiply its weight by the number of days of the year

- ***Search your neighborhood and find out if there are any illegal dumps there***.

  Note: You can support your findings with photos of the illegal dumps and present them to your peers (eg. by means of PowerPoint – presentation).

- ***Ask in the town or village where you live what possibilities there are for separating waste.***

  Note: You can extend the issue of separating of waste by other issues, eg. separation at home, at school, emphasise significance of waste separating.

Activity 2.1B - Resolubility of plastics and different materials in the soil

Materials:

- One worksheet per group

Suggestions for use:

At the beginning, the teacher gets pupils interested by asking problem-based questions. The teacher states a problem and tries to get all pupils involved. In the following stage, pupils become part of the investigation. Pupils work in groups and use worksheets - they gather information, ask questions, formulate hypotheses without teacher's direct instructions.

Solutions that can be found on the Internet:

Examples of doing the task

Waste is ranked from the shortest time of decomposition to the longest. Next to each type of waste there are also products made of the plastic in question.

1) **Apple core** depending on temperature and weather condition decomposes for *several weeks*.
2) **Newspaper and magazines** represent the component of municipal waste that is separated in the present. They are decomposed in the nature within *several months.* Weather also plays a role influencing their decomposition time. Separation of paper saves primary raw materials – wood, does not pollute the air and saves energy. Paper packages for packing products and food that we come across in retail chains are made of separated paper. Toilet paper and card paper that do not require high quality to function are also made.
3) **Aluminium tins** that represent a considerable part of packaging material mostly in drinks mean danger to nature. Tins dropped on the ground in the country decompose for about *20–100 years*. During the time of decomposition animals or people looking for relaxation in the country can be injured. The material from which package is made can cause cuts that can lead to pain and infections. Aluminium tins are suitable for recycling.
4) **Battery (accumulator)** – decomposition of a battery in the environment takes *200–500 years*.
5) **Rubber tyre** of a car represents a burden for the environment for about *265 years*.
6) **PET bottles and plastic sacks** we cannot imagine products in department stores without take about *500 years to decompose in the environment.*
7) **Glass** belongs to material that can be recycled very well and by throwing it away in the country we cause load for as long as *4000 years* until it is decomposed.

Resolubility of plastic and different materials in soil

Student‘s worksheet

Theoretical basis:

Waste is produced in every human activity. Its production and accumulation means a serious interference with the environment. Waste often contains substances that endanger almost all parts of the environment, i.e. quality of water, air and soil, they get into plants and through food chain threaten health and lives of animals and people. Right treatment of waste thus becomes as important as securing basic life needs. Apart from that, using waste as a secondary source of resources is becoming increasingly important..

The issue of waste is not new, it has always existed but became more widespread with a man appearing on the Earth. In the past, man only manufactured natural resources and waste was of the same substances. The environment was able to cope with them without problems. Solid waste decomposed in soil and enriched it with various precious elements. That way an eternal cycle was completed – everything that nature produces, returns to it after dying or being used. The cycle has been and increasingly is disrupted due to man. The environment is becoming increasingly contaminated with waste and its quantity exceeds self-cleaning ability of the nature.

Task 1

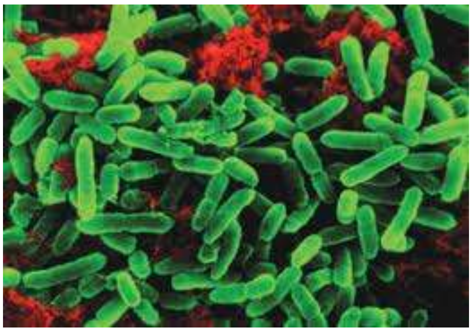
Rank the following waste according to the time of its decomposition in soil:

batteries and accumulators, apple core, newspaper and magazines, polystyrene, glass, rubber tyre, aluminium tins, plastic bottle and plastic bag.

1. ....
2. ....
3. ....
4. ....
5. ....
6. ....
7. ....
8. ....
9. ....

Task 2

Think about the fact how it is possible that some kinds of materials decompose in the environment within several weeks while some need hundreds of years for that. Use your knowledge of biology. The picture might be helpful to you.



....
....
....
....

Task 3

Answer the following questions. You have come across some of the answers in previous years of study. Now it is up to you to remember them☺.

- *Choose a plastic product you come across every day and describe its properties.*

  ....
  ....
  ....

- *Name at least 10 products made of plastic.*

  ....
  ……………………………………………………………………………………………….
  ....

- *How would you explain the term biologically decomposable municipal waste?*

  ....

- *Which of the above-mentioned waste is suitable for composting? Justify your answer.*

  ....
  ....

- *Which waste you should in no case throw away into the environment? Justify your answer.*

....

....

....

- *Write what chemical compounds a battery or accumulators contain. What dangerous gas compounds are produced in incineration of rubber tyres. Explain why they are dangerous for man and the environment.*

....

....

- *Propose some solutions of waste disposal. Justify your answer.*

....

....

....

....

…………………………………………………………………………………………………

…………………………………………………………………………………………………

Homework

Imagine you gave a lecture on „Illegal dumps and their impact on the environment“. What would you talk about? Look up the necessary information and prepare several sentences you would say.

Activity 2.2 Separation of waste

Learning aims:

- discuss the problem of accumulating waste and impact on the environment,
- understand the importance of appropriate treatment of waste,
- understand the importance of recycling as the only and effective alternative of waste disposal,
- learn to separate correctly.

Materials:

- worksheet

Suggestions for use:

A teacher asks problem-solving questions to pupils and finds out the level of their knowledge of the issue. In the next part of the lesson, pupils work in groups and use worksheets. They look up the necessary information on the Internet or ask the teacher.

Separation of waste

Student's worksheet

People produce a big amount of waste. It is necessary for different reasons to **separate** waste. Most households do that.

Discuss the following questions:

Why do people produce such an amount of waste?

What is the significance of separation of waste? What reasons are there for doing so? Can you separate waste correctly? Why don't some people separate waste?

Try to tackle the following tasks. You can consult your peers, ask the teacher or use the Internet.

Task 1

There are dustbins of different colours outside your house. There are pictures and texts on them explaining which rubbish belongs to which bin. Match the dustbins with the sorts of rubbish.

paper

glass

other municipal waste

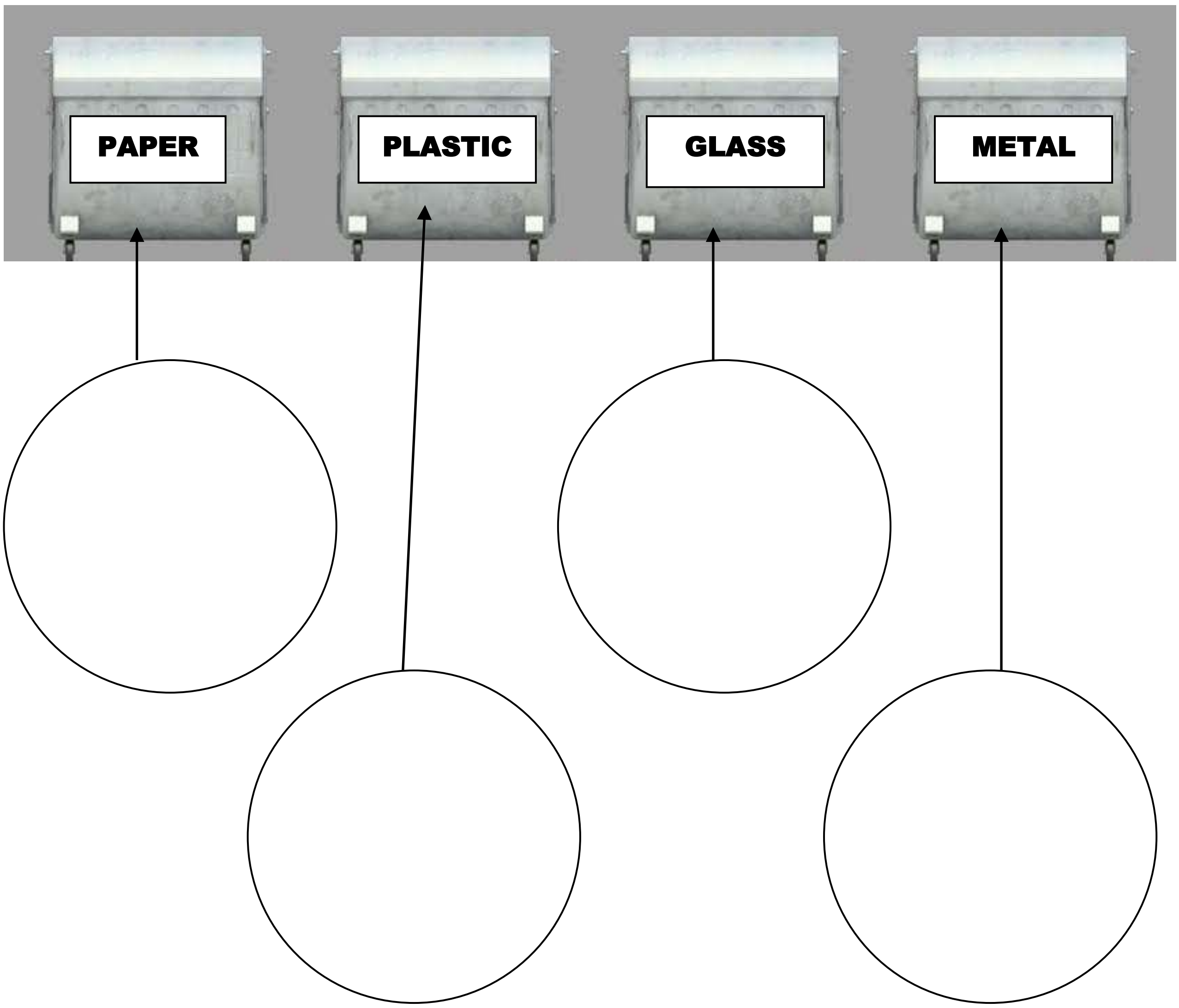
plastic

tetrapack

Task 2

The below-mentioned dustbins are outside your home. Decide which of the following things can be separated and which can't. Into the labels below the dustbins write the name of the thing you would throw into each.

A glass, milk cardboard box (tetrapack), electric bulb, cardboard, tin, plastic bag, porcelain vase, accumulator, mirror, shampoo bottle (clean), PET bottle, used batteries, magazine, yoghurt jar lid, toothpaste tube.



Which of the above things cannot be thrown into any of the bins for separated waste?

....

....

Which of the above things do you consider dangerous waste and it cannot be thrown away into any dustbin at all?

....

Task 3

In households, used batteries, expired medicine, old TV set, computer, furniture or a mobile phone also become waste. Write what you will do with them.

Used batteries ....

Expired medicine ....

Mobile phone ....

TV set, fridge, computer ....

Task 4

Write as many reasons for separating different waste as possible.

It is necessary to separate paper because

....

....

It is necessary to separate glass because

....

....

It is necessary to separate metals because

....

....

It is necessary to separate plastic because

....

....

It is necessary to separate Tetrapack because

....

....

Task 5

In dustbins for municipal waste other unnecessary things from households are gathered. They are regularly taken away by refuse collectors. Do you know where they are taken and what happens to them?

....

....

Propose at least one kind of waste that you think could be used in some way after separation.

I think ....should be separated as well because it could be used

....

Activity 2.3 Influence of acid rains on plastic products

This activity is focused on plastic waste that is in contact with acid rains. A question arises whether acid rains have an influence on decomposing of plastics. Pupils have acquired knowledge about acid rains, their reasons and impact on the environment. Based on experiments they have to decide if acid rains have an influence on decomposing of plastics.

Learning aims:

- know the reasons of acid rains and their impact on the environment,
- based on experiments decide if acid rains have any influence on decomposition of plastic materials.

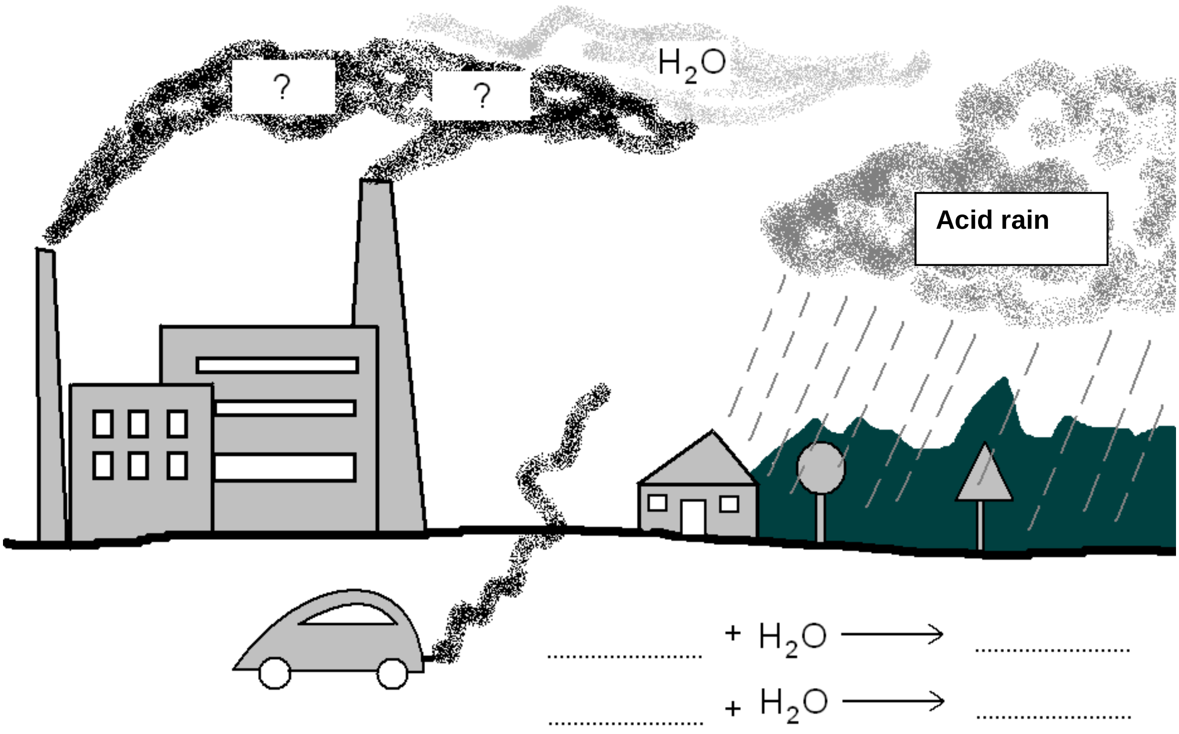
Suggestions for use:

A teacher asks questions concerning reasons of acid rains. A discussion follows focusing on impact of acid rains on different materials, including plastic. Pupils formulate hypotheses and write their answers into worksheets.
Pupils study the impact of acid rain on plastic and other selected materials (chalk, cotton, wood) in their experiments. They compare the resistance of different materials at the end of the experiment. They write the findings into a table and draw conclusions.

Acid rains and plastic

Student's worksheet

You have become familiar with the topic therefore it should not be difficult for you to tackle the following tasks.



How and why is acid rain produced?

....
....
....
....
....
....
....

....
....
....

Write at least three negative impacts of acid rain on the environment:

- ....
- ....
- ....

Which materials are damaged by acid rain?

....
....

What is pH of acid rain?

....

Discuss:

Are all materials damaged by acid rain? Which acids cause production of acid rains?

Work out specific solutions of acid rain prevention.

Task 1

You are going to study four kinds of plastic you have already become familiar with. Revise their names and make pairs:

POLYETHYLENE

POLYPROPYLENE

POLYSTYRENE

POLYVINYL CHLORIDE

Verify the impact of acid rains on plastic products based on the experiment.

Formulate a hypothesis:

....
....
....

Task 2: Find out the influence of sulfuric acid and nitric acid with different pH on plastic materials

Materials:

Beakers, pipettes, sulfuric acid, nitric acid, different plastic materials: bottle cap (HDPE) , plastic bag (PP), water jar (PS), CD (PVC), chalk, cotton, wood, pH-meter

Procedure:

Pour diluted sulfuric acid with pH = 2 into first seven beakers. Put a piece of plastic into each of other four beakers and reference materials (chalk, cotton, wood) into the remaining three beakers. Repeat the procedure for pH of 3, 4, 5 . Complete the table with records of changes after one hour, one day and one week. Repeat the procedure with nitric acid as well and record the changes in the tables.

Findings:

Tab.1 : Effect of sulfuric acid on different materials depending on time

pH	Effects of sulfuric acid after	Plastic materials				Other materials		
		HDPE	PP	PS	PVC	chalk	cotton	wood
2	One hour							
	One day							
	One week							
3	One hour							
	One day							
	One week							
4	One hour							
	One day							
	One week							
5	One hour							
	One day							
	One week							

Tab.2 : Effect of nitric acid on different materials depending on time

pH	Effects of nitric acid after	Plastic materials				Other materials		
		HDPE	PP	PS	PVC	chalk	cotton	wood
2	One hour							
	One day							
	One week							
3	One hour							
	One day							
	One week							
4	One hour							
	One day							
	One week							
5	One hour							
	One day							
	One week							

Task 3

How do acid rains effect plastic products?

....

How did you prove the above fact?

....

....

Compare effects of sulfuric and nitric acids on plastic products.

....

....

Compare the resistance of plastic materials to acid rains with that of other materials that you studied.

....

....

....

Activity 2.4 Recycling plastics – using project-based method

This activity is focused mainly on team work of pupils. They make up teams in the class, three or four-member ones most preferably. The teacher has worksheets that they distribute in groups (each group has one worksheet). It is advisable to distribute the worksheets at least one month ahead so that pupils have enough time to gather necessary information. The result of pupils‘ work is not only the answers to the questions in the worksheet but also their PowerPoint presentations or poster presentations in front of other pupils.

1) Worksheet for „Journalists“

Identify yourself with smart journalists that want to reveal what is behind a particular problem. Your task is to understand the system of symbols you ca come across in almost all packages nowadays. Hardly anyone knows what different symbols mean and if producers put right symbols on packages. Your task will be to find out the truth and then to let it know to the world by means of a newspaper article.

Tasks for journalists:

1) Have a look at different packages of food, PET bottles, boxes, etc. and notice different triangles and similar symbols.
2) Tear off the symbols or draw them in the paper.
3) Try to find out what different symbols mean and how you should handle the specific package.
4) Try to find out how waste is handled in your town.
5) Draw a simple comics „From the life of PET bottles“.
6) Focus on separated waste and try to answer the question „ What happens to a PET bottle you throw into a bin for separated waste? “.
7) Write a newspaper article in which you will depict your project

2) Worksheet for "Detectives"

Task: investigate life cycles of glass and plastic bottles.

1) Find out the advantages and disadvantages of glass and plastic bottles. Incorporate the data into the table.
2) Compare the life cycle of a glass and plastic bottle and try to make graphs describing the two cycles.
3) How is recycling of glass and plastic bottles carried out?
4) Find a plant in your neighbourhood where plastics are recycled and find out what products are made there and how.
5) How long does it take paper, glass and plastic to decompose in the environment?
6) Take a look in the history and find out who was the first to make a plastic and what name was given to the plastic.
7) How are plastics made? Find out at least two procedures for their production.

3) Worksheet for „Common citizens"

Your group will represent common citizens who are trying to understand separating of waste. Your task is to find out what kinds of bins for separated waste are common in this country, what belongs to which container and what, on the contrary, must not be put into it.

Work out the answers to the following questions:

1) What kinds of bins for separated waste are there?
2) Make a table (tab.9) with an overview of waste that belongs and does not belong to the bins for separated waste. Give at least five examples for each item.

Tab. Proposal of a table for different waste that belongs or does not belong to the bin

Bin	***Belongs***	***Does not belong***
Paper		
Plastics		
Glass		

3) How much waste do you produce per week? Gather all the waste during one day (eg. at the weekend), weigh it in the evening and multiply by seven.

4) What percentage of the produced waste was represented by plastics?
5) Do you separate waste at school? How?
6) How far from the school are the nearest bins for separated waste?

4) Worksheet for „Employees of a firm processing plastics“

Imagine that the members of your group are employees of a firm that processes plastics.

1) Find out if there are such firms in Slovakia.
2) Invent a name for your firm.
3) Divide the positions in the company in the group.
4) Find out how such a company works.
5) Find out three procedures used in processing plastics (state sources).
6) Try to describe the procedures so that your peers could understand.
7) Make a drawing and graph to describe the procedures and make them into a graph.
8) Focus on recycling in more detail. If it is among the above mentioned procedures, devote most of your time to it, if it is not, describe it separately.
9) Why is it not appropriate to incinerate PET bottles?

SUBUNIT 3. Polymers around us

Activity 3.1 Materials around us and what plastics and polymers are

Learning aims:

- to understand the concept of polymer and plastic, to be able to distinguish between these concepts.
- to perceive the importance and the significant expansion of polymers and plastics as materials for society and human life.

Materials:

- literature, the Internet

Suggestions for use:

Procedure and notes for teachers (italics in blue refer to the notes for teachers):

- Discuss the topic of materials

  Select 10 random items; write them on a piece of paper.

  - *Students can select anything, the list can be as follows:*
    - *chair*
    - *car*
    - *rucksack*
    - *jacket*
    - *cup of yogurt*
    - *pencil*
    - *bench*
    - *spectacles*
    - *handkerchief*
    - *school bag*
    - *notice board*
  - *Once the students make their lists, ask them a question concerning the presence of polymers and plastics in the given products:*

  For the products listed, highlight those products, where the materials they are made from, contain polymers

  For the products listed it is possible to write e.g. the following description and the students should identify the following materials:

- *☑ chair – can be wooden, metal legs. Wood is a material consisting mainly (ca about 43 %) of cellulose polymer, which is polymeric glucose. The chair can be from "an artificial material", e.g. from polyethylene or polypropylene, then it naturally contains a polymer, it can also have a cover which is often made of plastic fibres*
- *☑ car – the present car is composed of many polymers, whether the textile fibres on the seats, dashboards, rugs, etc. In today's cars, a share of plastics reaches 12-15% (http://www.autorevue.cz/automobily-jen-z-plastu-uz-se-to-blizi) and it is still increasing. This is the weight percentage, i.e. the car weighing 2000 kg contains roughly 280 kg of polymers. Since the polymers have a density 4x-8x lower than e.g. steel, a volume share of plastics in the car can be around 50 %.*
- *☑ rucksack – rucksacks are at present made of mainly synthetic fibres, which are naturally the polymers.*
- *☑ jacket – similarly to rucksacks, these products are nowadays made of mostly synthetic polymeric fibres. E.g. today's very popular Gore-Tex is a polymer polytetrafluoroethylene (PTFE) laminated between the layers of polyamide or polyester. The jacket (or even the rucksack) can also be made of cotton, which is also a polymer (cellulose) or other natural fibres, which are also nearly exclusively polymeric substances.*
- *☑ cup of yogurt – packaging material of our tasty yogurt is very often, indeed almost exclusively, a polymer, often a polystyrene (PS). Yogurt can be packed in glass; however it is not very common.*

- *☑ pencil – a wooden pencil is a polymer (as it contains cellulose), ballpoint pens tend to have a body made of synthetic polymers.*
- *☑ bench – most commonly wooden; i.e. polymeric, there are also the ones made of synthetic polymers.*
- *☑ spectacles – can be polymer-free, e.g. with metal frames and glass, but such spectacles are usually more expensive, moreover also heavier, in particular when the glass is dioptric (and with more dioptres). Therefore even in the production of spectacles, polymers are promoted and frames from synthetic polymers are not an exception as well as the lenses. An advantage of such spectacles is a high variability of the product, low weight and last but not least a reasonable price.*
- *☑ handkerchief – they are usually made of cotton or paper, both composed of polymer - cellulose.*
- *☑ school bag – it is similar to the rucksack, often made of synthetic fibres and synthetic polymers, including also the elements such as buckles, etc. If they are made of natural fibres, these are again, overwhelmingly and almost exclusively, polymers.*
- *☑ Notice board – if it is wooden or cork, it contains polymers, cellulose or suberin (polymer, of which cork is largely composed; it is responsible for its properties)*

- *Students naturally will not correctly identify all the materials, e.g. they often do not identify wood as a material containing largely a polymer, and the teacher therefore will lead the students to identify a number of items. The teacher can also write the materials on the blackboard and discuss them with the students.*
- *In conclusion it can be stated that (and our selection was really random) most products contain some polymeric substances, namely in the form of functional material (i.e. not only as packaging or aesthetic matter). This also applies to a yogurt cup (in our examples), it would not be possible or would be difficult to transport, keep it, etc., without a proper packaging. The products that do not contain a polymeric material are not numerous (e.g. purely metal products, ceramics, diamonds, graphite, etc.)*
- *In conclusion it can therefore be stated that a majority of products around us contain the polymeric material. The importance of polymeric substances is therefore huge and to understand their composition, properties and analysis is extremely important, even necessary for the society and human life.*

We have roughly determined which products contain a polymer. But what is actually a polymer? Create the best possible definition of polymer. You can also use other sources such as e.g. subject-field or other literature or the Internet. If you use a definition already created by somebody else, you have to be able to explain it to the others using examples and be ready to accept their criticism or the revelation that you do not understand the definition.

- *Students usually guess what a polymer is but they do not know it exactly. Therefore we let them form a hypothesis in groups and from this hypothesis to create a definition or at least an explanation of the concept. This will be subsequently (e.g. by selected groups) delivered to the other groups. In the discussion guided by the teacher, these groups then confront each other and assess critically their definitions and refine and strengthen the knowledge of the concept. Next we will introduce the concept of plastic:*

Is a plastic the same as a polymer? Try to explain the difference between these concepts.

- *The teacher again guides the students' discussion. They first guess if it is the same or not, and then they try in groups to guess the difference between these concepts. With the help of the teacher they should arrive at the description of the concept "plastic". Neither generally is the concept of plastic somehow sharply defined, therefore nor the students will probably arrive at a clear conclusion. The concepts of polymer and plastic often coincide with a given product, but the polymer is a more general concept. We are referring to plastics not earlier than at the moment when the polymer represents a multi-component constructional and technical material. If therefore the polymer is not designed* *for technical processing, we should not call it a plastic. In practice, plastics are often called synthetic polymers, i.e. such materials that are artificially synthesised (therefore they are also often called artificial materials). Natural polymers (paper, wood, cotton) are not called plastics, though they are often for us constructional materials.*

What is a synthetic polymer and which of the selected products contain a synthetic polymer

- By a similar discussion as in the previous cases, the students will determine what it is a synthetic polymer (i.e. a polymer prepared by synthesis from a monomer), they will understand in such a way the concepts of monomer and polymerization reaction (polymerization). The teacher will critically evaluate the definitions and explanations of the concepts given by the students. From the above mentioned list, a synthetic polymer is contained or can often be contained in:
  - *☑ chair – a chair can be made of "an artificial material", e.g. from polyethylene or polypropylene, then it naturally contains a polymer, it can also have a cover, which is often made of synthetic fibres*
  - *☑ car – the present car is composed of many polymers, whether the textile fibres on the seats, dashboards, rugs, etc. In today's cars, a share of plastics reaches 12-15% (http://www.autorevue.cz/automobily-jen-z-plastu-uz-se-to-blizi) and it is still increasing. These are mostly synthetic polymers such as polyethyleneterephthalate (PET), polystyrene (PS) polyethylene and many others.*
  - *☑ rucksack – rucksacks are at present made of mainly synthetic fibres, which are naturally the polymers.*
  - *☑ jacket – similarly to rucksacks, these product are nowadays made of mostly synthetic polymeric fibres. E.g. today's very popular Gore-Tex is a polymer polytetrafluorethylene (PTFE) laminated between the layers of polyamide or polyester. The jacket (or even the rucksack) can also be made of cotton, which is also a polymer (cellulose) or other natural fibres, which are also nearly exclusively polymeric substances.*
  - *☑ cup of yogurt – packaging material of our tasty yogurt is very often, indeed almost exclusively, a polymer, often a polystyrene (PS). Yogurt can be packed in glass; however it is not very common.*
  - *☑ pencil – if we consider a wooden pencil, it does not contain a synthetic polymer but there are also the ones with the body of synthetic polymers (ballpoint pens, micropencils).*
  - *☑ bench – most commonly wooden; though benches can be made of synthetic polymeric materials, so far it is not common.*
  - *☑ spectacles – can be polymer-free, e.g. with metal frames and glass, but such spectacles are usually more expensive, moreover also heavier, in particular when the glass is dioptric (and with more dioptres). Therefore even in the production of spectacles, polymers are promoted and frames of synthetic polymers are not an exception as well as the lenses. An advantage of such spectacles is a high variability of the product, low weight and last but not least a reasonable price.*
  - *☑ handkerchief – they are usually made of cotton or paper, both composed of polymer – cellulose, synthetic polymers are not so far commonly used for the production of handkerchiefs*
  - *☑ school bag – it is similar to the rucksack, often made of synthetic fibres and synthetic polymers, including also the elements such as buckles, etc. If they are made of natural fibres, these are again, overwhelmingly and almost exclusively, polymers.*
  - *☑ Notice board – if it is wooden or cork, it contains polymers, cellulose or suberin (polymer, of which cork is largely composed; it is responsible for its properties). However there are also notice boards made of polystyrene foam (PS), which is a synthetic polymer*
- *In conclusion it can be stated that polymeric materials are contained in a large majority of products, synthetic polymeric materials are then a part of a smaller number of products but in spite of this, a half or more than a half of selected products can contain them.*

Why are synthetic polymeric materials so widespread? We will try to answer it through the following activity.

Students' worksheet

Materials around us and what plastics and polymers are

Task 1: Select 10 random items; write them on a piece of paper.

Task 2: For the products listed, highlight (into white small box prior to the name of the item) those products, where the materials they are made from, contain polymers! What part of the item is made from polymer (write into a box right to the name of the item)? Discuss!

Task 3: You have roughly determined which products contain a polymer. But what is actually a polymer? Create the best possible definition of polymer. You can also use other sources such as e.g. subject-field or other literature or the Internet. If you use a definition already created by somebody else, you have to be able to explain it to the others using examples and be ready to accept their criticism or the revelation that you do not understand the definition ☹!

Polymer definition:

Explanation and examples:

Find answers to the following questions! Use internet, suitable references, literature and discussion!

a) Is the term plastics synonym for the term polymer? Try to explain the difference between these concepts!

b) What is a synthetic polymer and which of the selected products contain a synthetic polymer

Activity 3.2 Polymerization – polycondensation.

Learning aims:
1) To show one way of polymer preparation.
2) Understanding of term polycondensation as a method of polymer preparation.

Materials:
solution of adipoylchloride in hexane, aqueous solution of hexane-1,6-diamine, beaker, glass bar, tweezers

Procedure:
1) Pour solution of adipoylchloride in hexane into narrow higher beaker.
2) Pour carefully aqueous solution of hexane 1,6 diamine into the beaker with solution of adipoylchloride under the layer of hexane.
3) Thin layer of synthetic polymer is formed at interface of both of the layers.
4) Take the polymer by tweezers and pull it out above the surface of the solutions and coil it on the glass bar.

Discussion:
Polymers can be prepared by three various polyreactions. They are polymerization, polycondensation and polyadition. Polymerization is addition of monomer on double bond of monomer (by a macroion or by a radical). During polycondensation, the polymer from typically bifunctional monomers is formed and some small molecules like water or carbon dioxide are released. Polyamides (Nylon, Silon) are typically prepared by polycondensation. They are mosly prepared by the reaction of bifunctional carboxylic acid (or they chlorides) and diamines, when water or hydrochloric acid are released.

$$H_2N-(CH_2)_6-NH_2 + ClOC-(CH_2)_4-COCl \xrightarrow[-HCl]{} \left[-HN-(CH_2)_6-NH-CO-(CH_2)_4-CO-\right]_n$$

What are mechanical properties of formed polymer?
It is hard and solid fiber.

Which group of polymers the prepared polymer belongs to?
Polyamides.

Polymerization – polycondensation.

Task1: Prepare the famous polymer – analogy of polyamide nylon.

Chemicals and aids: solution of adipoylchloride in hexane, aqueous solution of hexane-1,6-diamine, beaker, glass bar, tweezers

Procedure:
1) Pour solution of adipoylchloride in hexane into narrow higher beaker.
2) Pour carefully aqueous solution of hexane-1,6-diamine into the beaker with solution of adipoylchloride under the layer of hexane.
3) Thin layer of synthetic polymer is formed at interface of both of the layers.
4) Take the polymer by tweezers and pull it out above the surface of the solutions and coil it on the glass bar.

Observation:

Results and discussion:

Questions:
1) What are mechanical properties of formed polymer?

2) Which group of polymers the prepared polymer belongs to?

Conclusion:

Activity 3.3 Cross-linking of polymers

Learning aims**:**

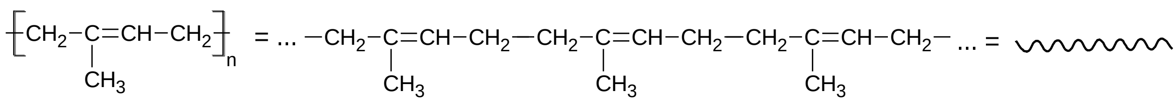
1) Understanding of the process of cross-linking of polymers and a consequent change of mechanical properties of polymer

Materials**:**
borax, two beakers (one smaller and one bigger), white glue, balances, hot water, glass bar, dyes, spoon, cloth

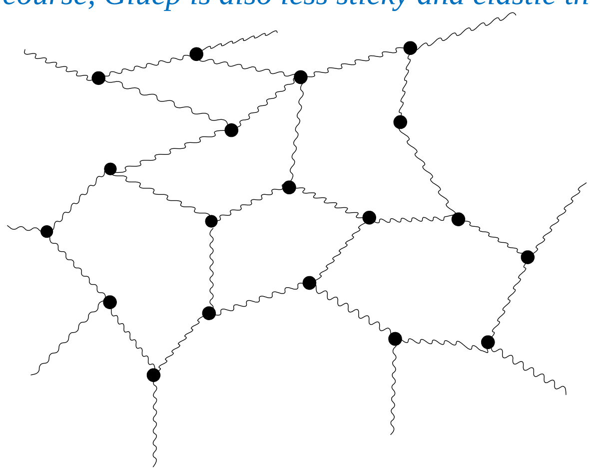
Procedure**:**

1) Dissolve ca 4 g of borax in 100 mL of hot water in a beaker and well stir up to complete dissolution of borax.
2) Dissolve 10 mL of white glue in 5-6 mL of hot water in the second beaker and add few drops of selected dye. Well mix.
3) Add 2 spoons of borax solution to mixture of water and glue in the second beaker and stir.
4) A clod is formed. Remove it, dry it and compact it in palms for few minutes.
5) Play few minutes with formed polymer, follow its mechanical properties.

Discussion**:**
Synthetics polymers are substances which consist of long chains of big molecules – macromolecules. Their structure is similar to chain. The macromolecules are composed of a large number of smaller periodically repetitive units like segments of chain.



Linear polymer
White glue is a mixture of polymer and water. Molecules of the polymer are stacked like small pieces of spaghetti. Tangled molecules give to the white glue sticky character but it is not liquid. If we put the white glue on air, the water from the glue is evaporating from the polymer and polymer chains are stacked to the surfaces and connect them together.
If we add a Borax, which contains borate ions, the ions can form a connection between the chainsof the polymer molecules and three-dimensional network is formed. As a consequence, the properties are changed and the Gluep is more solid than the original white glue (like in the case if you overcook the spaghetti).Of course, Gluep is also less sticky and elastic than the original white glue.



You know that white glue is linear non-cross-linked polymer. What happened after addition of borax? *The cross-linked polymer has been formed with three-dimensional polymer network. Chains has been prolonged.*

How the properties of formed polymer changed?

The Gluep is more solid than the original white glue (like in the case if you overcook the spaghetti).Of course, Gluep is also less sticky and elastic than the original white glue.

Why is white glue the glue? What is the mechanismus of glue effect?

White glue is a mixture of polymer and water. Molecules of the polymer are stacked like small pieces of spaghetti. Tangled molecules give to the white glue sticky character but it is not liquid. If we put the white glue on air, the water from the glue is evaporating from the polymer and polymer chains are stacked to the surfaces and connect them together.

Cross-linking of polymers

Task 1: Accomplish and interpret the following experiment, preparation of polymer called Gluep.

Chemicals and aids: borax, two beakers (one smaller and one bigger), white glue, balances, hot water, glass bar, dyes, spoon, cloth

Procedure:

a. Dissolve ca 4 g of borax in 100 mL of hot water in a beaker and well stir up to complete dissolution of borax.
b. Dissolve 10 mL of white glue in 5-6 mL of hot water in the second beaker and add few drops of selected dye. Well mix.
c. Add 2 spoons of borax solution to mixture of water and glue in the second beaker and stir.
d. A clod is formed. Remove it, dry it and compact it in palms for few minutes.
e. Play few minutes with formed polymer, follow its mechanical properties.

Observation:

Results and discussion: interpret the results!

Questions:

1) You know that white glue is linear non-cross-linked polymer. What happened after addition of borax?

2) How the properties of formed polymer changed?

3) Why is white glue the glue? What is the mechanismus of glue effect?

Conclusion:

Activity 3.4 Preparation of polymers, influencing their properties

Learning aims**:**

1) On the basis of the experiment we will verify the fact that the conditions of preparation can influence the structure and consequently also the properties of the resulting polymer. It is therefore absolutely necessary to satisfy the conditions of preparation if our goal is that the polymer is expected to fulfil its function.

Materials**:**

Polyurethane foam (spray), two empty matchboxes, a lamp, and a watch

Procedure**:**

1) Take empty matchboxes and soak one of them in water. Both of them should be partially closed.
2) Try to fill them with the same amount of polyurethane foam, while the first to fill up will be a dry box.
3) Observe how fast the polyurethane foam increases.
4) Wait until the foam hardens and dries. Cut the box and compare the structure of PUR foam.

Discussion**:**

1) Why was one of the boxes wetted and what were the consequences effecting the formation of polymer.
2) According to the structure of polymer, for which purposes can be the polymer recommended.

Polyurethane (PUR) foams in a spray form can be one–component (prepolymer) or two-component (two monomers). In the polyaddition –NH– groups are formed, which can, in a smaller extent, convert into isocyanate groups. During this reaction, there occurs the initiation of these groups by water (air moisture), an intermediate product is formed – aryl carbamic acid, which leads to the elimination of carbon dioxide that will foam up the polyurethane.

$$\underbrace{\ldots\text{–}R\text{=}N\text{=}C\text{=}O}_{\text{isocyanate}} + H_2O \rightarrow \underbrace{\ldots\text{–}R\text{–}NH\text{–}COOH\ldots}_{\text{aryl carbamic acid}} \rightarrow \underbrace{\ldots\text{–}R\text{–}NH_2}_{\text{amine}} + CO_2\uparrow(gas)$$

The formed amine reacts with isocyanate (monomer or also a newly formed group) and a polyurethane polymer is formed.

$$\ldots\text{–}R\text{=}N\text{=}C\text{=}O + NH_2\text{–}R\text{–}\ldots \rightarrow \ldots\text{–}R\text{–}NH\text{–}CO\text{–}NH\text{–}R\text{–}\ldots$$

PUR foams are used as insulation; their advantage is that they are waterproof but on the other hand they absorb air moisture, ensuring thus "breathing" of the insulated structure.
The reaction is initiated by water; the presence of water in the reaction mixture is therefore helpful for a full reaction throughout the entire volume and for a formation of quality reinforced polymer across the entire volume, which should be evident when the polymer was cut in half. Minimally the presence of water will fasten the reaction, i.e. the foam is formed in a shorter time.
From the experiment it is also evident that the structure and consequently also the properties of polymer can be affected by the conditions of preparation, which will further broaden the structure of polymer properties.

Prepared polyurethane foam, on the left PUR foam formed with a wetted box.

Cross section through PUR foam, on the left PUR foam formed with a wetted box.

Students' worksheet

Preparation of polymers, influencing their properties

Task 1: Explore how the conditions of preparation of polymer can affect the structure and properties of polymer.

Chemicals and aids: Polyurethane foam (spray), two empty matchboxes, a lamp, a watch, water

Procedure:

1) Take empty matchboxes and soak one of them in water. Both of them should be partially closed.
2) Try to fill them with the same amount of polyurethane foam, while the first to fill up will be a dry box.
3) Observe how fast the polyurethane foam increases.
4) Wait until the foam hardens and dries. Cut the box and compare the structure of PUR foam.

Observation: What is the difference between PUR foams formed in wet and dry box? Add photos, if you can.

Results and discussion: Discuss the results of the experiment.

Questions:

1) Why was one of the boxes wetted and what were the consequences effecting the formation of polymer.

2) According to the structure of polymer, for which purposes can be the polymer recommended.

Conclusion:

Activity 3.5. Properties of polymers

Learning aims**:**

1) Through their own exploration, students should explain that polymers are substances of very diverse properties. These properties are connected with a chemical structure of polymer. This can be used for the selection of a proper material for design and production of the given product but also for the identification of unknown samples of polymers.

Suggestions for use:

We will try to explore the properties of some mostly synthetic polymers. The supplied samples of polymers will undergo several tests, from which we try to deduce the properties of these polymers. Try to select the properties that could be studied with polymers, e.g. based on the properties that we would like to find in some of the products.

A range of observed properties can be broad, important for the products can undoubtedly be:

- *Weight of product – observed property of the material will be density; it is of great importance e.g. for airspace and automotive industry. E.g. weight saving of 100 kg will restrict fuel consumption in average by 0.4l (http://www.autorevue.cz/automobily-jen-z-plastu-uz-se-to-blizi)*
- *Wear resistance – observed properties are strength and hardness of material*
- *Colour of product, possibility of its choice – it is optimal if the product can be coloured as necessary, i.e. a plastic is basically colourless or white and little tinged*
- *Possibility of processing or production of directly the shape of the given product – possibility of forming through synthesis or processing of synthetic polymer*
- *Flammability – some products warm up when a synthetic polymer is used for their production; the polymer should be non-flammable and should not be easy to ignite. During its burning or decomposition (depolymerisation or degradation) toxic substances should not be released – the observed property is behaviour in the flame.*
- *Changes due to heating – the product should not at common operating temperatures change its shape or degrade in any way. On the other hand, formability at reasonably high temperatures is a big advantage through processing (moulding, injection moulding), it reduces the costs for product processing and offers a wide range of possibilities as for the shape and function of the product – this property can be observed through heating on the cooker or the hob.*
- *Resistance to chemicals – e.g. sewage piping should resist the substances commonly discharged to the sewage system. Important is resistance to chemicals when cleaning the plastic parts of the product or chemical cleaning of textiles made of synthetic polymers not to cause their damage – the test will be solubility in different solvents.*

  Some properties of synthetic polymers, such as appearance, density, tip puncture and behaviour in the flame, will be observed in the following experiment; other properties should be discussed.

Students themselves will propose the experiments, which will allow observing the properties given in the discussion and they try to estimate the results.

Materials:

Gas burner, toluene, chloroform, water, formic acid, sulphuric acid, petrol, ethanol, cyclohexane, phenol, hob or cooker, paper or white board, two beakers of 100-150 ml, needle thermocouple

Samples of plastics (PE – polyethylene, PP - polypropylene, PS - polystyrene, PVAc – polyvinyl acetate, PMMA – polymethylmethacrylate, PC – polycarbonate, PA – polyamide, PUR – polyurethane, PET – polyethylene terephthalate, PVC – polyvinylchloride, PTFE – polytetrafluoroethylene, MF – aminoplastics)

Students can bring the samples of plastics from home; it will be optimal if they find out on the product, according to the abbreviation on the given product, what kind of plastic it is. The following *survey refers to the most common plastics and some typical products made of them (in the brackets you can find the number code, which also often appears on the products – it is primarily used for material recycling):*

PE – polyethylene (2 a 4) - foil, packaging, plastic greenhouses for growing plants, plastic greenhouses for silage pits, dishes – sieves, strainers, cups, cosmetics packaging

PP – polypropylene (5) – medical aids (e.g. syringes, urinals…), metal tools handles, storage bottles for chemicals, packaging of makeup removers, ointments, drops, packaging material (boxes, yogurt cups, etc.)

PS – polystyrene (6) –softened PS - insulation materials for thermal insulation of houses and structures, mechanical and acoustic insulating packaging materials, protective packaging for electronics, thermos packaging; hardened PS - CD covers, videocassettes, packaging for the so-called "black electronics" and for pressing the kitchen items – dishes (from yogurt and cheese), graters, hangers, bowls, cheap and durable cladding tiles, model airplanes and boats, toys

PVAc – polyvinyl acetate – painting materials (trade name Latex), adhesives, translucent roofing or dental implants

PMMA – polymethylmethacrylate - shields and goggles and helmets, environment for preservation of preparations, replacements of teeth, joints and cartilages, spectacle glasses, contact lenses, cuvettes, aquariums, etc.

PC – polycarbonate – CDs and DVDs (data area layer), insulator in electronics, polycarbonate plates, instrument covers (mp3 players), lenses, components of cameras, video cameras, flashes, etc. (http://www.koplast.cz/ostatni-termoplasty-popis-termoplastu-0/)

PA – polyamide – sprockets, bearings, covers, colour foils, tights, dental floss, racket strings, parachutes, ropes, synthetic textile fibres (e.g. layer in Gore-Tex)

PUR – polyurethane – insulation (PUR foam),molitan, artificial leather (e.g. barex), textile fibres (lycra), toys, mattresses, upholstery filling

PET – polyethylene therephthalate (1) - synthetic textile fibres, tape foils, packaging for beverages (PET bottles) and foodstuffs and other liquids

PVC – polyvinylchloride (3) – sewage piping, consumer goods, water containers and similar products (cans, etc.)

PTFE – polytetrafluorothylene – surfaces of pans; ironing surfaces, ski bases, medical implants (seldom rejection by a human body), protective garments (e.g. for fire-fighters), apparatuses for chemical industry, electrical insulation products, etc.

MF – aminoplasticss – painting materials, adhesives, insulators, for production of consumer goods (e.g. dishes), electro technical material, lining (e.g. Umakart)

Polyisoprene – stoppers, tyres, constructional components of transportation means, condoms, lubricating rubber, etc.

Chloroprene – wetsuits

Testing of materials proposed by the students and corrected by the teacher should include the following tests:

Polymer tests:

__*Appearance test*__*:* polymer can be pre-characterised and also identified by appearance according to the shape of the product (foil, fibres, moulding, …). Describe thoroughly the appearance and shape of the product in the following table. It is possible to tick more than one option. Optical properties shall be determined as follows; in the distance of about 1 cm behind the sample place the text and according to its visibility through the sample determine its transparency:

Plastic	Foil (F), fibre (VL), moulding (VY)	optical properties-transparent (Pů), translucent Pr), opaque N)	colouring-transparent (P), coating (K)	opacity -bright (L), matt (M)	roughness-smooth (HL), rough (HR)	adhesiveness sticky (L), non-sticky (N)	feel-waxy (V), soft(M) , hard (T)
PE							
PP							
PS							
PVAc							
PMMA							
PC							
PA							
PUR							
PET							
PVC							
PTFE							
MF							
Polyisoprene							

It is natural that the products can be of different appearance and shape in spite of the fact that they are made from the same polymer. Therefore it is possible to select in the table more than one category (option) for one polymer. Nevertheless this information can provide us with valuable data. E.g. from some polymers it is nearly impossible to make a foil, or foils are not made from them. If, therefore, the product is a foil, it is probably made from (the previously referred polymers) PP, PS, PVC or PE. Some polymers cannot be made transparent or colourless (phenolic plastics) etc.
Completing the table depends on the samples delivered. Its main importance lies in the fact that polymers differ from each other in their properties and cover an entire spectrum of appearance, shapes and properties.

Density of polymer: Density of polymer can be determined by comparing its interaction with several different liquids of known densities. The more liquids the better; we divide the polymers into three groups based on the comparison with water (density is 1.00 $g \cdot cm^{-3}$) and chloroform (density is 1.50 $g \cdot cm^{-3}$).

Procedure: Pour water into one of the beakers and chloroform to the other (work in a fume hood!!!). Throw a sample of plastic gradually into both of the beakers and observe if it is immersed or remains on the surface. Then show, in the following table, the given plastic within the range of densities:

Plastic	0-1.00 $g \cdot cm^{-3}$	0-1.50 $g \cdot cm^{-3}$	>1.50 $g \cdot cm^{-3}$
PE	X		
PP	X		
PS	X (foam)	X	
PVAc		X	
PMMA		X	
PC		X	
PA		X	
PUR	X	X	
PET		X	
PVC		X	
PTFE			X
MF		X	X
Polyisoprene		X	

What are the results from the observed data?
From the results it is evident that a number of plastics have a higher density than water, polyolefins (PE a PP) have it even lower. However, only exceptionally, the density of polymers exceeds 1.5. Synthetic polymers are therefore relatively light materials (e.g. of cc. 5-6 x lower density than steel or cc. 2x lower density than alumina). If they meet the other required properties, they are suitable for constructional components in aircraft industry, automotive industry, etc., where every saved kilogram counts.

Determination of hardness by tip puncture: we observe mechanical properties of polymer (rigid, hard, brittle, and tough) and deformation behaviour. A practically conducted test is undoubtedly more complex; we can only approximately (qualitatively) arrange the studied samples of polymer according to the needle tip penetration into the polymer sample.
Procedure:
Take a needle and insert it into the sample of plastic. Prior to this, insert the needle with its upper end into a rubber stopper or a similar material so that the subsequent pressure on the sample of plastic would be as constant as possible. Qualitatively estimate the penetration of the needle into the sample and arrange the individual samples into the groups according to the ease of needle penetration:

Group I, easy penetration	*PE, Polyisoprene, PVC (softened), PVAc, PUR, PET*
Group II, higher pressure necessary	*PP, PVC, PS, PTFE*
Group III, uneasy penetration	*PMMA, PC, PA*

Resistance to chemicals, solubility test:
We are looking for a chemical or solvent in which the given polymer can dissolve.
Procedure:
We sprinkle the sample of plastic with a solvent and observe (after cc. 60 seconds), if the plastic is sticky. Then the test can be considered as positive. On the basis of your exploration, fill in the following table:

Plastic	toluene	petrol	chloroform	ethanol	formic acid	cyclohexane	water	Sulphuric acid concentrate
PE	X	X						
PP	X	X						
PS	X	X	X					
PVAc				X				
PMMA			X					
PC			X					
PA					X			
PUR								
PET								X
PVC						X		
PTFE								
MF								
Polyisoprene	X		X			X		

Which conclusion can be made from the filled table?
The studied synthetic polymers are materials of diverse chemical properties, according to its structure soluble in different solvents, mostly of non-polar nature. In majority cases these are substances resistant to water and ethanol. Particularly resistant to chemicals are PTFE and MF. The application of suitable material is defined by its properties or, in turn, the properties determine

the use of material for the given application. E.g. PE cannot be used for applications where non-polar aromatic solvents occur; however it is suitable for applications with water and polar solvents.

Behaviour in the flame: (according to http://ufmi.ft.utb.cz/texty/kzm/KZM_05.pdf) Based on the polymer composition, the given sample of polymer exerts a typical behaviour manifested through flame colouration, odour, burning (flammable vs. non-flammable), smoke, etc. You can also assess the rest of the sample whether it is charred, brownish, almost unchanged or e.g. swollen. With your samples of polymers you observe their behaviour in the flame and after their removal from the flame according to the following instructions, and record the results in the following table.

Ease of ignition of the sample

a) Sample is easy to ignite (ZÁP)
b) Is not easy to ignite (NEZ)

Flammability – sample after ignition and removal from the flame:

a) Continues to burn (HOŘ) until it stops burning,
b) Slowly extinguishes (UHAS) and is not capable of continuous burning and after removal from the flame it extinguishes at different rate
c) Flammable only in the flame but after removal it immediately extinguishes; or non-flammable, it only melts in the flame but does not burn at all (NE)

Colouration of the flame

b) Luminous flame without a blue or green base (SVB)
c) Luminous flame with a blue or green base (SVZ)
d) Non-luminous blue flame (Z)

Smoke – throughout burning the smoke is or is not produced, a character of smoke is also observed; it depends on the chemical structure of polymer and additives (added substances – initiators, plasticizers, etc.) of the polymer. Smoke is observed looking against a sheet of paper or other white mat

a) Thick black sooty smoke (HČS)
b) Not apparent or little apparent smoke (N)
c) Intensive and dark – dark colour of smoke is evident (IT)

E.g. polymers with aromatic nuclei in the chain (PS, PC) produce a thick black sooty smoke. Polymers that do not contain double bonds with single carbonaceous chain (polyolefins, PE, PP) do not release smoke when burning.

Odour of smoke after removal of the sample from the flame: A chemical composition and a structure of polymer influence the nature of substances that are released during burning or depolymerisation or degradation of polymer in the flame. Odour of some of these substances can be characteristic.

Procedure:

Immediately after removal from the flame, we carefully and appropriately sniff and identify odour. It can be:

Paraffin-like (P) - (similar to the smell of burning candle), acid (K), styrene (S), dentacryl (D), honey-like (M), phenolic (F), after the charred horn (R), pungent (Š), amine (A), undefined (N).

Character of charred residue – after removal of sample residue from the flame, the sample exerts a characteristic nature corresponding to its chemical composition. The sample can e.g. only melt or burn out and melt or it leads to its degradation with the occurrence of other coloured substances. E.g. polyolefins are easy to burn and they melt without occurrence of coloured products; the other parts of material have a rough surface due to swelling with releasing gases, sometimes soot occurs, which gives colour to the polymer residue (polymers with aromas).

Procedure:

The burning sample is removed from the flame and carefully extinguished. The charred residue should be explored in terms of colour and further exploration is done by touch (touching by fingers). Subjective observations are recorded.

We can distinguish several degrees of the appearance of charred residue:

a) smooth, no changes or brownish colour (HLH)
b) rough, brownish colour (DH)
c) black or prevailing black (C)
d) smoky (OČ) – soot from the sample rubs against the skin
e) smoulders and leaves ash (DP)

After completing all the experiments in the flame, fill up the following table:

Plastic	Ease of ignition	Flammability	Colouring of flame	Smoke	Odour	Appearance of charred residue
PE	*ZÁP*	*HOŘ*	*SVZ*	*N*	*P*	*HLH*
PP	*ZÁP*	*HOŘ*	*SVZ*	*N*	*P*	*HLH*
PS	*ZÁP*	*HOŘ*	*SVB, smoky*	*HČS*	*S*	*C, OČ*
PVAc	*ZÁP*	*HOŘ*	*SVB, sparks*	*N*	*N*	*DH*
PMMA	*ZÁP*	*HOŘ*	*Z (yellow tip)*	*IT*	*D*	*DH*
PC	*ZÁP*	*NE*	*SVB, smoky*	*HČS*	*F*	*C, OČ*
PA	*ZÁP*	*UHAS*	*Z (yellow tip)*	*IT*	*R*	*HLH*
PUR	*ZÁP*	*HOŘ*	*Z (yellow edge)*	*IT*	*A*	*HLH*
PET	*ZÁP*	*HOŘ*	*SVB, smoky*	*IT*	*M*	*C, OČ*
PVC	*NEZ*	*NE*	*SVZ, green base*	*N*	*K*	*C*
PTFE	*NEZ*	*NE*	*SVZ, green base*	*N*	*N*	*HLH*
MF	*NEZ*	*UHAS*	*SVB*	*N*	*A*	*C*
Polyisoprene	*ZÁP*	*HOŘ*	*SVB*	*IT*	*Š, P*	*OČ, DH*

Melting of polymer on the hob and monitoring the transition temperature:
Polymers are often amorphous or only partially crystalline materials. Therefore they cannot be given a concrete and exact melting temperature but rather a range of temperatures. Moreover, and for the exploitation of polymer as a material it is undoubtedly important, before reaching the melting temperature at any temperature (or rather within a range of temperatures), polymers soften or transit into a flexible state. This temperature (range) is called the glass transition temperature and is an important parameter for the given polymer. Let us try to roughly determine this glass transition temperature.
Procedure: On the hob or heating plate of the cooker, we place a metal plate (which can be damaged) and on this plate we place a sample of the plastic. Temperature of the plate will be measured by a thermocouple followed by observation of the plastic sample. Once the plastic starts to soften, we record the temperature. The experiment will be performed 3x. The results will be recorded in the table.

Plastic	Temperature of glass transition [°C]	Temperature of melting [°C]
PE	*-125 - -80*	*-*
PP	*-20 - 100*	*-*
PS	*95*	*240*
PVAc	*28*	*-*
PMMA	*105*	*-*
PC	*150*	*267*
PA	*50*	*-*
PUR	*-*	*-*
PET	*69*	*-*
PVC	*81*	*-*
PTFE	*-*	*327*
MF	*-*	*-*
Polyisoprene	*-70*	*-*

(data in the table according to http://faculty.uscupstate.edu/llever/Polymer%20Resources/GlassTrans.htm). The results may quite naturally vary (which can be discussed by the students) since the temperature of glass transition depends on a number of parameters, in particular on the structure of the polymer (LDPE, HDPE – Low Density PE vs. High Density PE, atactic vs. isotactic, polymerisation degree, etc. Nevertheless it is a significant property of the polymer and it is desirable for the students to get an idea of what is in question.

What conclusion results from the conducted experiments?

The target of the conducted experiments is (was) to show that synthetic (and not only synthetic) polymers are substances of many varied properties (with both higher and lower density, flammable and also non-flammable, hard and soft, flexible and non-flexible, of different appearance, colour and resistance to environmental effects. These physical and chemical properties (e.g. products of burning) depend on their chemical composition, structure and other properties of the given polymer (e.g. degree of polymerisation). From this it results that a selection of a proper monomer and reaction conditions (from which the structure of polymer often results) allow a preparation of usually such material that will suit our purpose (kitchenware, covers for electronics, chairs, cars, etc.). It is desirable to note that, though the performed experiments do not support this, other possibilities are offered by a combination of polymeric materials (and the production of the so-called composite materials). Due to this, really only a few products and applications do not allow the use of a proper polymer for their production; therefore the polymers are so widespread and can be found in nearly any product or in majority of them. However a selection of other material can often be necessary, e.g. for applications at high temperatures, etc. it should be noted that another advantage of a number of polymers is often the ease of processing or machining at reasonably high temperatures and also a low price. Along with a high variability of technical options in the use of polymeric materials (colouration, processing, appearance, low demands), this makes the polymers a clear choice for the selection of the material for the given product.

Moreover, the students within the performed experiments learnt the properties of the individual synthetic polymeric substances.

The experiments also show that if the individual polymers differ from one another, the given experiments can also be used as identification tests for determination of the polymers. This is also the subject of the following activity.

Polymer properties

Task 1: Obtain the following samples of polymers to the research:

Polymer	Code	Recycling number	Note	Polymer	Code	Recycling number	Note
polyetylene	PE	2 and 4		polyuretane	PUR	x	
Polypropylene	PP	5		polyethylentereftalate	PET	1	
Polyvinylacetate	PVAc	x		Polyvinylchloride	PVC	3	
polymetylmetakrylate	PMMA	x		polytetrafluorethylene	PTFE	x	
polycarbonate	PC	x		aminoplastics	MF	x	
polyamide	PA	x		polystyrene	PS	6	

The following list can help you to get the samples of polymers. The most spread polymers are mentioned as well as some typical items made from them (in brackets, the recycling number of some polymers is also mentioned – the recycling number is written onsome products to make their recycling easier:

PE – polyethylene (2 a 4) - foil, packaging, plastic greenhouses for growing plants, plastic greenhouses for silage pits, dishes – sieves, strainers, cups, cosmetics packaging

PP – polypropylene (5) – medical aids (e.g. syringes, urinals…), metal tools handles, storage bottles for chemicals, packaging of makeup removers, ointments, drops, packaging material (boxes, yogurt cups, etc.)

PS – polystyrene (6) –softened PS - insulation materials for thermal insulation of houses and structures, mechanical and acoustic insulating packaging materials, protective packaging for electronics, thermos packaging; hardened PS - CD covers, videocassettes, packaging for the so-called "black electronics" and for pressing the kitchen items – dishes (from yogurt and cheese), graters, hangers, bowls, cheap and durable cladding tiles, model airplanes and boats, toys

PVAc – polyvinyl acetate – painting materials (trade name Latex), adhesives, translucent roofing or dental implants

PMMA – polymethylmethacrylate - shields and goggles and helmets, environment for preservation of preparations, replacements of teeth, joints and cartilages, spectacle glasses, contact lenses, cuvettes, aquariums, etc.

PC – polycarbonate – CDs and DVDs (data area layer), insulator in electronics, polycarbonate plates, instrument covers (mp3 players), lenses, components of cameras, video cameras, flashes, etc. (http://www.koplast.cz/ostatni-termoplasty-popis-termoplastu-0/)

PA – polyamide – sprockets, bearings, covers, colour foils, tights, dental floss, racket strings, parachutes, ropes, synthetic textile fibres (e.g. layer in Gore-Tex)

PUR – polyurethane – insulation (PUR foam),molitan, artificial leather (e.g. barex), textile fibres (lycra), toys, mattresses, upholstery filling

PET – polyethylene therephthalate (1) - synthetic textile fibres, tape foils, packaging for beverages (PET bottles) and foodstuffs and other liquids

PVC – polyvinylchloride (3) – sewage piping, consumer goods, water containers and similar products (cans, etc.)

PTFE – polytetrafluorothylene – surfaces of pans; ironing surfaces, ski bases, medical implants (seldom rejection by a human body), protective garments (e.g. for fire-fighters), apparatuses for chemical industry, electrical insulation products, etc.

MF – aminoplasticss – painting materials, adhesives, insulators, for production of consumer goods (e.g. dishes), electro technical material, lining (e.g. Umakart)

Polyisoprene – stoppers, tyres, constructional components of transportation means, condoms, lubricating rubber, etc.

Chloroprene – wetsuits

Instructions: Explore various samples of polymers, which you obtained yourself or were delivered by your teacher. Use various tests and write the results to the following tables.

Task 2: Try to select the properties that could be studied with polymers, e.g. based on the properties that we would like to find in some of the products. Write down them into the box bellow.

Task 3 – Appearance test: Do the appearance test with the sample of your polymer. Describe thoroughly the appearance and shape of the product in the following table. It is possible to tick more than one option. Optical properties shall be determined as follows; in the distance of about 1 cm behind the sample place the text and according to its visibility through the sample determine its transparency:

Polymer	Shape of the product: foil, fibre, moulding	Optical properties: transparent, transluent, opaque	Colouring: transparent, coating	Opacity: bright, matt	Roughness: smooth, rough	adhesiveness: sticky, non-sticky	feel: waxy, soft, hard
PE							
PP							
PS							
PVAc							
PMMA							
PC							
PA							
PUR							
PET							
PVC							
PTFE							
MF							
Polyisoprene							

Task 4 – test of density: Do a test of density of polymer and divide the polymer samples into three groups based on the comparison with water (density is 1,00 g·cm^{-3}) and chloroform (density is 1,50 g·cm^{-3}).

Chemicals and aids: chloroform, water, 2 beakers of 100-150 mL volume

Procedure: Pour water into one of the beakers and chloroform to the other (work in a fume hood!!!). Throw a sample of plastic gradually into both of the beakers and observe if it is immersed or remains on the surface. Then show, in the following table, the given plastic within the range of densities:

Polymer	**0-1,00 g·cm^{-3}**	**0-1,50 g·cm^{-3}**	**>1,50 g·cm^{-3}**
PE			
PP			
PS			
PVAc			
PMMA			
PC			
PA			
PUR			
PET			
PVC			
PTFE			
MF			
Polyisoprene			

Task 5 – Determination of hardness by tip puncture: follow mechanical properties of polymer

(rigid, hard, brittle, and tough) and deformation behaviour. A practically conducted test is undoubtedly more complex; we can only approximately (qualitatively) arrange the studied samples of polymer according to the needle tip penetration into the polymer sample.

Chemicals and aids: tip

Procedure: Take a needle and insert it into the sample of plastic. Prior to this, insert the needle with its upper end into a rubber stopper or a similar material so that the subsequent pressure on the sample of plastic would be as constant as possible. Qualitatively estimate the penetration of the needle into the sample and arrange the individual samples into the groups according to the ease of needle penetration. Fill in the following table:

Group I, easy penetration	
Group II, higher pressure necessary	
Group III, uneasy penetration	

Task 6 – Resistance to chemicals, solubility test: Try to find a chemical or solvent in which the given polymer can dissolve.

Chemicals and aids: toluene, chloroform, water, formic acid, konc. sulphuric acid, petrol, ethanol, cyklohexane, 8 beakers or test tubes of approximate volumes of 25-100 mL.

Procedure: Sprinkle the sample of plastic with a solvent and observe (after ca. 60 seconds), if the plastic is sticky. Then the test can be considered as positive. On the basis of your exploration, fill in the following table:

Polymer	**toluene**	**petrol**	**chloroform**	**ethanol**	**formic acid**	**cyklohexane**	**water**	**sulphuric acid konc.**
PE								
PP								
PS								
PVAc								
PMMA								
PC								
PA								
PUR								
PET								
PVC								
PTFE								
MF								
Polyisoprene								

Task 7 – flame test: Based on the polymer composition, the given sample of polymer exerts a typical behavior manifested through flame colouration, odour, burning (flammable vs. non-flammable), smoke, etc. You can also assess the rest of the sample whether it is charred, brownish, almost unchanged or e.g. swollen.

Chemicals and aids: gas burner (methane or propane-butane), chemical pliers

Procedure: Take you sample by chemical pliers and insert it into a flame and follow how it is easy to set the sample on fire. Consequently, with your samples of polymers, observe their behaviour in the flame and after their removal from the flame according to the following instructions:

Ease of ignition of the sample:

c) Sample is easy to ignite
d) Is not easy to ignite

Flammability – sample after ignition and removal from the flame:

d) Continues to burn until it stops burning,
e) Slowly extinguishes and is not capable of continuous burning and after removal from the flame it extinguishes at different rate
f) Flammable only in the flame but after removal it immediately extinguishes; or non-flammable, it only melts in the flame but does not burn at all

Colouration of the flame:

e) Luminous flame without a blue or green base
f) Luminous flame with a blue or green base
g) Non-luminous blue flame

Smoke – throughout burning the smoke is or is not produced, a character of smoke is also observed; it depends on the chemical structure of polymer and additives (added substances – initiators, plasticizers, etc.) of the polymer. Smoke is observed looking against a sheet of paper or other white mat:

d) Thick black sooty smoke
e) Not apparent or little apparent smoke
f) Intensive and dark – dark colour of smoke is evident

E.g. polymers with aromatic nuclei in the chain (PS, PC) produce a thick black sooty smoke. Polymers that do not contain double bonds with single carbonaceous chain (polyolefines, PE, PP) do not release smoke when burning.

Odour of smoke after removal of the sample from the flame: A chemical composition and a structure of polymer influence the nature of substances that are released during burning or depolymerisation or degradation of polymer in the flame. Odour of some of these substances can be characteristic. Immediately after removal from the flame, we carefully and appropriately sniff and identify odour. It can be: a) Paraffin-like - (similar to the smell of burning candle), b) acid, c) styrene, d) dentacryl, e) honey-like, f) phenolic, g) after the charred horn, h) pungent, i) amine, k) undefined.

Character of charred residue – after removal of sample residue from the flame, the sample exerts a characteristic nature corresponding to its chemical composition. The sample can e.g. only melt or burn out and melt or it leads to its degradation with the occurrence of other coloured substances. E.g. polyolefins are easy to burn and they melt without occurrence of coloured products; the other parts of material have a rough surface due to swelling with releasing gases, sometimes soot occurs, which gives colour to the polymer residue (polymers with aromas). The burning sample is removed from the flame and carefully extinguished. The charred residue should be explored in terms of colour and further exploration is done by touch (touching by fingers). Subjective observations are recorded.

We can distinguish several degrees of the appearance of charred residue:

a) Smooth, no changes or brownish colour
b) rough, brownish colour
c) black or prevailing black
d) smoky – soot from the sample rubs against the skin
e) smoulders and leaves ash

After completing all the experiments in the flame, fill up the following table:

Flame test results:

Polymer	*Ease of ignition*	Flammability	Colouring of flame	Smoke	Odour	Appearance of charred residue
PE						
PP						
PS						
PVAc						
PMMA						
PC						
PA						
PUR						
PET						
PVC						
PTFE						
MF						
Polyisoprene						

Task 8 – Melting of polymer on the hob and monitoring the transition temperature: Polymers are often amorphous or only partially crystalline materials. Therefore they cannot be given a concrete and exact melting temperature but rather a range of temperatures. Moreover, and for the exploitation of polymer as a material it is undoubtedly important, before reaching the melting temperature at any temperature (or rather within a range of temperatures), polymers soften or transit into a flexible state. This temperature (range) is called the glass transition temperature and is an important parameter for the given polymer. Let us try to roughly determine this glass transition temperature.

Chemicals and aids: Heating plate or cooker, metal plate, thermocouple

Procedure: On the hob or heating plate of the cooker, we place a metal plate (which can be damaged) and on this plate we place a sample of the plastic. Temperature of the plate will be measured by a thermocouple followed by observation of the plastic sample. Once the plastic starts to soften, we record the temperature. The experiment will be performed 3x. Record the results in the table.

Polymer	Temperature of glass transition [°C]	Temperature of melting [°C]
PE		
PP		
PS		
PVAc		
PMMA		
PC		
PA		
PUR		
PET		
PVC		
PTFE		
MF		
Polyisoprene		

Activity 3.6 Properties of polymers – elasticity and cross-linking

Learning aims**:**

1) Explanation of type of polymer structure and explanation of properties of the balloon in terms of polymer molecular structure (reinforcement, extension of chains, etc.) on the basis of a simple experiment.

Materials**:**

Vaseline, a balloon (higher number is better), a long wooden skewer

Suggestion for use:

Task: Try to pull a skewer through the balloon without an immediate burst. On the basis of your knowledge about the structure (e.g. found in the Internet), try to explain the behaviour and properties of polymer

Procedure:

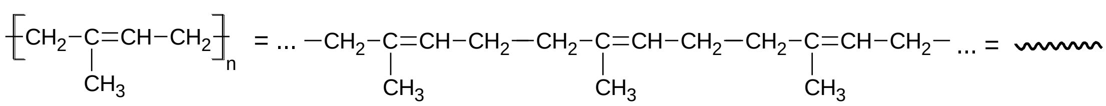
1) Inflate the balloon and tie it.
2) Dip the skewer into the Vaseline and spread over the entire length of the skewer.
3) Pull the skewer with a slow and gentle rotation against the knot of the balloon. Continue a gentle rotation of the skewer and proceed to the knot of the balloon.
4) When the skewer reaches the knot of the balloon, again, much more carefully, start a slower and gentler rotation of the skewer.
5) During the passage of the skewer through the balloon wall you can start pulling the skewer faster.
6) Try to pull the skewer across the balloon.

Discussion:

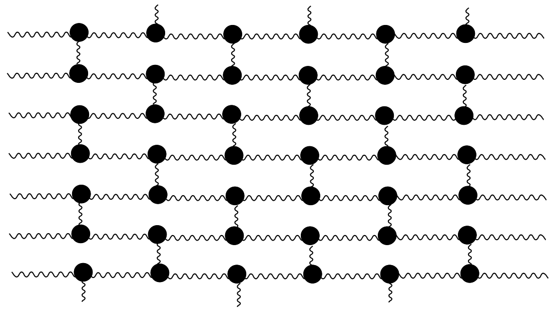
Explain the balloon behaviour, why it bursts in one case but why in principle it is possible to draw the skewer through.

Due to lower tension of the balloon near the top and the knot, it is possible to pull the skewer through the balloon without damaging it since the structure of polymer is not affected by the rupture of chains but only by their extension. During a "rougher" use of the skewer, there occurs a rupture of the polymer chains, and the balloon bursts. Forces acting on the reinforced polymers therefore influence their properties and possibilities of use.

The balloon is made from the material, which is called a reinforced polymer. I.e. that the polymeric chains, which are formed by macromolecules of a linear chain consisting of repetitive units linked by a covalent bond, are further grouped together to form a multidimensional structure.

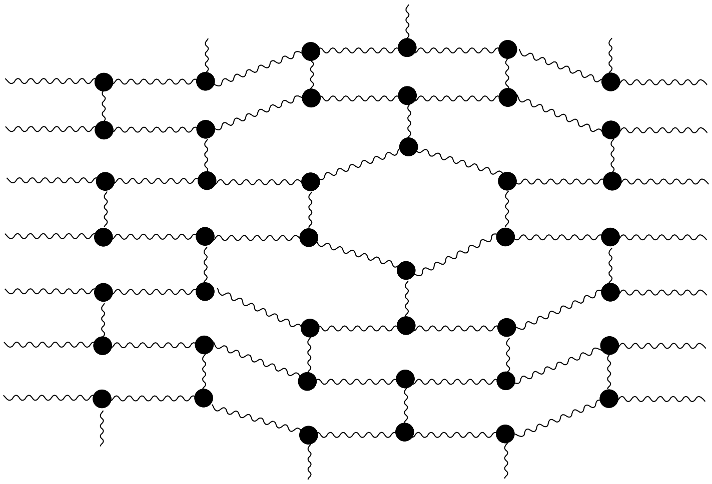


Linear polymer

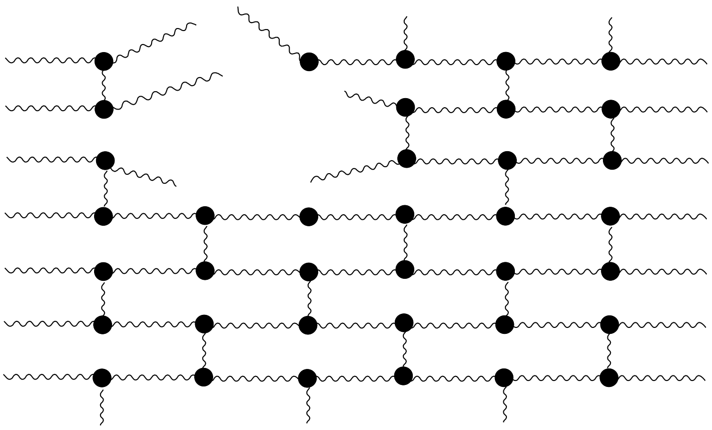


Reinforced polymer

This bond keeps the polymer molecules connected and allows the polymer extension up to a certain point where the force or tension on the lateral ligaments is to high and it leads to their breaking and the rupture of the polymer.



After extension of reinforced polymer



After rupture of reinforced polymer

Experience from implementation: the balloon should be inflated in the way that will allow its diameter being smaller than 10 cm (or in other words, shorter than the length of the skewer). The skewer should be pulled through very carefully.

a) Skewer through the balloon wall

b) Slow rotation of the skewer to penetrate through the wall

c) Skewer passage through the balloon wall

d) Skewer through the balloon

e) Removing the skewer out of the balloon

f) After the passage of the skewer the balloon slowly leaks

Students' worksheet

Properties of polymers – elasticity and cross-linking

Task 1: Explain structure and properties of rubber from the point of molecular structure.Use the following experiment: Try to pull a skewer through the balloon without an immediate burst. On the basis of your knowledge about the structure (e.g. found in the Internet), try to explain the behaviour and properties of polymer.

Chemicals and aids: Vaseline, a balloon (higher number is better), a long wooden skewer, internet, suitable literature

Procedure:

a. Inflate the balloon and tie it.
b. Dip the skewer into the Vaseline and spread over the entire length of the skewer.
c. Pull the skewer with a slow and gentle rotation against the knot of the balloon. Continue a gentle rotation of the skewer and proceed to the knot of the balloon.
d. When the skewer reaches the knot of the balloon, again, much more carefully, start a slower and gentler rotation of the skewer.
e. During the passage of the skewer through the balloon wall you can start pulling the skewer faster.
f. Try to pull the skewer across the balloon

Observation:

Results and discussion: Discuss results of the experiment.

Questions:

1) How is it possible that if we pull the skewer through the balloon slowly, the balloon do not burst, however, in the case of fast moves, it bursts immediately?

2) Why the balloon burst easier in the case of crosswise pulling the skewer through the balloon than in the case we pull the skewer directly across the balloon near the nodes?

3) Is it possible to brake the chains of the polymer?

Conclusion:

Activity 3.7 Properties of polymers – dissolution of polymers

Learning aims:

1) Understanding of structure of polymers and explanation of dissolving of polymers. Understanding of factors which influence solubility of polymers.

Materials:
Chocolate, sugar, oil, water, 4 beakers (50-100 mL), bar, tooth

Suggestion for use:
Task: Explore, whether the polymers are soluble in some solvents and what is responsible for the solubility.

Procedure:

1) Chew the chewing gum up and divide it to three parts, two smaller and one bigger. Try to save the bigger part in good condition, you will chew it again.
2) Prepare 4 beakers. Pour the oil into two beakers, then pour water also into two beakers. Try to dissolve the chewing gum in one beaker with water and, consequently, in beaker with oil. Do the same with sugar. Write down the results. In the other beakers with water and oil, try to dissolve the chocolate. Taste the water. Write down the results.
3) Take the biggest part of chewing gum and try to chew it up. Chew the chewing gum and add a chocolate. Chew it together. What happened? Write down the results.

Discussion:

Polymers usually are not very well soluble and their dissolution takes longer, because whole macromolecular chain has to be surrounded by molecules of solvent. However, it does not mean that polymers are insoluble. Some of them is possible to solve. On the other hand, we can deduce that cross-linked polymers are insoluble, because, in fact, they are "only one" molecule. Polymer in a chewing gum is polyisoprene, hence, it is formed of linear nonpolar chains. Regarding solubility, in case of polymers, the same rules as in the case of other substances are applied. Thus, nonpolar linear polymers are soluble in nonpolar solvents and polymers with polar chains and/or groups are soluble in polar solvents. Polyisoprene is nonpolar substance, hence, it is soluble in nonpolar solvents like oil, petrol etc. In the case of our experiment, the chewing gum is soluble in oil, but, it is not soluble in water. On the other hand, sugar, having a polar groups, is soluble in water but insoluble in oil. Chocolate contains cacao milk, which is a type of nonpolar oil. Hence, when we chew the chewing gum together with chocolate, the chewing gum is dissolved in cocoa milk.

What is the chewing gum? Is it polymer? What polymer?

Polymer in a chewing gum is polyisoprene, hence, it is formed of linear nonpolar chains. It is a polymer similar to a rubber.

Why the chewing gum was dissolved in a chocolate? Will be all the polymers solved in chocolate?

Polyisoprene is nonpolar substance, hence, it is soluble in nonpolar solvents like oil, petrol etc. In the case of our experiment, the chewing gum is soluble in oil, but, it is not soluble in water. On the other hand, sugar, having a polar groups, is soluble in water but insoluble in oil. Chocolate contains cacao milk, which is a type of nonpolar oil. Hence, when we chew the chewing gum together with chocolate, the chewing gum is dissolved in cocoa milk.

Students' worksheet

Dissolution of polymers

Task 1: Explore, whether the polymers are soluble in some solvents and what is responsible for the solubility.

Chemical and aids: chocolate, sugar, oil, water, 4 beakers (50-100 mL), bar, tooth

Procedure:

a. Chew the chewing gum up and divide it to three parts, two smaller and one bigger. Try to save the bigger part in good condition, you will chew it again.
b. Prepare 4 beakers. Pour the oil into two beakers, then pour water also into two beakers. Try to dissolve the chewing gum in one beaker with water and, consequently, in beaker with oil. Do the same with sugar. Write down the results. In the other beakers with water and oil, try to dissolve the chocolate. Taste the water. Write down the results.
c. Take the biggest part of chewing gum and try to chew it up. Chew the chewing gum and add a chocolate. Chew it together. What happened? Write down the results.

Observation:

Results and discussion:

Questions:

1) What is the chewing gum? Is it polymer? What polymer?

2) Why the chewing gum was dissolved in a chocolate? Will be all the polymers solved in chocolate?

Conclusion:

Activity 3.8 Identification of polymers

Learning aims:

1) On the basis of previous results the students will create a material, which will allow them the identification of the unknown sample of polymeric substance.

Materials:

Gas burner, toluene, chloroform, water, formic acid, sulphuric acid, petrol, ethanol, cyclohexane, phenol, hob or cooker, paper or white plate, two beakers of 100-150 ml, needle, and thermocouple

Samples of plastics (PE – polyethylene, PP - polypropylene, PS - polystyrene, PVAc – polyvinyl acetate, PMMA – polymethylmethacrylate, PC – polycarbonate, PA – polyamide, PUR – polyurethane, PET – polyethylene terephthalate, PVC – polyvinylchloride, PTFE – polytetrafluoroethylene, MF – aminoplastics)

Suggestion for use:

Task – identification of polymer: Within the previous activity, due to a number of experiments, you have revealed certain physical and chemical properties of some polymers. You have found out that these properties are quite varied. Try to identify the type of polymer in the unknown sample. However, prior to this, determine the strategy of how to identify the polymer in the sample and justify the individual steps. Based on this determination, work out a protocol in the form of a record containing the following parts:

a) Title of protocol: What is the subject of your work *(e.g. Identification of unknown sample of polymer)*
b) Procedure of test: in essence, a proposed strategy of identification procedure and its justification
c) Results of tests: results of the individual tests, i.e. how the sample responded to the individual tests *(e.g. into which category it belong as for its density, how it reacts in the flame – type of smoke, colouration of flame, ...)*
d) Discussion: What type of polymer it is and why – justification of your choice
e) Conclusion: Unambiguous conclusion about which polymer it is *(e.g. the studied sample of polymer is polypropylene.*

The students determine the type of polymer in the sample supplied by the teacher; however they should first determine an appropriate strategy to make the determination efficient. For this, they will use the results from the previous activity. Experiments should not therefore be experimentally demanding. An appropriate procedure can be e.g. first a performance of less selective but simple classification of polymers (e.g. classification of polymers based on their density), followed by more selective tests (hardness, solubility test and tests in the flame – colouration of the flame, smoke, charred residue, etc.). The last test can be the appearance test. Obviously there are also many other appropriate procedures; it is important for the students not to proceed randomly but they should plan and justify their procedure.

Unknown polymer identification

Task 1: On the basis of results of the preceding activities try to:

b) Choose a strategy how to determine unknown sample of polymer.
c) Create a material, which will allow the identification of the unknown sample of polymeric substance. You can use the tables acquired during preceding activities. The result can have different forms, for example a flow chart, similar graphical output or a manual for determination etc.
d) Work out a protocol in the form of a record containing the following parts:

- *Title of protocol:* What is the subject of your work (e.g. Identification of unknown sample of polymer)
- *Chemical and aids:* used chemicals and equipment
- *Procedure of the test:* in essence, a proposed strategy of identification procedure and its justification
- *Results of tests:* results of the individual tests, i.e. how the sample responded to the individual tests (e.g. into which category it belong as for its density, how it reacts in the flame – type of smoke, colouration of flame, …)
- *Discussion:* What type of polymer it is and why – justification of your choice
- *Conclusion:* Unambiguous conclusion about which polymer it is (e.g. the studied sample of polymer is polypropylene.

Chemicals and aids: gas burner, toluene, chloroform, water, formic acid, conc. Sulfuric acid, petrol, ethanol, cyclohexane, phenol, heating plate or cooker, paper or white plate, 2 beakers of volume of 100-150 mL, 8 beakers or test tubes of volume of about 25-100 mL, tip, rubber, thermocouple, sample of unknown polymer

Strategy of determination:

Identification of unknown sample of polymer:

Protocol of identification of unknown sample of polymer:

Title:

Chemicals, equipment and aids:

Procedure:

Results:

Discussion:

Conclusion:

Activity 3.9 Application of polymers

Learning aims:

1) On the basis of knowledge of polymer properties, the students should be able to deduce their application or vice versa, considering this application, they should be able to find a suitable polymer:

Materials:

Literature, the Internet, notes to activities 2 and 3.

From the selected products containing synthetic polymers, choose the two of them. Determine your requirements on these products (functional– incombustibility, strength, hardness, brittleness …; economic – low price, distribution options, …; aesthetic – possibility of colouration, processing into a desired shape, workability, …; health – no side effects). On the basis of the information obtained from the units 2 and 3 and possibly from the Internet and from the related literature, try to find a polymer appropriate for your application. Justify your choice. Refer both to positives and negatives of your choice:

Application 1: *Surface of pan*

Material requirements: *Temperature resistance, resistance to chemicals, non - sticky, good thermal conductivity, no occurrence of toxic products throughout degradation.*

Selected polymer: *PTFE – polytetrafluorothylene*

Justification: *PTFE is thermally very resistant (degrades above 250 °C, up to 250 °C there was no release of toxic vapours), which is above the usual temperature of pan surface (around 200 °C) suitable for frying. PTFE is also self - lubricating, which means that its surface is non - sticky. Due to this, fried foods do not "stick" to the pan surface, do not bake in but they bake evenly. This allows a low consumption of fat and oil (and healthier, less fatty meals). PTFE is also very resistant to acids, alkali, salts, and solvents even at higher temperatures; therefore it will not degrade due to the effects of e.g. acids or acidic substances in the food or dissolve in oil with a consequent deterioration of fried foods. The properties can be further improved by supplying additives, e.g. glass particles, which improve thermal conductivity and ensure a better thermal distribution within the pan.*
The price of PTFE is however many times higher than in the case of other polymers or also alternative materials (metals). Nevertheless, considering the fact that the alternatives are only a few and also have their disadvantages, it is evident that the higher price of the product, due to its advantages offered by the manufacturer, will be accepted. The amount of the material used will not also be so high to raise the price of the product above a reasonable level. A disadvantage could be the fact that the temperature of the pan could be, when the product is treated unsuitably, higher than 300 °C. Therefore it will be necessary to ensure (instructions for customers, choice of appropriate complaint terms, qualitative detection of temperature) a proper use of the product and avoidance of polymer degradation and damage. An evident disadvantage of PTFE is an improper wear resistance; the pan surface should therefore be appropriately treated; when working with it do not use metal items with sharp points.

Application 2: *Packaging material, e.g. yogurt cup*

Selected polymer: *PP – polypropylene*

Material requirements: *The selected polymer must not release toxic substances or react with preserved food. Because of transportation, the selected polymer must be reasonably strong, further it must be easy to process to enable a formation of any shape (because the product should be easy to sell). Packaging must not release its contents. An important requirement as for packaging will be its price, which should not exceed the price of the product. Temperature resistance is not important because the existence of the product at higher temperatures is not supposed (this will lead to damage of the packed product). On the contrary, a reasonable (i.e. lower) temperature of processing enables easy forming of polymer into a desired shape at reasonable energy costs.*

Justification: *There is a wide range of polymers; almost all of them have the required properties. Improper will undoubtedly be formaldehyde resins and aminoplastics (they can release toxic products). PTFE or PC is however eliminated due to a higher price; the cheapest polymers of appropriate properties are PE (indeed the cheapest) or PP. For PP speaks its higher strength.*

Discuss your choices with other groups. Try to oppose the choices of other groups.
Discussion can be over the properties, acceptability of price, aesthetic qualities of the product, etc.

Students' worksheet

Application of polymers

Task 1: From the selected products containing synthetic polymers, choose the two of them. Then, ask a classmate for his choices and write them down to the gray boxes bellow. Tell him your choices. Determine your requirements on these products (functional– incombustibility, strength, hardness, brittleness …; economic – low price, distribution options, …; aesthetic – possibility of colouration, processing into a desired shape, workability, …; health – no side effects). On the basis of the information obtained from the units 2 and 3 and possibly from the Internet and from the related literature, try to find a polymer appropriate for your application. Justify your choice. Refer both to positives and negatives of your choice:

Product 1: *Product 2:*

Product 1: requirements to the material of the product

Product 1: choice of the polymer and reasons

Product 2: requirements to the material of the product

Product 2: choice of the polymer and reasons

Task 2: Discuss your choices. Try to oppose to other classmates and groups.

Notes:

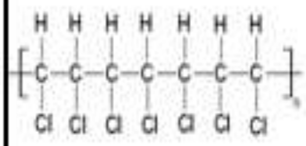
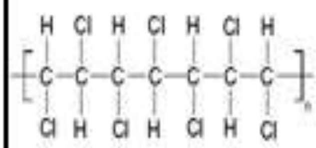
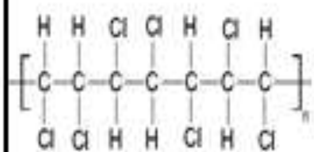
Activity 3.10 PAIRS

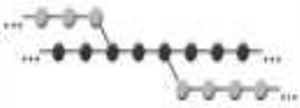
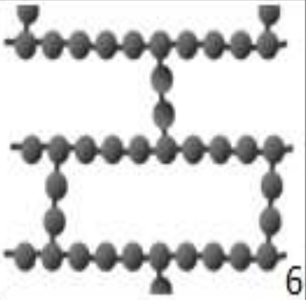
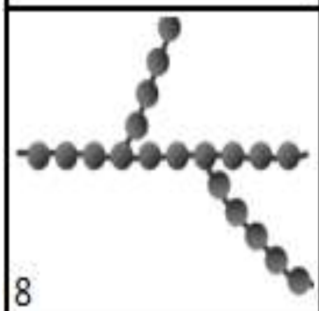
Learning aims:

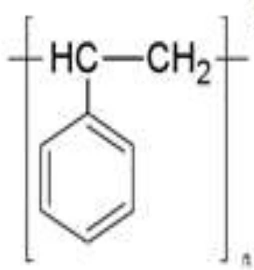
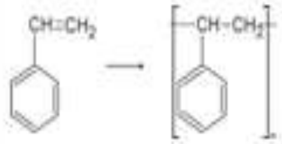
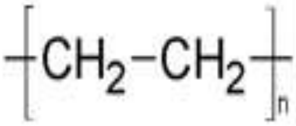
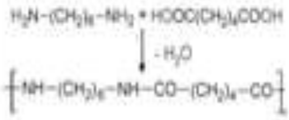
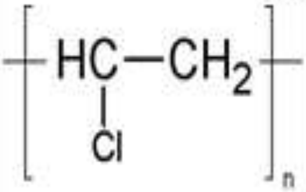
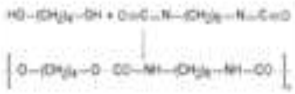
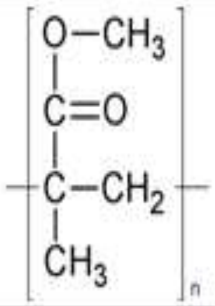
1) To learn new and reinforce the present knowledge on polymers and polymer substances using a popular game.

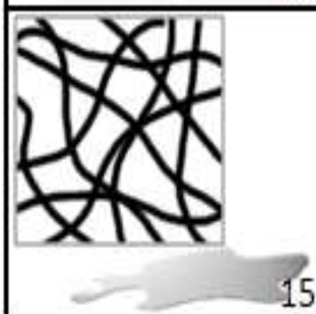
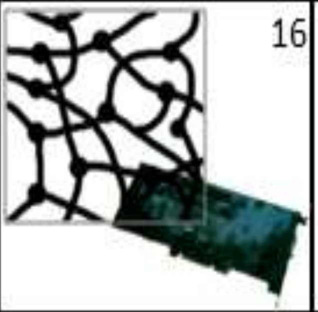
Materials and Instructions:

Print the following cards on a thick paper, cut to pieces with scissors and play the game PAIRS. What is difference? Two matching cards are not exactly the same, but there are some corresponding images, for example the polymer and its application, structure and its name etc. Follow them and try to learn as match as possible about the polymers. Enjoy!!!

 1	1 isotactic polymer	phenol plastic	 17
 2	2 syndiotactic polymer	 18	18 teflon
 3	3 atactic polymer	 19	19 chlorprene
 4	4 Statistic polymer	 20	20 homopolymer

 5	5 spacely cross-linked polymer	 21	21 Graft copolymers
 6	6 cross-linked polymer	 22	22 Statistical copolymers
 7	7 linear polymer	 23	23 block copolymers
 8	8 Syndiotactic polymer	 24	24 alternating copolymers

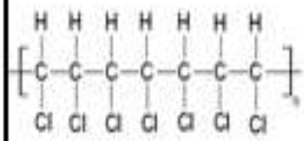
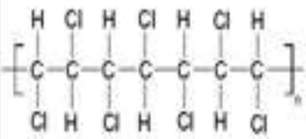
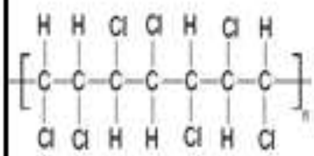
 9	9 	 25	25 polymerization
 10	10 	 26	26 polycondensation
 11	11 	 27	27 polyadition
12 	 12	 28	28 crystalline polymers

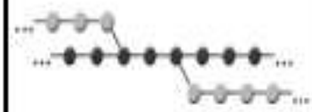
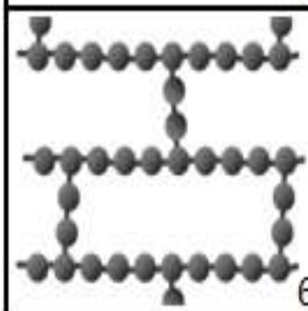
13 	13 PA6	 29	29 Amorphous polymers
 14	14 PA6,6	 30	30 partly crystalline polymers
 15	15 thermoset	 31	31 recyclation
 16	16 thermoplastics	 32	32 natural polymer

Students' worksheet

PAIRS?

Task 1: Print the following cards on a thick paper, cut to pieces with scissors and play the game PAIRS. What is difference? Two matching cards are not exactly the same, but there are some corresponding images, for example the polymer and its application, structure and its name etc. Follow them and try to learn as match as possible about the polymers. Enjoy!!!

 1	1 isotactic polymer	phenol plastic	 17
 2	2 syndiotactic polymer	 18	18 teflon
 3	3 atactic polymer	 19	19 chlorprene
 4	4 Statistic polymer	 20	20 homopolymer

 5	5 spacely cross-linked polymer	 21	21 Graft copolymers
 6	6 cross-linked polymer	 22	22 Statistical copolymers
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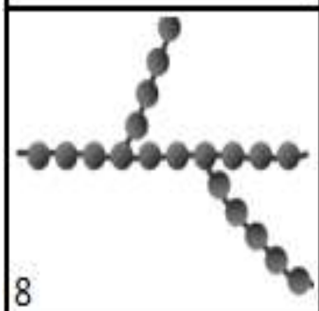
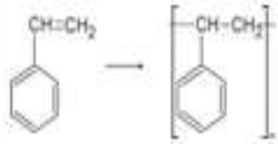
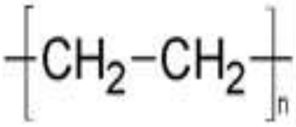
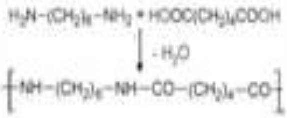
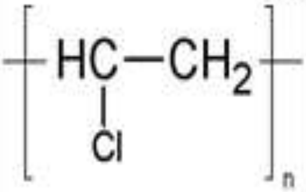
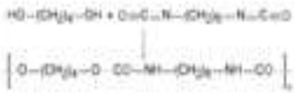
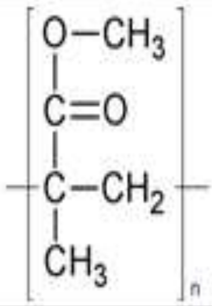
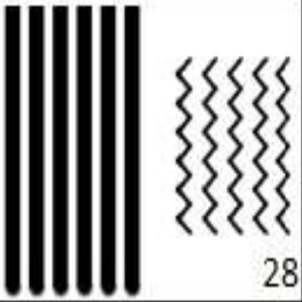
8 	8 Syndiotactic polymer	 24	24 alternating copolymers

 9	9 	 25	25 polymerization
 10	10 	 26	26 polycondensation
 11	11 	 27	27 polyadition
12 	 12	 28	28 crystalline polymers

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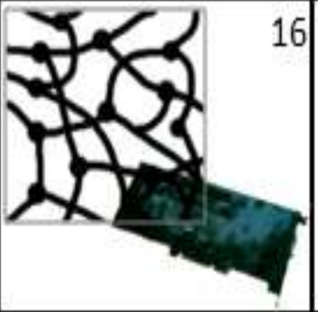
 16	16 thermoplastics	 32	32 natural polymer

Activity 3.11 Where can I find the polymer?

Learning aims:

1) On the basis of knowledge of polymer properties, the students should be able to deduce their application or vice versa, considering this application, they should be able to find a suitable polymer. Hence, the students should be able to find the corresponding polymer to a product and vice-versa.

Materials: Literature, internet, notes to the preceeding activities, worksheets.

Instructions:
Match the corresponding polymer and its application or product. Write the names of the polymers into the boxes bellow the corresponding product:

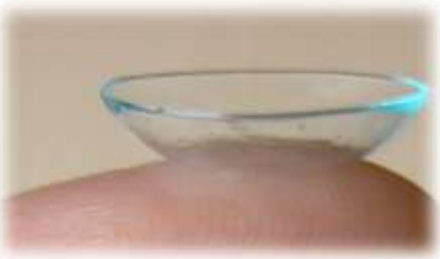
Polymethymetacrylate, polyisoprene, polystyrene, polyethylentereftalate, polyethylene, polyvinylchloride, melaminoplastics, Nylon or Silon

polyethylene

polystyrene

polyisoprene

polyvinylchloride



polymethylmetakrylate

polyethylentereftalate

Nylon or Silon

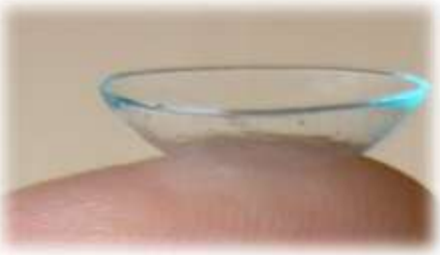
melaminoplastics

Students' worksheet

Where can I find the polymer?

Task 1: Match the corresponding polymer and its application or product. Write the names of the polymers into the boxes bellow the corresponding product:

Polymethymetacrylate, polyisoprene, polystyrene, polyethylentereftalate, polyethylene, polyvinylchloride, melaminoplastics, Nylon or Silon



<u>Activity 3.12 Estimate and discuss some information regarding polymers</u>

<u>Learning aims</u>:

1) Follow and understand employment of polymers in common life and their importance and applications in everyday life.

<u>Materials</u>:

Literature, internet, notes to preceding activities, worksheet.

<u>Instruction</u>:

Try to find (or estimate) the answers to the following 6 questions, your answers write down in boxes below and give the reasons for the answers. Consequently, find the correct information in the internet and discuss.

Question no. 1: When the European people met the natural rubber for the first time?

In 1493, when C. Columbus and his sailors followed Indians to play with elastic ball made from sap of Hevea braziliensis tree.

Question no. 2: When was the polyamide fiber synthetized for the first time?

In 1938, when American scientists tried to create a material which could substitute cotton and linen, materials, which squeeze and can be easily worn out. Nylon become quickly, in 1939, commercial hit, especially in the case of ladies, when nylons substituted stocking from nitrocellulose. In 1941, USA entered the WWII, and whole production of Nylon was consumed by war industry (parachutes, tires, tents, ropes etc.).

Question no.3: What factory is the biggest producer of polymers in the Czech Republic? Why?

The biggest producer of polymers in the Czech Republic is Unipetrol Litvínov company, where especially PE and PP are produced, ca. 600 tis. tons a year. There is a long-time tradition of production of PE. Another important factor is, that PE is mostly used as a wrapping material. To this area of usage, majority of plastics is used in the CR.

Question no. 4: What is (approximately) worldwide production of plastics (in years around 2010). Is it large production or not? Compare with other commodities!

World production of synthetic polymers is about 240 mil. tons. Production of iron is much bigger, ca. 1,414 mld. tons. On the other hand, polymers have much lower (about 8x) density, from this point of view, the difference is more reasonable. In a cars, the synthetic polymers forms 10-20% of their weight and the percentage still increases.

Question no. 5: Sort the following areas of application of synthetic polymers regarding one-year consumption and estimate percentage of them! - cars, constructions and buildings, wrapping, special applications.

wrapping 38%, construction, buildings - 21%, cars – 7%, special applications (OLEDs etc.) – 2%. 40% are short-term applications and 60% are long-term applications.

Question no. 6: Sort the following polymers by its one-year consumption! Estimate their percentage in consumption! – polyethylene, polyetylentereftalate, polyvinylchloride, polystyrene, polypropylene.

polyethylenes 28%, polypropylene – 18%, PVC – 12%, PS – 8% a PET – 7%.

Notes to discussion:

Students' worksheet

Estimate and discuss some information regarding polymers

Task 1: Try to find (or estimate) the answers to the following 6 questions, your answers write down in boxes below and give the reasons for the answers. Consequently, find the correct information in the internet and discuss.

Question no. 1: When the European people met the natural rubber for the first time?

Correct answer:

Question no. 2: When was the polyamide fiber synthetized for the first time?

Correct answer:

Question no.3: What factory is the biggest producer of polymers in the Czech Republic? Why?

Correct answer:

Question no. 4: What is (approximately) worldwide production of plastics (in years around 2010). Is it large production or not? Compare with other commodities!

Correct answer:

Question no. 5: Sort the following areas of application of synthetic polymers regarding one-year consumption and estimate percentage of them! - cars, constructions and buildings, wrapping, special applications

Correct answer:

Question no. 6: Sort the following polymers by its one-year consumption! Estimate their percentage in consumption! – polyethylene, polyetylentereftalate, polyvinylchloride, polystyrene, polypropylene.

Correct answer:

Notes - discussion:

Activity 3.13 Pointing out the importance of polymers in everyday life

Learning aims:

1) In a creative way to express and comprehend the importance of polymer for life of a human (or society) and their existence in the surrounding world

Suggestions for use:
Task: Write a text or essay of 2-4 pages entitled "Life with polymers" or "Life without polymers"

Still we are not plastic?

Mr N., a robust man in his sixties, finally digs in the morning out of blanket containing hollow fibres and with disgust throws it away. The blanket is light, pleasant to touch, but not very warn and in the cold mornings like this one he blames himself for being imprudent when his old good feather blanket flew out of the house. He rubs his eyes to see better but even this cannot help; therefore he rather reaches his spectacles, which are nearly entirely made of plastic, including the frames but also the "glasses". He could have a real glass, but with his six dioptres it would be too heavy and push his nose. Finally he stops the annoying sound coming from the alarm clock, which still remembers the time before his marriage and divorce. The old good alarm clock made of the first plastic still works so why to change it? From his bed he slides into the slippers knitted by his mother from viscose yam. He slowly shuffles to the bathroom where he cleans his few remaining teeth with a plastic toothbrush. He squeezes the toothpaste from the plastic tube, shoots water into the plastic cup, gurgles and puts on the dentals made of plastic. He combs the remnants of greyish hair with a plastic comb and shuffles back to the kitchen. On the plastic watch hanging above the door he finds out that he should increase the speed of getting dressed because otherwise he will not be on time to catch his means of transport. That is why he warms up a little water in the electric kettle to have some coffee, which he is going to drink in a hurry, but a few drops fell on his nylon shirt, which he decides to rather replace by a polyester T-shirt. He puts on his tesil trousers, takes up his plastic bag and says goodbye to a guinea pig Joe, the last remaining member of the family left after the divorce. Joe, instead of paying attention to him, is running in a plastic wheel. In the hall on the linoleum he slips into his shoes with an artificial sole, grabs a bunch of keys with plastic distinguishers and joins the bustle of the city. In front of the house he starts to solve the problem, which means of travel should be used. Shall he use a car of Trabant make, which with its plastic body looks, even after these 30 years, still preserved or to be pushed in the bus where he will hold a metal rod coated with a cable sleeve? Finally he decides to use a train where the plastics will pursue him minimally. What a mistake but he himself knows. He leaves the train after pressing a plastic button. In a crowd of people he leaves the station and looks around the street. Suddenly something hits his head, turns it so abruptly that his spectacles flip from his head and land on a dirty ground. He quickly picks them up exploring the surrounding to look for the attacker. Nearby he can see an empty bottle of sparkling water, which keeps being a toy of the wind that starts to rise. Mr N. shakes his head over some reckless fellows, grabs the bottle and throws it into the nearest container for plastics and checks the time on his watch. There is nothing to wait for, he slowly starts walking to work, on the way he passes the bakery where the shop assistant puts a couple of rolls for the customer into a polypropylene bag. For a while he is stalling at the traffic lights until a green little figure on the plastic background permits him to cross the street. Rather tired he opens the door of the workshop where he works. He puts on his overall with admixture of carbon and switches on his desktop computer (PC), a PC plastic case is *resonating a little but it always does when the hard disc starts working. Immediately afterwards Mr N. inserts a CD (also plastic) into the computer and starts the programme. Through a plastic window with plastic glass he is looking at a huge hall where, by means of advanced technology, all plastics are sorted. Time is passing by and suddenly there is lunchtime. Mr N. stops the process of sorting the plastics, puts on a nylon coat and leaves for his favourite lunch. He is looking forward to fruit dumplings served on a plastic plate and hot cocoa in a mug with a plastic saucer. When leaving an excellent lunch he meets the director's secretary, apparently with new silicone breasts. In the sanctuary of his small office he enjoys a couple of last undisturbed moments in his favourite plastic armchair. A horn sounds and the idyll is over, again a plastic data medium starts to turn and a new working process of sorting starts running. Plastic stoppers for the container N. 1, polypropylene bags for container N. 2, etc. The phone is rattling on the desk; Mr N. picks up a plastic receiver and tries to explain something to the person at the other end. The call ends, a sorting line slowly stops working. Today's shift is ending; several hundreds of plastics reached its destination and can again continue to serve after further treatment. Mr N. takes off his overall, takes up a plastic soap dose and leaves to have a shower. On his way home he makes a call from his mobile phone, which is more of plastic than anything else. After the call is finished, he inserts a plastic token in to the cart, he immediately heads to the cooled food in a PVC dish, at the baker's department he adds one bread roll and on the way to the cash desk he also takes a bottle of beer. When he is finally queuing, he starts looking for some money but does not have a single penny. There is no other way than to pull out a barex wallet, in which there is altogether thirty crowns and a plastic VISA. The shop assistant, having a look at the shopping and the card, rolls up her eyes, grabs it and waits until Mr. N. enters his PIN, while she is tapping the terminal with her artificial red painted nails. After one queue there is another. A bus station of suburban transportation is stuffed with people and Mr. N. asks himself where all these people are travelling. The bus stops at the station and people are attacking the front door; only by fortune they have not smashed from his hand a plastic Open Card prepared to use. Appropriately tired he enters his empty flat, turns the light on with a plastic switch, leaves the bag in the kitchen on the plastic tablecloth and warms up his evening meal in the microwave oven. Meanwhile he switches on an LCD TV, where a football match is currently running on the artificial grass. When looking at football players, his knee starts hurting; it will need an operation in the horizon of a couple of years. Time is relentless and also fooling about a plastic ball with his eight-year old grandson was not a wise thing to do. Watching of the game is interrupted by a peep of the microwave oven. For the goulash he opens a beer in a plastic bottle and on the plastic worktop he cuts yesterday's bread. On the plastic tray he adds a plastic glass and cutlery and heads to the living room where, while eating, he watches the game and, at half past seven, he switches the programme by a plastic remote controller to learn what has happened in the modern plastic world. The TV presenter's voice is sprawling around announcing that finally the mountaineers lost a week ago in the Alps have been found and only due to their lightweight waterproof equipment with a good thermal insulation they were able to survive. Mr. N. shakes his head and continues listening. "Next news can amuse some of you but it is not a joke…" the silence is broken by the presenters voice "…several hospitals are announcing a lack of plastic transfusion and infusion sets and disposable plastic gloves. Instead of these things they were sent silage tilts (PE) and mulching fabric (PP)." Mr. N. bursts laughing, he is going to take away the garbage and take a cookie from the plastic bag, which he feels like eating. On his way back he sits down at his PC to have a look if someone sent him an e-mail or not. When writing his password he drops crumbs onto a plastic keyboard. A new virtual world appears in front of him. On the screen he can see a photo of his grandson taken by a plastic digital camera, the photo from the same day where his grandson is together with his son and daughter in law, was printed on the plastic printer* *and now it is displayed behind Plexiglas. He starts yawning. He quickly checks the e-mails, nothing interesting, only a few special offers for plastic optical fibres, air wheels to protect from bedsore and a flyer for the sale in the Outlet. E-mail with a joke about a lady who refused to board the plane after her grandson had said that the plane components were also made of plastic. Normally he would probably laugh about it but not after a tough day today; the only thing he is longing for is to go to bed. He grabs for the controller and wants to switch off the TV when he is stopped by a voice of the presenter who is just announcing that today even a lot of men undergo plastic operations. Mr. N. turns off both the TV and the computer and heads for the bathroom where for the second time today he uses a plastic tooth brush. Looking in the mirror he starts to observe himself and examine whether we are still of flesh and blood. To his relief we are. Toothless, in his pyjamas, he goes to see the last living being that does not consider him to be a freak. Joe is chewing his leaf given to him three hour ago. When Joe sees Mr.N., he will look at him and Mr. N. would not give anything for it that Joe would like to tell him the leaf is "plastic". With "Good bye, chap", he is leaving for his chilly bed where he is awaited by "his blanket called frostie", which is a familiar name of his blanket from hollow fibres. Before he takes off his light plastic spectacles, he orders his alarm clock and finally, after a long exhausting day, he buries under the blanket where he is going to dream about another plastic world.*

Discussion:
Read each other's essays and discuss the world of polymers. Are they really so important for our lives or could we do without them? Which items made of synthetic polymeric substances would you gladly give up and which, on the contrary, you would not. Which materials would you recommend to replace them? What would it mean for us?
Probably, we would able to substitute majority of polymer substances. On the other hand, it would cause lack of traditional materials, increase of prices, increase of weight of the products and, sometimes, the esthetical value of the product.

Significance of polymers in common life

Task 1: Write an essay (2 up to 4 pages). Theme is „Life with polymers“ or „Life without polymers“.

Title of the essay:

Essay:

Task 2: Read each other your essays and discuss the "world of polymers". Are they really so important or not? Which products made from synthetic polymers are not important for you and, the other way around, which are really important for you. What materials would you use instead of them? What would be a consequence?

Notes to discussion:

European Science and Technology in Action Building Links with Industry, Schools and Home

Polymers around us

B – Classroom Materials

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Students' worksheet

Materials around us and what plastics and polymers are

Task 1: Select 10 random items; write them into the gray box bellow.

Task 2: For the products listed, highlight (into white small box prior to the name of the item) those products, where the materials they are made from, contain polymers! What part of the item is made from polymer (write into a box right to the name of the item)? Discuss!

--

Task 3: You have roughly determined which products contain a polymer. But what is actually a polymer? Create the best possible definition of polymer. You can also use other sources such as e.g. subject-field or other literature or the Internet. If you use a definition already created by somebody else, you have to be able to explain it to the others using examples and be ready to accept their criticism or the revelation that you do not understand the definition ☹!

Polymer definition:

Explanation and examples:

Find answers to the following questions! Use internet, suitable references, literature and discussion!

a) Is the term plasticssynonymfor the term polymer? Try to explain the difference between these concepts!

b) What is a synthetic polymer and which of the selected products contain a synthetic polymer?

Students' worksheet

Cross-linking of polymers

Task 1: Accomplish and interpretthe following experiment, preparation of polymercalledGluep.

Chemicals and aids: borax, twobeakers (one smaller and one bigger), whiteglue, balances, hot water, glassbar, dyes, spoon, cloth

Procedure:

1) Dissolve ca1 g of borax in 25 mL of hot water in a beaker and well stir up to complete dissolution of borax.
2) Dissolve 10 mL of white glue in 5-6 mL of hot water in the second beaker and add few drops of selected dye. Alternatively, you can take liquid glue. Well mix.
3) Add slowly borax solution to mixture of water and glue in the second beaker and stir.
4) A clod is formed. Remove it, dry it and compact it in palms for few minutes.
5) Play few minutes with formed polymer, follow its mechanical properties.

Observation:

*Results and discussion:*interpret the results!

Questions – help for discussion:

1) You know that white glue is linear non-cross-linked polymer. What happened after addition of borax?

2) How the properties of formed polymer changed?

3) Why is white glue the glue? What is the mechanism of glue effect?

Conclusion:

Students' worksheet

Properties of polymers – elasticity and cross-linking

Task 1: Explain structure and properties of rubber from the point of molecular structure. Use the following experiment: Try to pull a skewer through the balloon without an immediate burst. On the basis of your knowledge about the structure (e.g. found in the Internet), try to explain the behavior and properties of polymer.

*Chemicals and aids:*Vaseline, a balloon (higher number is better), a long wooden skewer, internet, suitable literature

Procedure:

6) Inflate the balloon and tie it.
7) Dip the skewer into the Vaseline and spread over the entire length of the skewer.
8) Pull the skewer with a slow and gentle rotation against the knot of the balloon. Continue a gentle rotation of the skewer and proceed to the knot of the balloon.
9) When the skewer reaches the knot of the balloon, again, much more carefully, start a slower and gentler rotation of the skewer.
10) During the passage of the skewer through the balloon wall, you can start pulling the skewer faster.
11) Try to pull the skewer across the balloon

Observation:

*Results and discussion:*Discuss results of the experiment.

Questions – help for discussion:

1) How is it possible that if we pull the skewer through the balloon slowly, the balloon do not burst, however, in the case of fast moves, it bursts immediately?

2) Why the balloon burst easier in the case of crosswise pulling the skewer through the balloon than in the case we pull the skewer directly across the balloon near the nodes?

3) Is it possible to brake the chains of the polymer?

Conclusion:

Students' worksheet

Dissolution of polymers

Task 1: Explore, whether the polymers are soluble in some solvents and what is responsible for the solubility.

*Chemical and aids:*chocolate, sugar, oil, water, 4 beakers (50-100 mL), bar, tooth

Procedure:

1) Chew the chewing gum up anddivide it to three parts, two smaller and one bigger. Try to save the bigger part in good condition, you will chew it again.
2) Prepare 4 beakers. Pour the oil into two beakers, then pour water also into two beakers. Try to dissolve the chewing gum in one beaker with water and, consequently, in beaker with oil. Do the same with sugar. Write down the results.In the other beakers with water and oil, try to dissolve the chocolate. Taste the water. Write down the results.
3) Take the biggest part of chewing gum and try to chew it up. Chew the chewing gum and add a chocolate. Chew it together. What happened? Write down the results.

Observation:

Results and discussion:

Questions – help for discussion:

1) What is the chewing gum? Is it polymer? What polymer?

2) Why the chewing gum was dissolved in a chocolate? Will be all the polymers solved in chocolate?

Conclusion:

Students' worksheet

Polymer properties

The following list can help you to get the samples of polymers. The most spread polymers are mentioned as well as some typical items made from them (in brackets, the recycling number of some polymers is also mentioned – the recycling number is written on some products to make their recycling easier:

Polymer	**Code**	**Recycling number**	**Note**	**Polymer**	**Code**	**Recycling number**	**Note**
polyetylene	PE	2 and 4		polyuretane	PUR	x	
Polypropylene	PP	5		polyethylentereftalate	PET	1	
Polyvinylacetate	PVAc	x		Polyvinylchloride	PVC	3	
polymetylmetakrylate	PMMA	x		polytetrafluorethylene	PTFE	x	
polycarbonate	PC	x		aminoplastics	MF	x	
polyamide	PA	x		polystyrene	PS	6	

PE – polyethylene (2 a 4) - foil, packaging, plastic greenhouses for growing plants, plastic greenhouses for silage pits, dishes – sieves, strainers, cups, cosmetics packaging

PP – polypropylene (5) – medical aids (e.g. syringes, urinals…), metal tools handles, storage bottles for chemicals, packaging of makeup removers, ointments, drops, packaging material (boxes, yogurt cups, etc.)

PS – polystyrene (6) –softened PS - insulation materials for thermal insulation of houses and structures, mechanical and acoustic insulating packaging materials, protective packaging for electronics, thermos packaging; hardened PS - CD covers, videocassettes, packaging for the so-called "black electronics" and for pressing the kitchen items – dishes (from yogurt and cheese), graters, hangers, bowls, cheap and durable cladding tiles, model airplanes and boats, toys

PVAc – polyvinyl acetate – painting materials (trade name Latex), adhesives, translucent roofing or dental implants

PMMA – polymethylmethacrylate - shields and goggles and helmets, environment for preservation of preparations, replacements of teeth, joints and cartilages, spectacle glasses, contact lenses, cuvettes, aquariums, etc.

PC – polycarbonate – CDs and DVDs (data area layer), insulator in electronics, polycarbonate plates, instrument covers (mp3 players), lenses, components of cameras, video cameras, flashes, etc. (http://www.koplast.cz/ostatni-termoplasty-popis-termoplastu-0/)

PA – polyamide – sprockets, bearings, covers, colour foils, tights, dental floss, racket strings, parachutes, ropes, synthetic textile fibres (e.g. layer in Gore-Tex)

PUR – polyurethane – insulation (PUR foam),molitan, artificial leather (e.g. barex), textile fibres (lycra), toys, mattresses, upholstery filling

PET – polyethylene terephthalate (1) - synthetic textile fibres, tape foils, packaging for beverages (PET bottles) and foodstuffs and other liquids

PVC – polyvinylchloride (3) – sewage piping, consumer goods, water containers and similar products (cans, etc.)

PTFE – polytetrafluorothylene – surfaces of pans; ironing surfaces, ski bases, medical implants (seldom rejection by a human body), protective garments (e.g. for fire-fighters), apparatuses for chemical industry, electrical insulation products, etc.

MF – aminoplasticss – painting materials, adhesives, insulators, for production of consumer goods (e.g. dishes), electro technical material, lining (e.g. Umakart)

Polyisoprene – stoppers, tyres, constructional components of transportation means, condoms, lubricating rubber, etc.

Chloroprene – wetsuits

Task 1 – Appearance test:

Polymer can be characterised by appearance according to the shape of the product (foil, fibres, moulding, …). It is natural that the products can be of different appearance and shape in spite of the fact that they are made from the same polymer. Nevertheless, this information can provide us with valuable data. E.g. from some polymers, it is nearly impossible to make a foil, or foils are not made from them. If, therefore, the product is a foil, it is probably made from (the previously referred polymers) PP, PS, PVC or PE. Some polymers cannot be made transparent or colourless (phenolic plastics) etc.

Completing the tablebellow depends on the samples delivered. Its main importance lies in the fact that polymers differ from each other in their properties and cover an entire spectrum of appearance, shapes and properties.

Do the appearance test with the sample of your polymer.Describe thoroughly the appearance and shape of the product in the following table. It is possible to tick more than one option. Optical properties shall be determined as follows; in the distance of about 1 cm behind the sample place the text and according to its visibility through the sample determine its transparency:

Polymer	Shape of the product: foil, fibre, moulding	Optical properties: transparent, transluent, opaque	Colouring: transparent, coating	Opacity: bright, matt	Roughness: smooth, rough	adhesiveness: sticky, non-sticky	feel: waxy, soft, hard
PE							
PS							
PC							
PET							
PVC							
PTFE							

Task2 – test of density: Do a test of density of polymerand divide the polymer samples into three groups based on the comparison with water(density is 1,00 g·cm^{-3}) and chloroform (density is 1,50 g·cm^{-3}).

Chemicals and aids: chloroform, water, 2 beakers of 50 -150 mL volume

Procedure: Pour water into one of the beakers and chloroform to the other (work in a fume hood!!!). Throw a sample of plastic gradually into both of the beakers and observe if it is immersed or remains on the surface. Then show, in the following table, the given plastic within the range of densities:

Polymer	**0-1,00 g·cm^{-3}**	**1,00 -1,50 g·cm^{-3}**	**>1,50 g·cm^{-3}**
PE			
PS			
PC			
PET			
PVC			
PTFE			

Task 3 – Resistance to chemicals, solubility test: Try to find a chemical or solvent in which the given polymer can dissolve.

Chemicals and aids: toluene, chloroform, water, 3 beakers or test tubes of approximate volumes of 25-100 mL.

Procedure: Sprinkle the sample of plastic with a solvent and observe (after ca. 60 seconds), if the plastic is sticky. Then the test can be considered as positive. On the basis of your exploration, fill in the following table:

Polymer	**toluene**	**chloroform**	**water**
PE			
PS			
PC			
PET			
PVC			
PTFE			

Task 4 – flame test: Based on the polymer composition, the given sample of polymer exerts a typical behavior manifested through flame colouration, odour, burning (flammable vs. non-flammable), smoke, etc. You can also assess the rest of the sample whether it is charred, brownish, almost unchanged or e.g. swollen.

Chemicals and aids: gas burner (methane or propane-butane), chemical pliers

Procedure: Take you sample by chemical pliers and insert it into a flame and follow how it is easy to set the sample on fire. Consequently, with your samples of polymers, observe their behaviour in the flame and after their removal from the flame according to the following instructions:

Ease of ignition of the sample:

a) Sample is easy to ignite
b) Is not easy to ignite

Flammability – sample after ignition and removal from the flame:

b) Continues to burn until it stops burning,
c) Slowly extinguishes and is not capable of continuous burning and after removal from the flame it extinguishes at different rate
d) Flammable only in the flame but after removal it immediately extinguishes; or non-flammable, it only melts in the flame but does not burn at all

Smoke – throughout burning the smoke is or is not produced, a character of smoke is also observed; it depends on the chemical structure of polymer and additives (added substances – initiators, plasticizers, etc.) of the polymer. Smoke is observed looking against a sheet of paper or other white mat:

a) Thick black sooty smoke
b) Not apparent or little apparent smoke
c) Intensive and dark – dark colour of smoke is evident

E.g. polymers with aromatic nuclei in the chain (PS, PC) produce a thick black sooty smoke. Polymers that do not contain double bonds with single carbonaceous chain (polyolefines, PE, PP) do not release smoke when burning.

Odour of smoke after removal of the sample from the flame: A chemical composition and a structure of polymer influence the nature of substances that are released during burning or depolymerisation or degradation of polymer in the flame. Odour of some of these substances can be characteristic. Immediately after removal from the flame, we carefully and appropriately sniff and identify odour. It can be: a) Paraffin-like - (similar to the smell of burning candle), b) acid, c) styrene, d) dentacryl, e) honey-like, f) phenolic, g) after the charred horn, h) pungent, i) amine, k) undefined.

Character of charred residue – after removal of sample residue from the flame, the sample exerts a characteristic nature corresponding to its chemical composition. The sample can e.g. only melt or burn out and melt or it leads to its degradation with the occurrence of other coloured substances. E.g. polyolefins are easy to burn and they melt without occurrence of coloured products; the other parts of material have a rough surface due to swelling with releasing gases, sometimes soot occurs, which gives colour to the polymer residue (polymers with aromas). The burning sample is removed from the flame and carefully extinguished. The charred residue should be explored in terms of colour and further exploration is done by touch (touching by fingers). Subjective observations are recorded.

We can distinguish several degrees of the appearance of charred residue:

a) Smooth, no changes or brownish colour
b) rough, brownish colour
c) black or prevailing black
d) smoky – soot from the sample rubs against the skin
e) smoulders and leaves ash

After completing all the experiments in the flame, fill up the following table:

Flame test results:

Polymer	*Ease of ignition*	Flammability	Smoke	Odour	Appearance of charred residue	Notes, other observations
PE						
PS						
PC						
PET						
PVC						
PTFE						

Students' worksheet

Unknown polymer identification

Task 1: On the basis of results of the preceding activities try to:

a) Choose a strategyhow to determineunknown sample of polymer.
b) Create a material, which will allow the identification of the unknown sample of polymeric substance. You can use the tables acquired during preceding activities. The result can have different forms, for example a flow chart, similar graphical output or a manual for determination etc.
c) Work out a protocol in the form of a record containing the following parts:

- *Title of protocol:* What is the subject of your work (e.g. Identification of unknown sample of polymer)
- *Chemical and aids:* used chemicals and equipment
- *Procedure of the test:*basically, a proposed strategy of identification procedure and its justification
- *Results of tests:* results of the individual tests, i.e. how the sample responded to the individual tests (e.g. into which category it belong as for its density, how it reacts in the flame – type of smoke, colouration of flame, …)
- *Discussion:* What type of polymer it is and why – justification of your choice
- *Conclusion:* Unambiguous conclusion about which polymer it is (e.g. the studied sample of polymer is polypropylene).

Strategy of determination:

Identification of unknown sample of polymer:

Protocol ofidentification of unknown sample of polymer:

Title:

Chemicals, equipment and aids:

Procedure:

Results:

Discussion:

Conclusion: