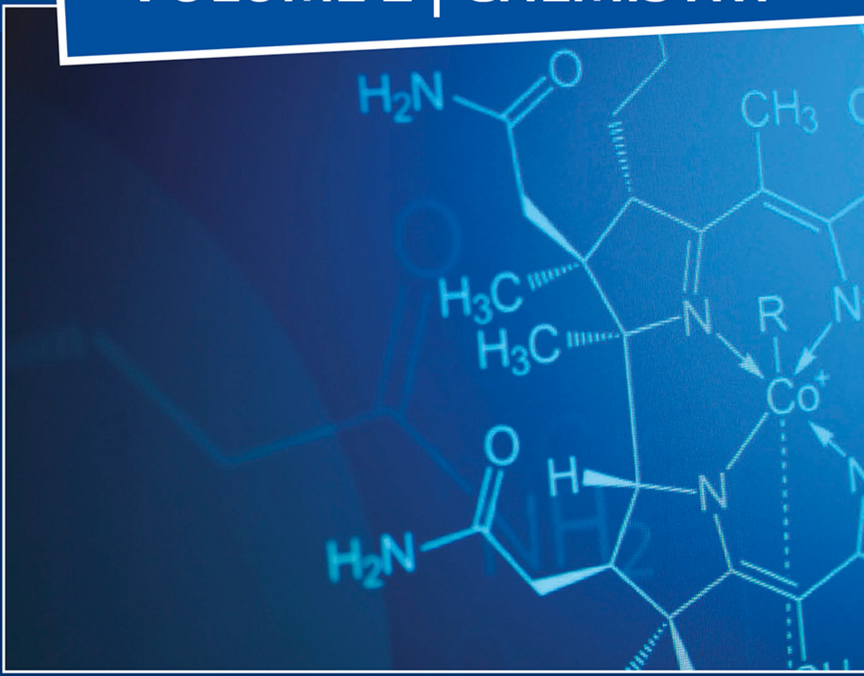
Establish

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

VOLUME 2 | CHEMISTRY



ESTABLISH IBSE
Teaching & Learning Units:

Exploring Holes
Chemical Care
Cosmetics
Plastic & Plastic Waste
Chitosan – Fat Magnet?

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Teaching & Learning Units

Volume 2

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SEVENTH FRAMEWORK PROGRAMME | SCIENCE IN SOCEITY
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European Research Area

This teaching and learning resource is presented in four volumes and has been produced within the scope of the ESTABLISH Project, which has received funding from the European Union’s Seventh Framework Programme for research, technological development and demonstration under grant agreement no 244749 (2010-2014).

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ABOUT ESTABLISH

ESTABLISH is a pan-European project funded by the European Union's Seventh Framework Programme (FP7) involving fourteen partners from across eleven countries (Ireland, Sweden, Poland, Czech Republic, Malta, Slovakia, Estonia, Italy, Germany, Netherlands, Cyprus). The aim of the ESTABLISH project is to promote and facilitate the use of inquiry-based approaches in the teaching and learning of science and technology across Europe with second level students (ages 12-18 years).

Through the collaborative efforts of these partners, a series of 18 inquiry-based science education (IBSE) teaching and learning units have been developed through piloting and trialling with teachers in the classroom. These units form the core resource for the implementation of ESTABLISH teacher education programmes.
These booklets provide background information for teachers on the ESTABLISH approach to IBSE and presents several of these units which focus on particular chemistry-related themes selected to be appropriate for the second level science curriculum.

Participating Institution	**Country**
Dublin City University	Ireland
AG Education Services	Ireland
Umea Universitet	Sweden
Uniwersytet Jagiellonski	Poland
Univerzita Karlova v Praze	Czech Republic
Acrosslimits Limited	Malta
Univerzita Pavla Jozefa Safárika v Košiciach	Slovakia
Tartu Ulikool	Estonia
Universita degli Studi di Palermo	Italy
Malmö University	Sweden
Leibniz-Institut fuer die Paedagogik der Naturwissenschaften und Mathematik an der Universitat Kiel	Germany
Centre for Microcomputer Applications	Netherlands
Martin Luther Universitaet Halle-Wittenberg	Germany
Frederick University	Cyprus

These materials serve as exemplary materials for science teachers and instructors of teacher professional development to experience the benefits of inquiry-based science education approach and are offered openly to inspire, guide and stimulate the further development of IBSE resources and practices. Electronic versions of these units and associated classroom materials are available openly for download from the project website at www.establish-fp7.eu and at www.castel.ie/establish.

The ESTABLISH project (2010-2014) is coordinated by Dr. Eilish McLoughlin, Dr. Odilla Finlayson, Dr. Sarah Brady and Dr. Deirdre McCabe from the Centre for the Advancement of Science and Mathematics Teaching and Learning (CASTeL) at Dublin City University (DCU).

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EXPLORING HOLES

The development of this unit has been led by the ESTABLISH partners:

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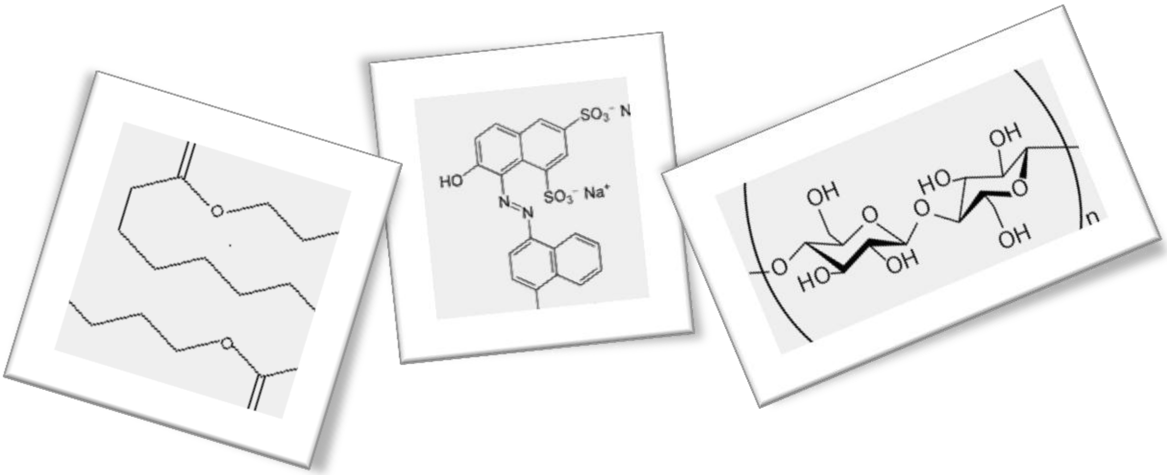


UNIT CONTENTS

I. Unit description

In this unit, the links between chemical structure, properties and use/application will be made. This unit can also be used to address the representation of materials at macro, sub-micro and symbolic levels.

The unit is built around the theme of 'holes' and that not all holes are visible to the naked eye. Various materials will be tested to determine if they can be effectively used as filters (therefore have holes) and also if different filters have different sized holes. Polymer films are interesting materials here as their structure can be altered by the addition of plasticisers and therefore the size, shape and extent of the holes can be varied. In this unit, polymers can be synthesised with different sized holes. This can be developed into further applications such as dialysis, separations, osmosis etc. Also, the use of polymers films with controllable holes is particularly useful in applications such as in drug release (as in hydrogels) and in environmental protection (as antimicrobial coatings).

The unit is divided into 3 subunits which can be used independently at different levels. Each subunit can take different directions and emphasis depending on the curriculum and particular learning aims of the teacher. The subunits can also be used in a spiral type curriculum with subunit 1 focussed at an introductory chemistry level, subunit 2 at intermediate level and subunit 3 at the higher stages of second-level school.

The activities are designed in such a way that they could be used in different areas of chemistry and biology – e.g. in dialysis or food contamination.

Throughout the unit, the emphasis should be on developing understanding of molecular size and shape and particularly on linking molecular properties to structure to macro properties.

- **Student Level:**

Sub unit	Student level	Topic
Subunit 1:	Early second level (11-13)	Visible holes
Subunit 2:	Mid second level (13-15)	Invisible holes
Subunit 3:	Upper second level (15-17)	Interesting holes

- **Discipline(s) involved:** Chemistry
- **Estimated duration:** Each subunit is flexible as they are designed to fit into a topic already taught through the curriculum. A time estimate has been given for each of the activities within the subunits.

II. IBSE Character

This unit can be used to develop the students' ability to plan investigations, develop hypotheses, distinguish alternatives, searching for information, constructing models and debating with peers. As each teacher will implement the unit in different ways, the emphasis can be placed on different sections and hence different elements of inquiry.

Each of the subunits can be used for each aspect of inquiry. In each subunit, the teacher may start with either a series of questions or with an interactive demonstration e.g. in subunit 2, the initial demonstration may be of iodine passing through cling film which then leads to questions for further investigations such as to the reproducibility, does this always happen, does this effect depend on the film used, does this effect depend on the particular molecules used, and determination of the film characteristics. These activities may be guided, bounded or lead into open inquiry activities.

Alternatively, the sub unit could be introduced by discussing examples of polymers we use every day, such as cling film, and addressing common misconceptions about its properties in keeping elements of the environment from spoiling food. Another application is in rain coats where the layer is impervious to water in one direction but permeable to water vapour in the other direction.

The focus of this unit is to provide ideas and activities that can be implemented in an inquiry based series of lessons. The initial activities given in this unit will form the background for further more open inquiry activities by the students.

The activities given are not developed to be performed in a linear order. Particular activities can be selected for use in various types of inquiry. The series of activities should be aligned to students' ideas and questions so that creativity, imagination and flexibility are always an integral part of the inquiry based teaching and learning.

III. Science Content Knowledge

For **subunits 1 and 2** the required science knowledge is a basic understanding of the particulate nature of matter and particle movement based on diffusion and osmosis.

Subunit 3 applies more specific knowledge on different polymers such as superabsorbers, cyclodextrines and PVC.

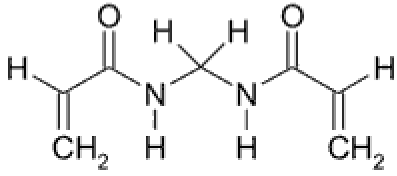
Polymers belong to the group of macromolecular substances. They are compounds with the number of atoms bound together by covalent bonds in a macromolecule reaching molecular masses of hundreds to millions. Polymers are divided into natural and synthetic polymers. Synthetic polymers can be prepared by processes of polycondensation, polyaddition or polymerization. Special **superabsorbing polymers (SAP) – so-called superabsorbents** can be included in the group of special polymers.

What is a superabsorbing polymer?
A superabsorbing polymer is a polymer that is able to absorb at least ten times its own mass of liquid, i.e. 10 g liquid for every 1 g of the dry polymer. It swells in water solutions and gel is produced.

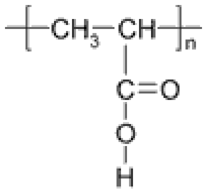
Superabsorbents are polymers with a significant ability to absorb liquids which is seen by an increase in their volume, so-called swelling. They absorb aqueous liquid solutions and make granular gels of permanent consistency with them. The amount of absorbed liquid depends significantly on the ion content and the pH of the given absorbed solution.

Some superabsorbents are able to absorb as much as 2000 times their own weight. When using a 0.9% aqueous solution of table salt, the polymer will absorb 50 times of its own weight – this is similar to the absorption of human urine into nappies.
Superabsorbent polymers have become an integral part of hygiene products (for example in nappies, ladies hygiene products, hygiene goods for incontinent patients) in the last decade. They are also used as protection for undersea cables from moisture, textile mats under frozen food, for preserving moisture in the soil, etc.
Certain problems arise however, when using polymers based on SAP. First of all, they are for single use. Thus they are not environmentally friendly as they are not biodegradable and are difficult to recycle. Development of a new generation of superabsorbents is therefore based on renewable material (polysaccharides – pectins, starch, cellulose), which are biodegradable.

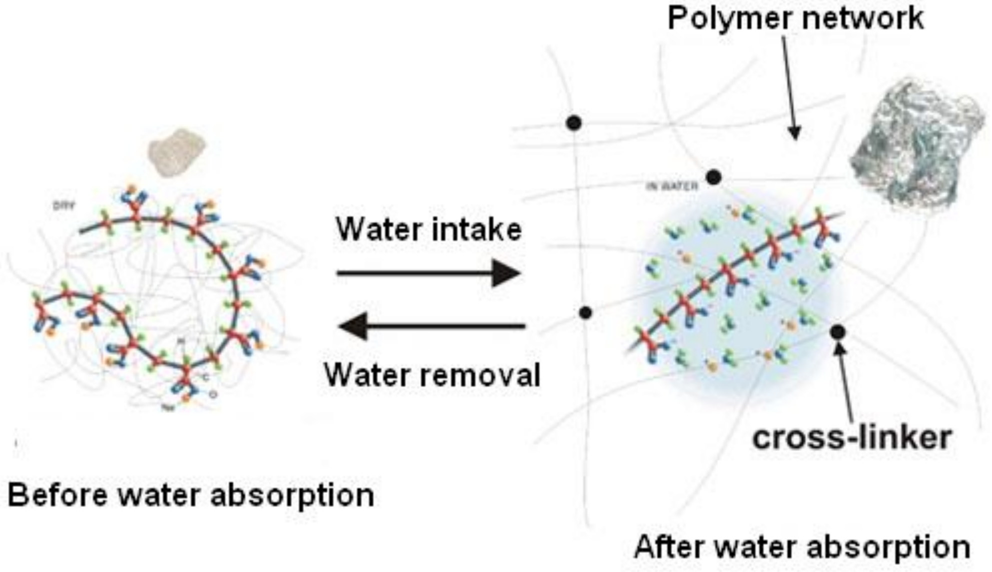
Hydrogels have many important applications. For example in tissue engineering (hydrogels can contain human cells for repairing tissues), in administration of medicines, in biosensors (gels reacting with specific molecules, such as glucose or antigens), contact lenses (silicone hydrogels, poly acrylamides) and healing gels.



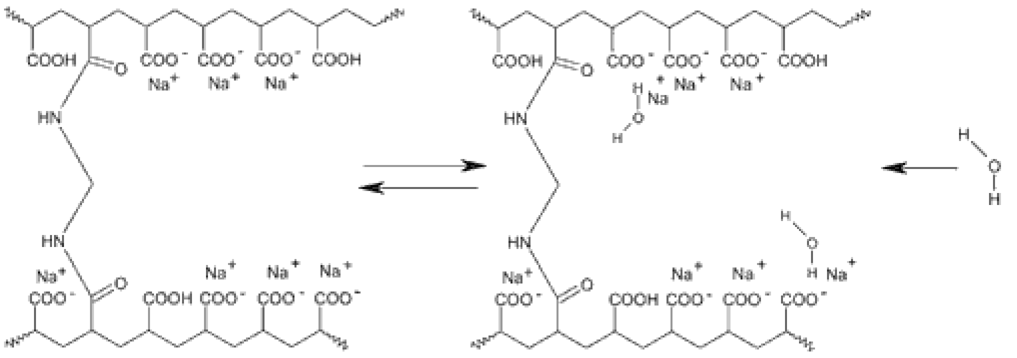
N,N-methylen-bis-acrylamid



polyacrylic acid



Scheme of the superabsorbent structure before and after water absorption

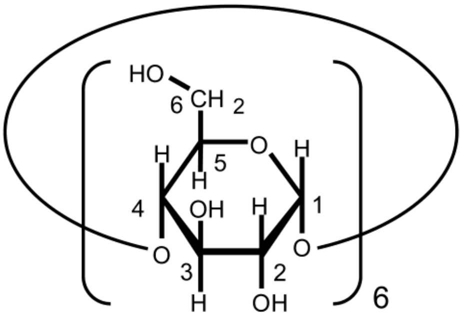


Chemical structure of superabsorbent - networked sodium salt of polyacrylic acid before and after water absorption

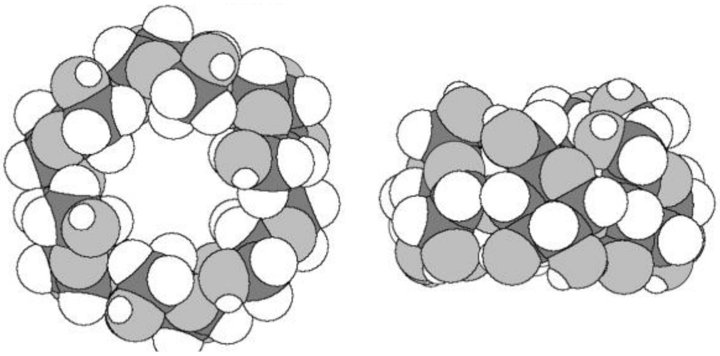
Above figures from Bilek, M., Opatrny O.: Superabsorpèní polymery ve výuce chemie (Superabsorption polymers in chemistry education), online, cit: 2011-06-30, date: 2008-01-21, available from: http://stary.rvp.cz/clanek/393/1875

Cyclodextrines are polycarbohydrates

α-Cyclodextrin (αCyD), which is a cyclic oligosaccharide of six α(1→4) linked α-D-glucopyranoside units, can be topologically represented as toroids (figure below). α-D-glucopyranoside units in αCyD are usually in the most stable chair conformation.



αCyD



Space filling model of α-CyD. Left: view through the hole. Right: side view.

Image taken from the IChO, Japan 2009

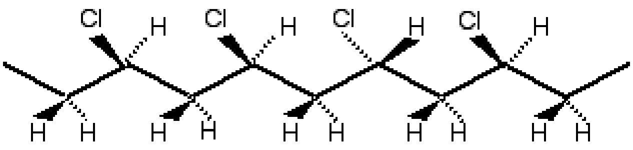
Membrane films have different polymeric composition – e.g. cellulose, parafilm, Teflon, clingfilm (polyvinylchloride), polypropylene, dialysis membranes. Note that particular household films may have local / brand names that may not be recognisable in other countries. The composition of some of the common polymers are shown below.

Polyvinyl Chloride (PVC)

PVC is a flexible plastic consisting of long chains. Each chain consists of repeating units where every second carbon atom has a chlorine atom attached.

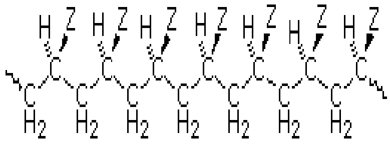
The polymerisation of vinyl chloride produces mainly atactic polymer molecules. This means that Cl are orientated randomly along the chain.

Atactic PVC - the Cl atoms have random orientations along the chain.

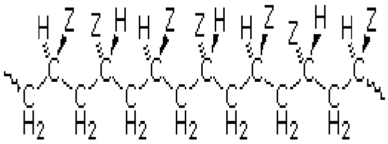


Because of the way the chlorine atoms stick out from the chain at random, and because of their large size, it is difficult for the chains to lie close together. Therefore, atactic PVC is mainly amorphous with only small areas of crystallinity.

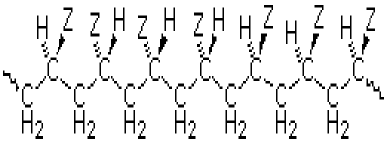
However PVC polymer chains can also be isotactic, with Cl atoms in the same orientation along the chain. (Syndiotactic is where the Cl atoms are in opposite orientation – see figure next page where Z = Cl)



isotactic



syndiotactic



atactic

When PVC plastic is bent it becomes opaque where the bend occurs. This is due to the chlorine groups being forced into the same orientation along the chain (isotactic). The polymer chains can then move closer together and become more crystalline.

Properties and uses

You normally expect amorphous polymers to be more flexible than crystalline ones because the forces of attraction between the chains tend to be weaker. However, pure PVC tends to be rather hard and rigid.

This is because of the presence of additional dipole-dipole interactions due to the polarity of the carbon-chlorine bonds. Chlorine is more electronegative than carbon, and so attracts the electrons in the bond towards itself. That makes the chlorine atoms slightly negative and the carbons slightly positive. These permanent dipoles add to the attractions due to the temporary dipoles and hence hold the chains closer together.

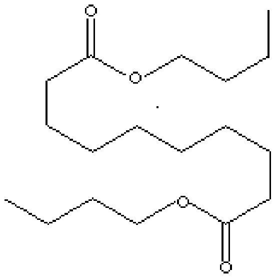
Plasticisers

Plasticisers are added to polymers to make the material softer, more flexible and therefore more workable. PVC is the most widely plasticised polymer due to its excellent plasticiser compatibility characteristics. Molecules which contain both polar and non-polar groups act as good plasticizers, as the polar group helps retain the molecule within the polymer chains and the non-polar part separates the chains, hence increasing flexibility.

Dibutyl sebacate is a commonly used plasticiser in polymers used in food packaging and in the pharmaceutical industry in polymer coatings for tablets and granules.

The dibutyl sebacate molecule works by bonding to the polymer chain through the oxygen atom on the plasticiser. The bulky plasticiser wedges itself between the polymer chains and pushes them further apart from each other. This causes the plastic to become more flexible.

Another compound used as plasticizer is sodium lauryl sulphate.

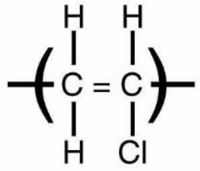
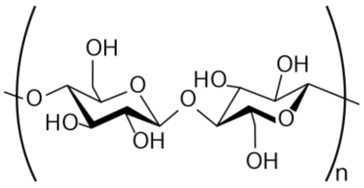
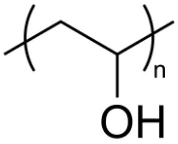
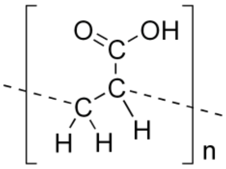
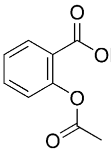
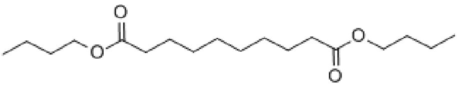
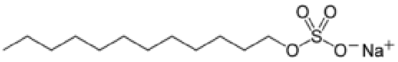
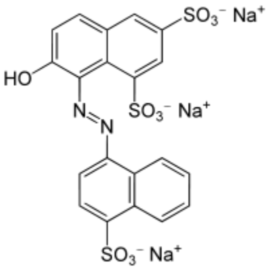
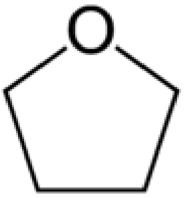
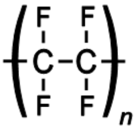


Dibutyl Sebacate

Resources:

- Polymer Website; (Macrogalleria – teaching materials); http://pslc.ws/mactest/maindir.htm - accessed 17 DEC 2010
- Overview of Dialysis; Thermo Fischer Scientific Inc; http://www.piercenet.com/files/TR0020-Dialysis-overview.pdf - accessed: 17 DEC 2010
- Overview of Plasticisers; AZoM.com - the A to Z of Materials online resource; http://www.azom.com/Details.asp?ArticleID=1224 - accessed 17 DEC 2010
- Molekulares Sieben: Mit Einmachfolie ins Diskontinuum (Molecular Sieves experiment); CHEMKON, 2004, Vol 11,(3); http://onlinelibrary.wiley.com/doi/10.1002/ckon.200410011/pdf - accessed 17 DEC 2010
- Overview of Silver nanoparticles (project report - N344); Aalborg university, Faculty of Physics and Nanotechnology, http://repetit.dk/files/projects/p3.pdf - accessed 17 DEC 2010

Figure below shows the building unit (monomer) of some common polymers, plasticizers and other molecules used in this unit.

Polyvinyl Chloride (PVC): **$(CH_2CHCl)n$** 	Cellulose: **$(C_6H_5O_{10})n$** 	Polyvinyl Alcohol (PVA): **$(C_4H_6O_2)n$** 
Poly(acrylic) Acid (PAA): **$(C_3H_4O_2)n$** 	Acetylsalicylic Acid: ***$C_6H_4(OCOCH_3)CO_2H$*** 	Dibutyl sebacate: **$C_{18}H_{34}0_4$** 
Sodium Lauryl Sulfate (SLS) aka Fairy Liquid: **$NaC_{12}H_{25}SO_4$** 	Red Food Dye (E124): **$C_{20}H_{11}N_2Na_3O_{10}S_3$** 	Tetrahydrofuran (THF): **C_4H_8O** 
Polytetrafluoroethylene aka Teflon:  **C_nF_{2n+2}**		

IV. Pedagogical Content Knowledge

Students can find the particulate state of matter difficult to conceptualise and model. Later on, they have to draw conclusions from structure-properties to microscopic properties, which they also find difficult.

It is well known from the literature that many students expect air or water to be between particles rather than nothing between particles. So the perspective on holes in this unit particularly highlights the emptiness in between matter and confronts them with the “horror vacui”. It is also well documented that students transfer microscopic properties onto particles. When a coloured solution is seen –

what is causing the colour? Linking colour to the molecule can therefore be difficult for students.

Possible arguments to explain observations will be based on 'colour', imperfections in the membrane, density, mass of particles. Discussion (and further experiments) will counter these arguments.

Linking molecular structure to macro properties can be difficult for students. Subunit 2 and 3 can therefore be helpful as properties of polymer films are changed, e.g. to be dependent on the amount of plasticizers added or the pH of a solution added to a superabsorber. Hence, the structure of the polymer must be different.

By analysing structure-property-relations, students also have to combine experimental observations with model-based explanations. The role of models as an essential addition to experiments could be highlighted to form a better understanding of the nature of science and inquiry-based approaches.

V. *Industrial Content Knowledge*

By pointing out the use of the same polymers in completely different contexts, the interaction between research, societal developments and industry becomes more obvious to the students.

The use of polymers in medical applications is extensive. Dialysis machines use a semi-permeable tubing in the treatment of toxic waste material thus alleviating the problems associated with kidney failure. Gas permeable contact lenses allow more oxygen to reach the cornea thus preventing swelling of the eye. Polymeric membranes incorporated with silver nanoparticles can be used in the treatment of wounds and infections. Hydrogels, which in the process of swelling in water have the ability to release compounds from their matrix, can act as efficient drug delivery systems. Sensor research uses semi-permeable polymer membranes in monitoring air quality and detection of certain gases like carbon monoxide. Both impermeable and semi-permeable polymeric membranes are also used in the food industry e.g. in food packaging, meat packaging (e.g. Western Plastics in Ireland (www.westernplastics.ie). Many clothes are based on polymers, and those which are most relevant to this unit include waterproof breathable jackets that display resistance to rain passing through the membrane but allow water vapour to be transported outwards using solid state diffusion e.g. Gore-Tex (http://www.gore-tex.com/remote/Satellite/home).

- www.packagingtoday.com (manufacturers)
- http://www.membrane-mfpi.com/
- http://www.foodplast.com/index.asp?page=29

VI. Learning Path(s)

Sub Unit 1: Visible Holes

This subunit introduces the idea of "holes" in materials which we can see and use on a daily basis. These holes are used in sieves, as a means of separation e.g. large stones from sand, coffee filters, muslin in cheese production etc. The idea that there is a lack of holes in some materials should also be discussed as well as their uses.

The learning outcome of this sub unit is that students recognise that holes exist in many materials, and can be used to separate substances. However, the separation depends on both the size of the holes and the sizes of the substances to be separated.

This subunit can also be used to introduce the concept of osmosis and diffusion.

Sub Unit 2: Invisible Holes

This sub unit develops on what the student has learned from Visible Holes and focuses on Invisible Holes. To understand the existence of invisible holes and processes of substances being able to pass these holes, students have to enter the world of particles. To introduce them to this "new world", surprising and fascinating phenomena are used, such as the "sieving of different dyes". Following this, the students are invited to develop a series of experiments to investigate properties of sieves, particles and diffusion processes.

This can be followed by questions whether all membranes (plastics) are the same (Activity 2.1). Different polymer films can be investigated and polymer films can be made with different levels of plasticiser and retested (Activity 2.5). Do they all have the same structure? Additionally, different compounds can be used on the same films to determine the pore size (Activity 2.2).

As an application, the leaching of plasticisers from packaging will be explored and can link to food packaging and possible hazards (Activity 2.5). Leading questions throughout the unit allow the students to progress from activity to activity as well as develop activities of their own.

Students can examine the uses of holes in dialysis membranes, in polymers used for absorbance, and in other polymer packaging materials.

Sub Unit 3: Interesting Holes

This unit deals with the idea of Interesting Holes which can be used in many medical and environmental technologies. Students can investigate different functional polymers such as superabsorbers and cyclodextrines to find out and explain why these polymers absorb solutions, such as water, or smells. The properties of hydrogels, as drug delivery systems, are investigated.

Nanotechnology can be applied to both medicine and environmental science using silver nanoparticles as an example. These can be incorporated into polymeric membranes which can then be used to treat wounds, burns and infections as the silver ions migrate from the membrane and attack any bacterial or fungal cells. They can also be used to coat different materials to enhance sterility.

Activity	Inquiry Type	E-emphasis
1.1 Making sieves	Open inquiry	Exploration
1.2 Observation and explanation of filters	Guided Inquiry	Elaboration
1.3 Use of filters in industry	Bounded Inquiry	Evaluation
1.4 Separation challenge	Open Inquiry	Extend
1.5 Assessment activity	Open Inquiry	E-Assessment
1.6 Transfer: Air filters	Guided Inquiry	Extend
2.1 Membranes with invisible holes	Guided Inquiry	Exploration
2.2 Set of activities on diffusion, particles and holes	Guided Inquiry/open	Elaboration
2.3 Transfer and Extension/Assessment: Dialysis	Bounded Inquiry	E-Assessment
2.4 What is the best wrapping material?	Open Inquiry	Exploration
2.5 Extra Activities	Guided Inquiry	Extend
3.1 Investigating the development of particular polymer products	Open Inquiry	Exploration
3.2 Investigations of properties and factors affecting SAP	Guided/Open Inquiry	Elaboration/Exploration
3.3 Properties and applications of cyclodextrines	Bounded Inquiry	Elaboration
3.4 Extra Activities		

VII. Assessment

Assessment can take several different forms depending on the age level of the students. The focus can be on prediction and associated reasoning e.g. questions predicting properties of ‘fictional’ polymers with various plasticizers. Generation of concept maps to link main ideas may also be useful.

Specific activities have been suggested that can be used for assessment (Activity 1.5 and 2.3)

VIII. Student Learning Activities

Activity 1.1: Making sieves
Learning aims:
This sub-unit will illustrate how different materials can be used as sieves. Separation depends on the hole size in the ‘sieve’ as well as the particle size of the compounds/materials to be separated. Hence this subunit focuses on the microscopic properties and structures. • to recognize the need for holes to separate materials • to recognize the need for particular size of holes matching the size of the materials to be separated • to construct a model and debate with peers.
Materials:
Mixture of different sized seeds (or the like), filter paper, scissors, containers, “distractors”, such as magnet, glue…
Suggestions for use:
Present students with the challenge to separate the seeds without touching the seeds using some of the materials provided. We expect at least some students to come up with the idea of sieves. Of course they can also discuss other methods of separation. If the idea of preparing a sieve from the paper does not arise, discussion can be directed towards the use of sieves in everyday applications.
Possible questions:
• Why did you create your technique as you did? • What are the advantages and disadvantages of your technique compared to others? • What do you already know about separation procedures in every-day life?

Activity 1.2: Observation and explanation of filters

Learning aims:

- to observe carefully and describe observations
- to use models
- to distinguish alternative (models).

Materials:

Coffee filter, empty tea bags as filters, different mixture such as tea, coffee, orange juice, mud in water, pictures of particle models of different sizes

Suggestions for use:

Start by showing the class the coffee filter paper and asking them what they think it is or what it can do. Ask the students why they think the coffee granules do not pass through the filter paper but the water can? Why has the water in the cup now turned brown? Ask the students to discuss whether the sieve from the previous activity could be used when making coffee.

Students carry out tests on the mixtures provided and work out which can be separated by filtration and which can’t and why.

Possible questions:

- Why do mud, coffee granules, … do not pass through the filter paper but the water can?
- How could you use the models in the picture on the worksheet to explain your observation?
- What is the difference between tea and mud in water?

Activity 1.3: Use of filters in industry

Learning aims:

To recognize the importance of filters for industry and society

Materials:

Sour milk, gauze or muslin

Suggestions for use:

Students should work out that the mixture that is provided can be separated by pouring it through gauze, thus separating curd from whey.

Sieves can have important uses within the food industry. Muslin is used in cheese making to separate the liquid whey from the solid curd. It is also used in wine making to remove sediments.

Possible questions:

- Why are sieves used in food industry?
- What are important factors to consider when choosing sieves for the food industry?

Activity 1.4: Separating challenge

Learning aims:

- to differentiate between solutions and mixtures
- to recognize the importance of different solubilities
- to identify possibilities of recovering salts from solutions .

Materials:

Salt, water, dirt, beaker

Suggestions for use:

Tell the students that you have spilled your salt on the floor where it has mixed with small dirt particles and other impurities on the floor. Ask the students to come up with an experiment using the idea of sieves to obtain a pure sample of salt from the mixture. Advise students to think about the previous activities when devising their experiment. Students should use the idea from the coffee filter that if the salt is dissolved in the water it can fit through the filter paper and the water can then be evaporated off.

Possible questions:

- Why can you not separate salt from dirt using a sieve (without water)?
- Why can you not separate salt from water using a filter paper?
- What other techniques could you use to regain the salt from the water

Activity 1.5: Assessment: Crime story

Learning aims:

Students have to use separation techniques they have learned to solve the murder mystery.

Materials:

See Worksheet in Classroom Materials

Suggestions for use:
A crime scene can be set up and student groups given samples of evidence from the scene. They develop their own sequence of activities in order to determine the most likely culprit. Details are given in the Classroom Materials.
Possible questions:
See Worksheet

Activity 1.6: Transfer: Air filters in car engines
Learning aims:
To transfer the knowledge developed from solids and liquids to gases
Materials:
Salt, water, dirt, beaker
Suggestions for use:
Students read stimulus material about car engine air filters and answer questions about how it works, what happens if it is not there and why racing cars have only a thin filter. This activity could also form the basis of assessment to determine the students ability to transfer the concepts covered to other applications.
Possible questions:
See Worksheet in Classroom Materials

SUB UNIT 2. INVISIBLE HOLES

Invisible Holes Experiment

Learning aims:

- In this subunit the students will transfer their macroscopic knowledge onto the invisible level of atoms and molecules.
- They will develop a better understanding of the particulate nature of matter.
- The activities can be used to show the existence of molecules and that they have different sizes.
- Students can investigate different pore sizes in polymer films.

The sequence of activities within this subunit is based on this central experiment.

Materials:

Chemicals: Red food dye solution, Iodine-Starch, Solution Potassium Permanganate Solution, Iodine-Dextrin solution, Iodine Solution (Just for Part 2)
Apparatus: 4 Rubber bands, 5x50ml beakers, 4 lengths of visking tubing, 5 sheets of cling film, 10ml plastic dropper.

Procedure (Part 1):

Central experiment

- Prepare a 1% starch solution with water at 70°C
- Add iodine and leave iodine and starch solution to one side (Turns blue)
- Add 0.5g of dextrin to 100ml of water and then add a few drops of iodine (Turns red)
- Open the visking tubing lengths by holding it under running water for a few minutes. Tie one end with an elastic band tightly. Ensure the elastic band is stretched very tightly so that no liquid leaks out.
- Add a different solution (from list of chemicals above) into each of the four lengths carefully using a dropper. Stick the dropper to the bottom of the visking tubing and release the solution. Make sure none of the solutions touch the outside membrane. Tie off the other end of the visking tubing firmly with an elastic band.
- Submerge each tube into different beakers of water.
- Record what is observed over 10 minutes.
- Wash all glassware and dispose of visking tubing.

Procedure (Part 2)

- Repeat this experiment using cling film instead of visking tubing as follows:
- Fill 5 beakers with water and loosely place strips of cling film over the top Try not

to stretch the cling film. Make a slight dip in the cling film to fill with solution. Take note of whether the cling film touches the water or not. Secure the edges of the cling film around the side of the beaker.

- Add a different solution onto each of the five cling film strips resting on the beakers. Make sure the solutions do not overflow the sides of the beakers.
- Leave overnight and record your observations the following day.
- Compare and contrast the results from part one and two and suggest reasons for your findings.

Possible questions:

See worksheet in Classroom Materials

Activity 2.1: Membranes with invisible holes

Learning aims:

- To draw conclusions from observations
- To explain the phenomenon through the existence of invisible holes and the movement of particles
- To distinguish alternative explanations and debate with peers

Materials:

Worksheet 2.1 or central experiment

Suggestions for use:

The teacher could either demonstrate the phenomenon as shown in the central experiment and let the students develop questions or start with a context of wrapping food. Worksheet 2.1 offers a possibility to investigate different plastic wrappings. Examples of investigations could be:

1. Iodine diffusing into a soluble starch solution
(i) No membrane
(ii) Jam pot cover
(iii) Plastic bag/cling film
(iv) Latex glove
2. Vinegar diffusing into water with Universal indicator
(i) No membrane
(ii) Jam pot cover
(iii) Cling film/ roasting bag
(iv) Latex glove/plastic bag

Students match results to models of particles – both in solution and hole size.

Teacher should encourage a discussion of possible reasons and let the students deal with and encourage the development of the idea of particles of different sizes or membranes with holes of different sizes as one explanation.
Possible questions:
See worksheet in Classroom Materials

Activity 2.2: Set of activities on diffusion, particles, and holes
Learning aims:
• to develop the concepts of particles moving, of particles in solution moving • to introduce diffusion and osmosis • to develop and apply mental models • to control variables • to be able to predict, observe and explain processes.
Materials:
See worksheets 2.2a-2.2e
Suggestions for use:
The activities can be carried out in a learning cycles in small groups. The teacher can decide whether there should be a particular sequence to the activities or a free combination. Station 1 focuses on diffusion which can be explained by the Brownian motion. Station 2 focuses on the permeability of polymer membranes. Stations 3 and 4 extend the concept of particles and holes to different sizes of particles and explain it through molecular models. Station 5 develops visual models for the invisible structures and processes.
Possible questions:
See worksheets in Classroom Materials

Activity 2.3: Transfer and extension: Dialysis
Learning aims:
• to apply knowledge to an important/medical process • to assess the capability to transfer understanding to an authentic context
Materials:
See electronic classroom materials, worksheet 2.3 and associated animation

Suggestions for use:

This activity can be used either as transfer context or as an assessment.

Possible questions:

See worksheet

Activity 2.4: What is the best wrapping material?

Learning aims:

- to develop criteria for wrapping material
- to develop mental models

Materials:

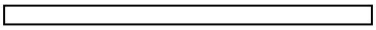
none

Suggestions for use:

This activity is a thinking exercise that leads to the aspect of producing polymer films.
The starting question could be: When preparing a sandwich, what's the best material to use to wrap it? What criteria would you apply? Below are possible factors that students might suggest: availability, cost, environmental impact (biodegradable, combustible, ...), insoluble in water, impermeable to fat and water, non-reactive (e.g. with acids in various foods), odourless and tasteless, keeps odours in (or out), ..., breathable or not?
The students should then rank the criteria they have named in order of importance and find out if there were materials that have the properties of higher ranked criteria. This ranking and questioning will lead to the suggestion of a plastic (cling film). Analyse what properties plastics have from the list of criteria. *Water will not pass through it; therefore it is impermeable, maybe inferring that there are 'no holes'*.

To get students to start thinking at a deeper level, askt them to draw what a sheet of cling film looks like.

Ask them about the size and the number of atoms in the thickness of the film.



Invite the students to imagine shrinking themselves down to the size of an atom and ask them what the plastic will look like then.

Experimentally - show briefly that cling film will hold water.
Show Cling Film as an example of a polymer, made up of monomer units, each monomer is long chain. The students could be invited to think again about the size of the chains, the polymers, the atoms, etc.
A following question could be on the making of films and if it was possible to make films without holes (see extra activities 2.5). The following questions could then lead to further investigations:

- Will anything else pass through holes e.g. oxygen?
- Can we make films with different sized holes?
- When a sandwich is wrapped, lots of other compounds present – e.g. fat, oil, ketchup etc. What are these compounds? Do they affect the film?
- If you are wrapping a hot dog, then temperature is important. So how does temperature affect the film?
- Can bacteria pass through the film?

Extra Activity 2.5 Syntheses and testing of products

Making polymer films often involves hazardous chemicals. It depends on the facilities and regulations whether these experiments can be carried out in the school classroom.

Activity 2.5a: Making Polyvinyl Chloride film
Learning aims:
• to make a film of PVC from powder PVC with and without a plasticiser • to compare both the physical and chemical properties of each sample
Materials:
Chemicals: Tetrahydrofuran (THF) or Toluene (solvent), Polyvinyl chloride powder, di-butyl sebacate or other plasticizer **Apparatus:** Hotplate, magnetic stirrer, beaker, glass substrate (e.g. beaker, clockglass, glass slide) All steps in this procedure must be completed under the fume hood

Procedure:

Polyvinyl chloride (PVC) is a cheap and durable plastic that is often used in pipes, signs and clothing. Plasticisers are often added to PVC to make it more flexible and easier to manipulate.

Making PVC (without a plasticiser):

- Using a hotplate and a magnetic stirrer, heat 20mLs of the solvent.
- Weigh out 1.5g of the polyvinyl chloride powder and add it slowly to the heated solvent.
- After 10 minutes the solution will become more viscous, at which point the beaker should be removed from the heat.
- Remove the magnetic stirrer and spread the PVC as thinly and as evenly as possible over a glass slide/clockglass/inside or outside a beaker. It is important here to spread the polymer thinly by moving the glass substrate while the solution is still hot.
- Leave the PVC in the fume hood to allow the THF to evaporate off (takes about 15 mins). The PVC film can then be removed easily from the glass substrate.

Making PVC (With a plasticiser):

- A number of samples of PVC can be made by repeating the steps above, each time adding different volumes of the plasticiser, di-butyl sebacate to the heated solvent.
- Follow the remaining steps as above and pour the solution onto the glass substrate trying to get as good a spread as possible.

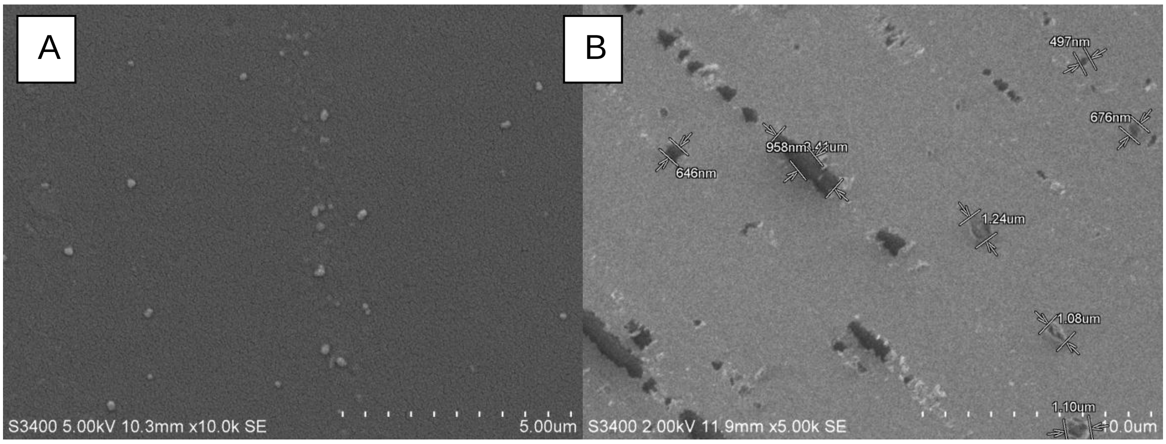
Sample No.	PVC (g)	THF(mL)	Di-butyl sebacate (mL)
1	1.5	20	0.5
2	1.5	20	1
3	1.5	20	2
4	1.5	20	3

- The PVC samples prepared can then be used in Activity 3.

Possible questions:

- What affect did the plasticiser have on the plastic?
- What do you think happens to the plastic when more plasticiser is added?

The following are SEM images of PVC films prepared as above with different quantities of plasticizer. Holes are clearly visible in sample B.



SEM images of A) un-plasticised PVC, and B) PVC with 2ml plasticiser displaying clear holes.

Activity 2.5b: Testing the Pore Size of Plasticised and Un-Plasticised PVC

Learning aims:

- To understand that the PVC films (with and without plasticizer, i.e. films with different sized holes) can be used to separate different compounds or the compounds can be used to determine the pore size (i.e. larger or smaller than the molecular size).

Materials:

Chemicals: Water, Iodine Solution, Potassium Permanganate solution
Apparatus: Test tubes, test tube stand, black marker, retort stands, 25 mL beakers, elastic bands, parafilm, plastic Pasteur pipettes, number of readymade PVC samples with varying plasticiser from activity 2.2.

Procedure:

Devise a suitable procedure using material available and previous experiments.

Possible questions:

- Rank each PVC film in terms of permeability, starting from non-permeable to permeable.
- Differentiate between the structure and size of iodine molecules and potassium permanganate molecules in solution.
- At what point does the plasticiser allow the PVC to become permeable to iodine? Explain what happens on a molecular level.

- Why was parafilm used as well as PVC?
- Give examples of other polymers you think may be permeable / impermeable and construct an experiment to test this.

Activity 2.5c: Removing Plasticiser from PVC Clingfilm

Learning aims:

- To understand the purpose of plasticisers

Materials:

Chemicals: PVC cling film (or PVC with plasticiser produced in activity 2), diethyl ether, hot water.
Apparatus: 250 cm^3 conical flask, 250 cm^3 beaker(s), graduated cylinder, hot plate, spatula, balance.

Procedure:

- Weigh out approximately 1 g of PVC cling film/plastic
- Measure out 75 cm^3 of diethyl ether into a 250 cm^3 conical flask.
- Warm up the flask for 5-10 minutes in a water bath at 50°C in a fume cupboard. If a hot plate is not available then an unheated beaker of hot water can be used instead as diethyl ether boils at 35°C.
- Decant the diethyl ether from the conical flask into a 250 cm^3 waste beaker. Add fresh ether and repeat the process.
- Remove the cling film/plastic from the beaker using a spatula after it has undergone two runs of diethyl ether and allow it to dry off in a fume cupboard.
- Weigh the cling film/plastic again and note the difference. Calculate the percentage weight loss (which should be over 20%).
- To collect the sample of the plasticiser, distil off the ether in the waste beaker and you will obtain a viscous oil.

Possible questions:

- Compare and contrast the appearance and texture of the plastic before and after the experiment.
- On a molecular level, what occurred to the polymer chains on removal of the plasticiser?
- Design an experiment whereby you could test the size of pores in polymers using a plastic containing plasticiser and one without.

SUB UNIT 3. INTERESTING HOLES

Overall learning aims:

Subunit 3 extends the students' understanding of particles through a systematic look at molecular structures, forces and interactions. As examples, functional polymers such as superabsorbers, cyclodextrines or hydrogels can be used. The aim of the IBSE investigations is to find out the effects of changing conditions on the properties.

Activity 3.1: Investigating the development of particular polymer products

Learning aims:

- to find out about particular products, including the people who came up with the ideas, the industry and the societal impact
- to use different sources of information systematically
- to make a short presentation

Materials:

Access to information sources

Suggestions for use:

Let the students form groups and provide them with suggestions on products, e.g. contact lenses, nappies and hydrogels for plants. They investigate the development of these projects and share information with the group in a suitable manner.

Activity 3.2a: Investigation of properties and factors affecting SAP function

Learning aims:

- to develop experimental series including control of variables
- to explain the absorption of water by using structures and intermolecular forces ("functional holes")
- to present findings in the forms of texts and graphs

Materials:

Baby nappies or superabsorber (available from laboratory suppliers);
Sodium chloride solution (concentrations 0.01 mol/l, 0.1 mol/l, 1 mol/l); Distilled water
4 beakers (250 ml), 4 large paper tea filter-each with 2 paperclips to close it, crucible tongs, graduated cylinder, weighing scale, plastic bag

Suggestions for use:

To start the investigation, the teacher could demonstrate how much water a small amount of SAP can take up. This could even be done in a fun way, e.g. by pretending to spill a cup of coffee which does not come out of its cup when turned over...
Referring to upper secondary level students, the investigation of properties of SAP and factors affecting them could be developed by the students themselves. In case this is not possible, the following activities can be suggested:

Extract the SAP from the nappy:

- Examine the layered assembly of a baby nappy and find out which layer contains the superabsorbing polymer.
- Pull apart the fibrous web with the pellets of superabsorber in a plastic bag. Blow into the bag and separate the pellets from the fibrous web by shaking the (closed) bag vigorously.

Determine the absorbency of SAP in water and in salt solution:

- Add 200 ml of different concentrations of sodium chloride solution to each of three beakers and add 200 ml of distilled water to a fourth beaker.
- Fill each of the 4 large tea filters with 2 g of the superabsorber, close with the paper clips and hang one in each beaker.
- Remove the filter after 45 minutes and allow excess liquid to drip off over the beakers for about 5 minutes (might have to use a funnel).
- Weigh the expanded tea filters and record the volume of the liquid remaining in the beakers.
- Repeat steps 3-6 with the aim to find out how the pH affects the retaining properties.
- Expand this activity to determine factors that affect absorption.

Possible questions:

- How could you explain the absorption of water with a simple model?
- How can you explain that the water does not get out again?
- How can you explain the influence of pH and concentration of ions on the structure-property relation?
- Compare the properties of SAP to other absorbing substances you could find at home. How could you explain the different properties through the different structures?
- Looking at nappies, how do the properties of urine differ from pure water? How could that influence the properties of SAP?

If the facilities and regulations allow for it, the following synthesis could be carried out:

Activity 3.2b: Synthesis of SAP

Materials:

Chemicals: distilled water, acrylic acid, N,N'-methylenebisacrylamid solution (MBA, w= 1%) (Xn), Ascorbic acid solution (w= 1.9%), H_2O_2 solution (w=0.6%) (C), Sodium hydroxide solution (c=0.5 mol/l) (C), Ethanol (T, F+)

Apparatus: Beakers, syringes (1ml, 2ml, 5ml), temperature sensor, spatula, glass stirrers, 2 pointed tweezers, spoon, crystallizing dish, graduated cylinders (50ml, 100ml)

Safety: Wear protective gloves and goggles. Work in the fume hood.

Procedure:

a) In a beaker, add the following solutions in the given order (use the syringes for measuring the liquids):

2.7 ml distilled water
2.0 ml acrylic acid
0.2 ml MBA-solution (w=1%)
1.4 ml ascorbic acid solution (w=1.9%)
0.7 ml H_2O_2 solution (w=0.6%)

Mix the contents of the beaker by gently swirling it. Let the beaker sit at room temperature. Record the temperature change during the reaction. The next part (part b) can follow right after cooling or the following day.

b) Transfer the product obtained to an evaporating dish. Pour 40 ml of sodium hydroxide solution c=0.5 mol/l) over the product.

With the help of the tweezers, separate the polymer into little pieces (be sure to wear protective gloves and goggles).
After complete absorption of the liquid by the gel (about 30 minutes), add 100 ml of ethanol (do so in the fume hood).
The content of the evaporating dish needs to be swirled around carefully from time to time (do not stir with a utensil because the gel is very sticky).
After about 10 minutes, remove the remaining liquid (make sure to dispose of this as organic solvent) and add 60 ml of ethanol.
Repeat the last step twice (after waiting 10 minutes each time). Depending on the consistency of the polymer pieces, they might have to be separated from each other or the container with the help of the tweezers.
After the last removal of the liquid, leave the product sit under the fume hood overnight (or put into the oven for 1 hour at 80°C).

Activity 3.3: Properties and applications of cyclodextrines

Learning aims:

- to develop experimental series including control of variables
- to explain the absorption of substances
- to identify applications of cyclodextrines

Materials:

The cyclodextrine needed in the following experiments can either be isolated as described in Activity 3.3d or be purchased commercially.

Activity 3.3a: Removal of Phenolphthalein

Materials:

Chemicals: alkaline Phenolphthalein solution [C] (made from 20 ml distilled water, 3 ml sodium hydroxide solution (5 M) [C] and 4 ml Phenolphthalein solution (0.1%) [F]), cyclodextrine
Apparatus: 2 pieces of cloth, pipette, spatula

Procedure:

Spread a thin layer of the cyclodextrine onto a piece of cloth. Add a few drops of the alkaline Phenolphthalein solution to both pieces of cloth.

Activity 3.3b: Removal of Maggi ®

Chemicals: cyclodextrine Maggi ® food seasoning, liquid
Apparatus: 2 pieces of cloth, spatula, piece of white cardboard

Procedure:

Spread a thin layer of the cyclodextrines onto a piece of cloth. Add a drop of Maggi ® food seasoning to both pieces of cloth.

Activity 3.3c: Removal of cigarette smoke

Materials:

Chemicals: cyclodextrine (product from activity 3.3d); cigarette
Apparatus: Gas syringe, Erlenmeyer flask (250 ml) with stopper, short piece of tubing, funnel, evaporating dish, pipette, tweezers, 2 pieces of cloth

Procedure:

Spread a thin layer of the gel-like precipitate (product from activity 3.3d) onto a piece of cloth. Place both pieces of cloth side by side into the Erlenmeyer flask.

Mount a funnel to the gas syringe via the piece of tubing. Fit a cigarette without filter into the funnel. Keep an evaporating dish ready for the cigarette ashes. Collect the cigarette fumes in the gas syringe. Pour the smoke into the Erlenmeyer flask and close the flask tightly right away. After about 1 minute, retrieve the pieces of cloth from the Erlenmeyer flask and dampen them.

Suggestions for use:

To start the investigation, the teacher could show an advertisement showing a product that promises to remove smells from fabric. The students need information on the structure of cyclodextrines. The students could make predictions about the forces at play. Before carrying out the investigations, the cyclodextrines could be extracted from Febreze® in the following way:

Activity 3.3d: Extraction from Febreze®

Materials:

Chemicals: Febrèze®, ethanol [F], ice

Apparatus: Heatable magnetic stirrer with stirring bar, beaker (100 ml), graduated cylinder (50 ml), beaker (400 ml) for cooling

Safety: Beware of possible boiling delays.

Note: The reduction of the water takes about 1 hour and that of the alcohol about 15 minutes.

Procedure:

- Pour 40 ml of Febrèze® into the small beaker and, while stirring, reduce the liquid almost until dry with the heatable magnetic stirrer.
- After letting the beaker cool, add 20 ml of ethanol and again, reduce the liquid almost until dry.
- Let the beaker cool and put it into larger beaker filled with ice water for a few minutes.
- Save the resulting gel-like precipitate for further investigations.

Activity 3.4a: Extra Activities - Testing sorption properties of hydrogel

Learning aims:

Examination of changing physical properties of dried and hydrated hydrogel

Materials:

Sodium polyacrylate or another hydrogel, distilled water, ceramic evaporating dishand spoon, beaker (150 cm^3)

Procedure:

Put one spoon of sodium polyacrylate into the evaporating dishand then add about. 100 cm^3 of water. Observe any changes.

Activity 3.4b: Testing volume phase transition in sodium polyacryte

Materials:

Obtained from the previous experiment hydrated sodium polyacrylate, phosphorus(V) oxide (P_4O_{10}), a desiccator, Petri dishes, porcelain spoon

Procedure:

Pour spoonful of P_4O_{10} onto Petri dishes and place it in the desiccator or a big jar with a tight cover. Place a few particles of hydrated hydrogel Into another Petri dish and put it into the desiccator. Observe the changes.

Possible Questions

- Does the volume of the substances change during the experiment?
- What could happen with water used in the experiment?
- How could you explain decreasing the size of hydrated hydrogel particles and the state change of P_4O_{10}?
- Are there other factors which could cause the observed effect?
- Which phenomena are observed in these experiments?
- What are the possible applications of the tested materials?

CHEMICAL CARE

The development of this unit has been led by the ESTABLISH partners:

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Leibniz- Institute for Science and Mathematics Education (IPN)
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.

UNIT CONTENTS

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 identify 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:

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.

- **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

Sub-unit 3 in particular 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 the knowledge background needed. Teachers must be able to choose household products, e.g. cleaners containing acids or bases. They must have general knowledge of the structures and properties of the substances, such as acetic acid, citric acid, or sodium hydroxide. Most important, they must consider all measures necessary for a safe conduct of students' experiments, as described in the material. However, as this content knowledge is 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 in a sterile way and for 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, and 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 the 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://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 people's digestive tract proteins are only degradable after their denaturation. This can happen by cooking or by gastric acid. This is an important process for the food hygiene 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 broken 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 a 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 involves use of 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 into 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 for particular applications which enables the development of functional textiles and specific technical textiles.

Synthetic fibres can be subdivided in cellulose, polymer fibres (synthetic chemical-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 unless it is exposed to temperatures of > 150˚C for a prolonged time. However, if it is 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, calcium, fat, and sodium can also be found 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.

Important qualities of wool include: 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.

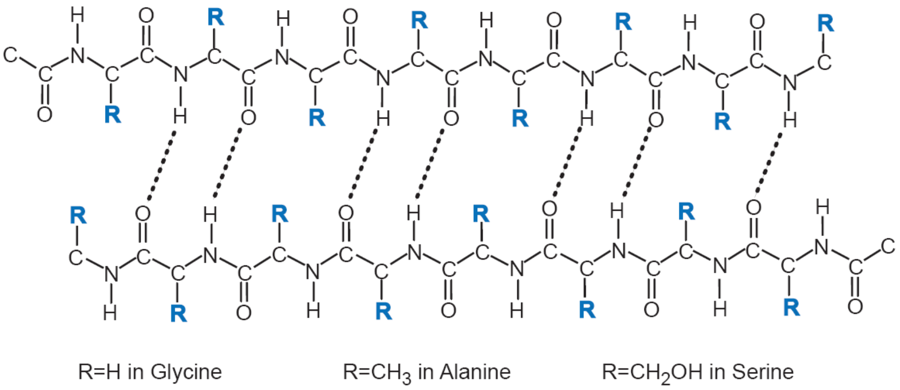
Source: Henkel. Waschen & Pflegen: Spezialratgeber Wolle. http://www.perwoll.de/waschen-pflegen/spezialratgeber/wolle-richtig-waschen.html#content61

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.

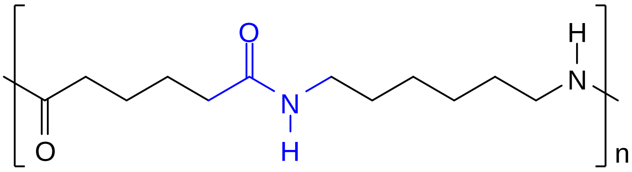
Silk is a natural fibre that is made up of proteins. The cocoons of the larvae of the mulberry silkworm are the base raw material of the silk fibre.

Extract 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.

Extract from the Nylon structure:



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 from reaction 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. Also, it melts instead of burning.

Sources:
http://en.wikipedia.org/wiki/Nylon
Karraß, Sigurd. Chemiefasern: Aufbau-Strukturen-Anwendungen. NiU-Chemie 6 (1995) Nr. 26, Seite 9-15.

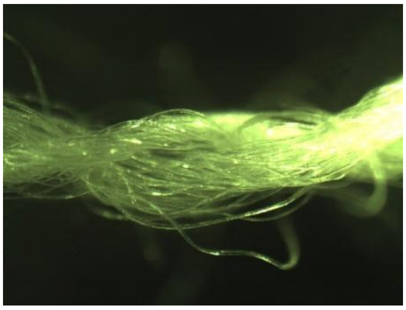
Additionally, **artificial/ viscose silk** is a half-synthetic fibre obtained from cellulose. **Microfibres** are fully synthetic fibres obtained from polyester or other fibres similar to Nylon.

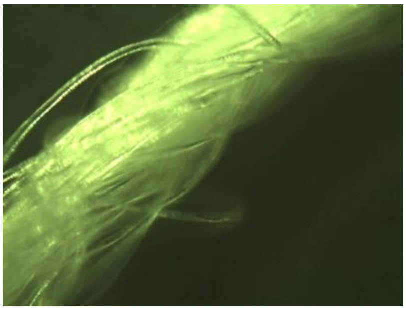
Thickness of fibres

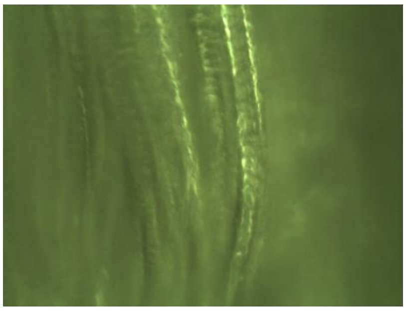
The following pictures of fibres were taken with a Motic BA 400 with different magnification (Source: Kirsten Fischmann, taken at IPN, Kiel, Germany):

4 x /0.10 10 x /0.25Ph 40 x /0.65Ph

wool:

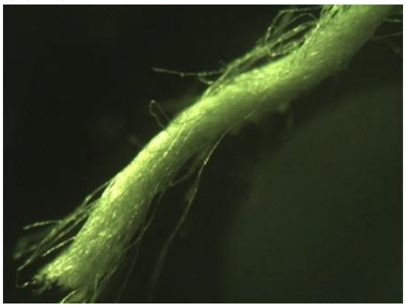


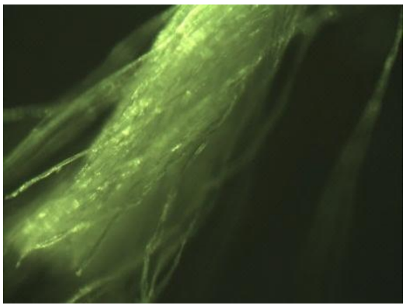




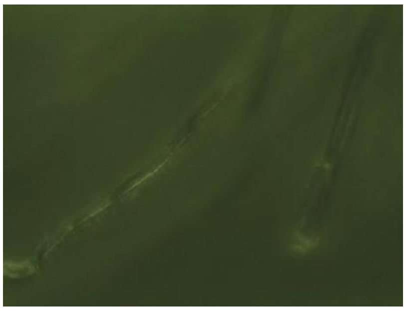
Here you can slightly see the scaly surface of the fibre.

cotton:

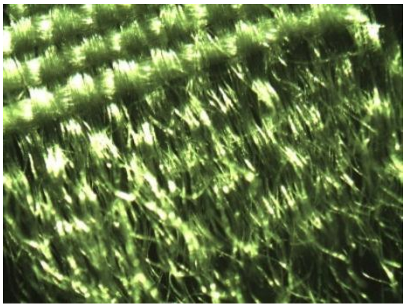


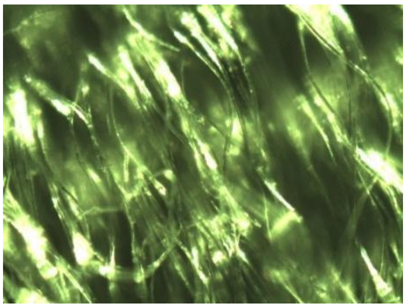


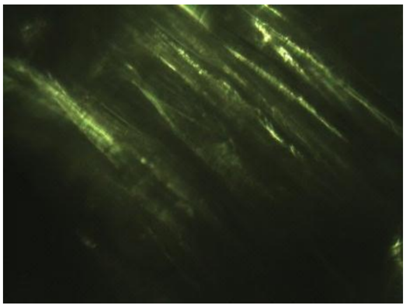
Notice the typical coiling of the fibre.



silk:

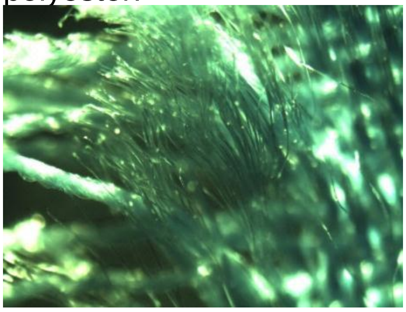


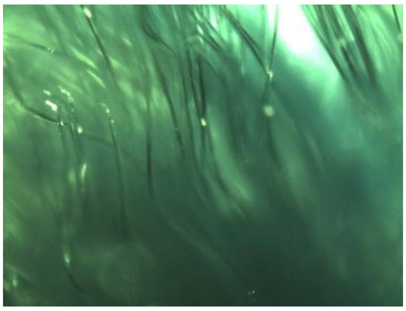


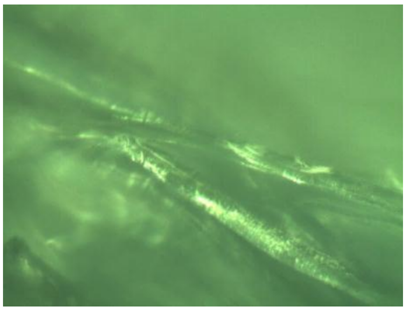


Slightly coiled fibre without scales.

polyester:

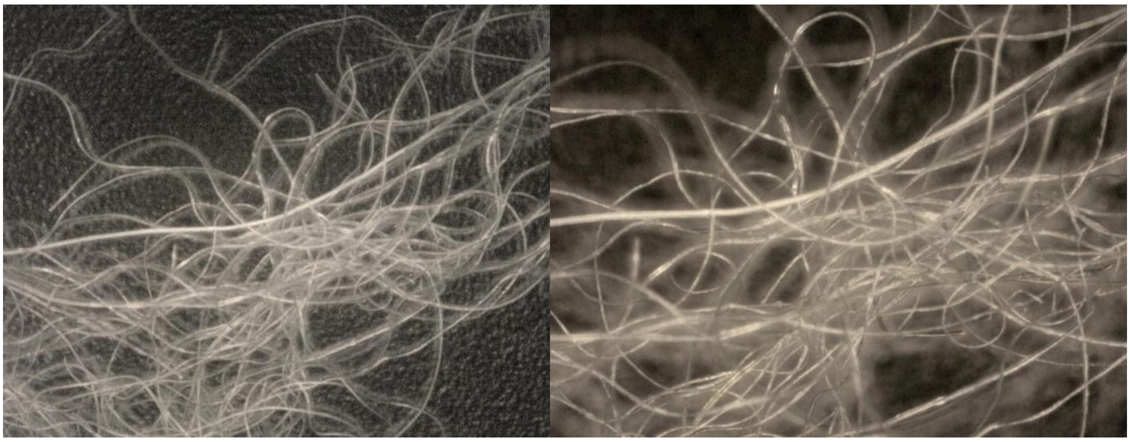




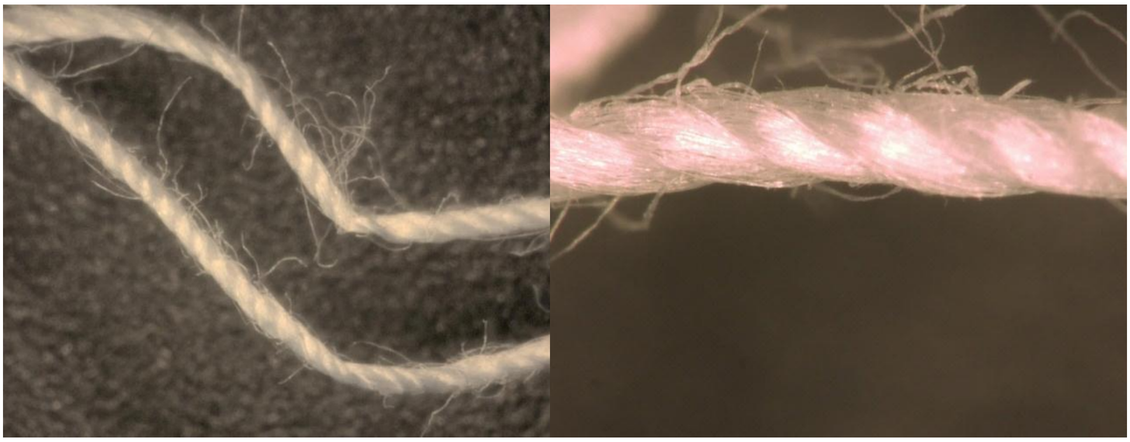


Straight fibre without scales.

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):

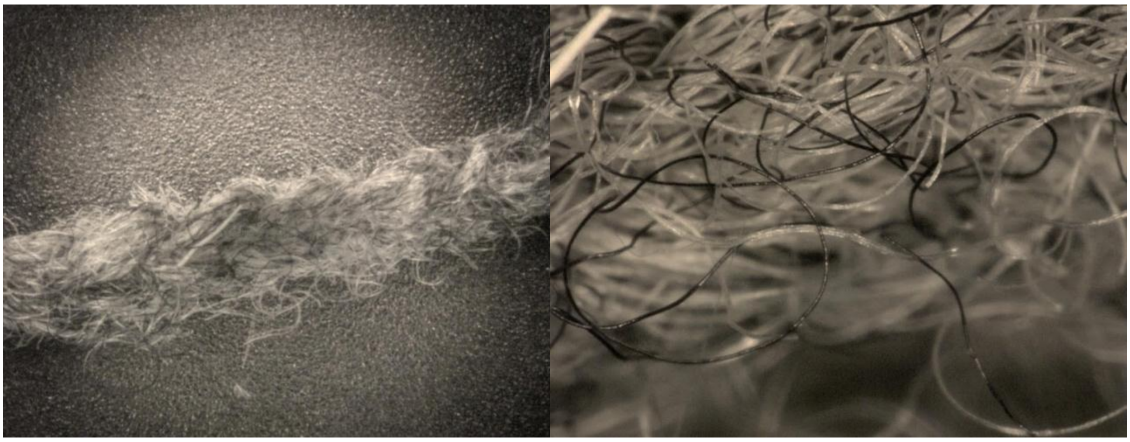


lamb wool fibres

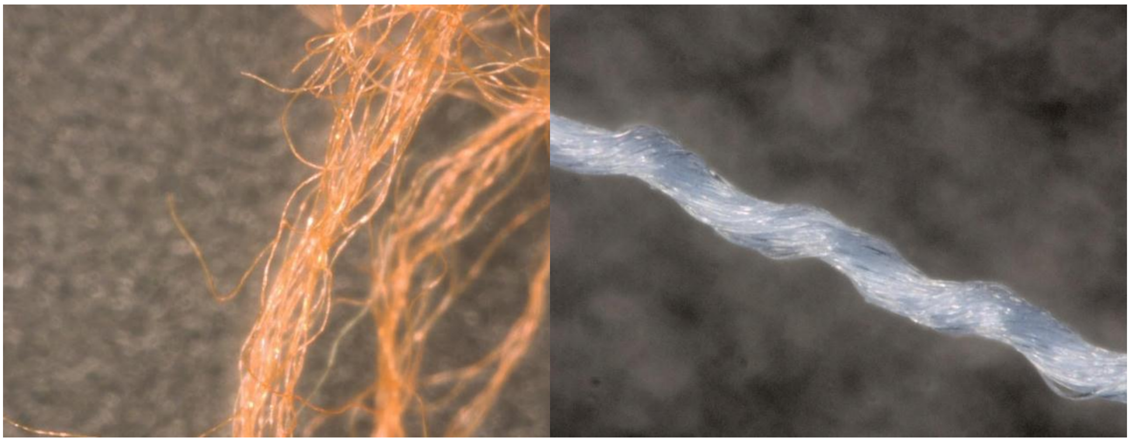


cotton fibres

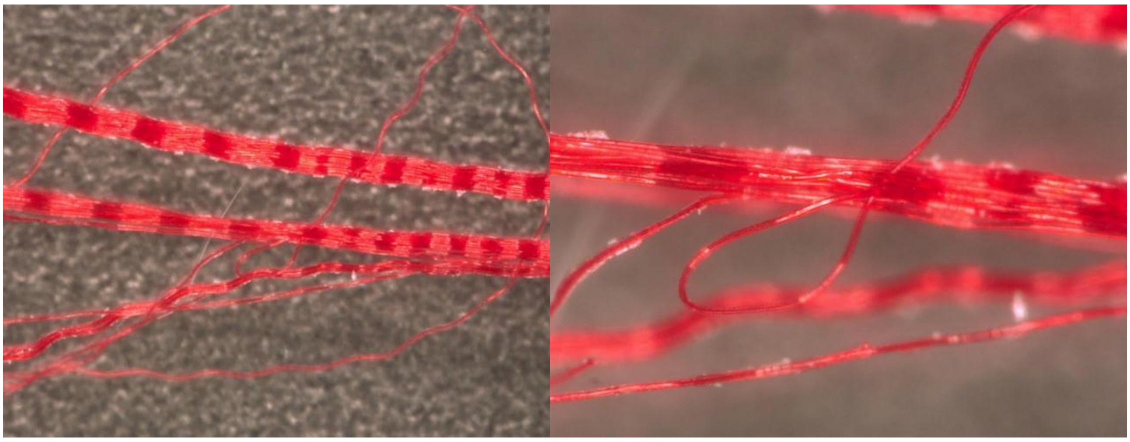
cotton, piece of textile



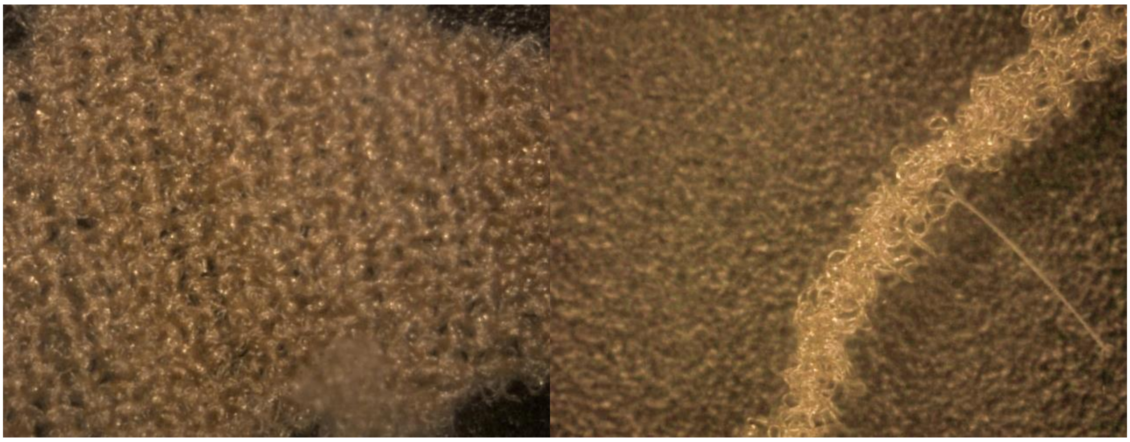
virgin wool fibre



different polyester fibres



polyamide fibres



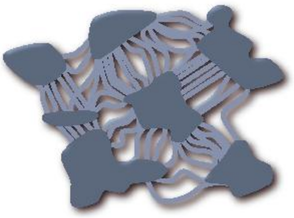
nylon tights

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 are 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.



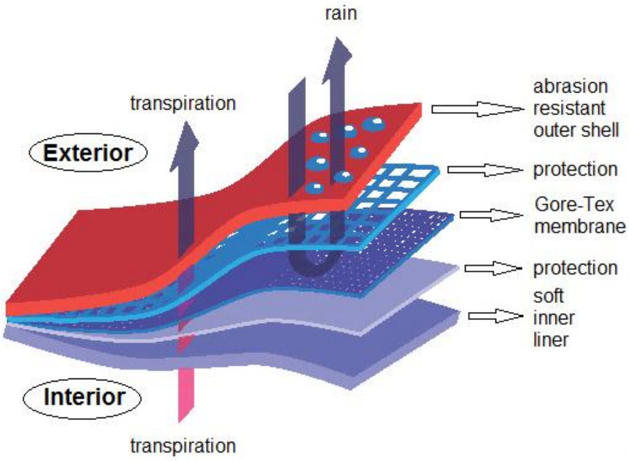
Size of islands about 10µm. Figure adapted from: http://en.wikipedia.org/wiki/Gore-Tex

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.

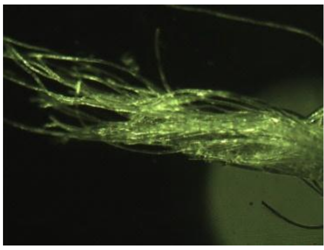
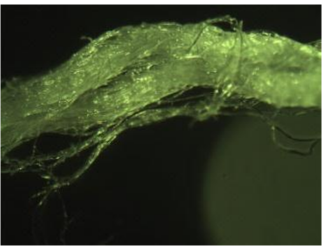
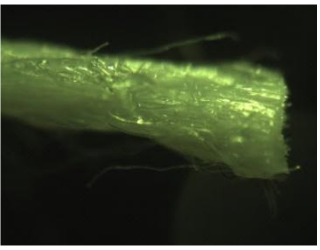
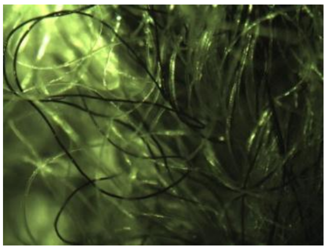
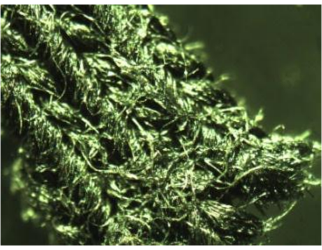
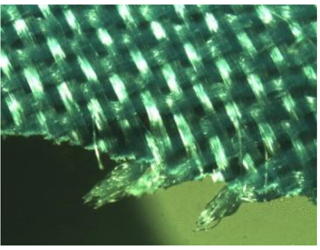
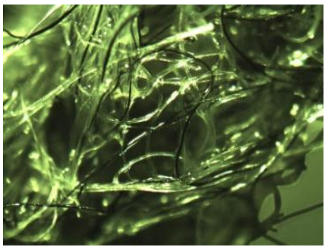
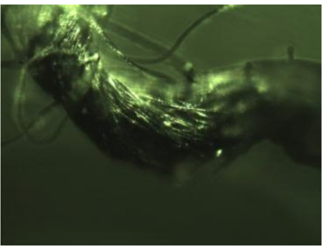
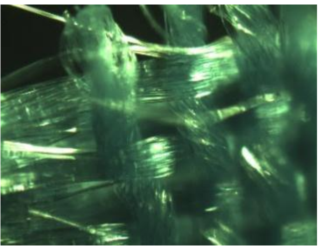
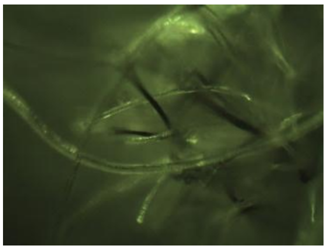
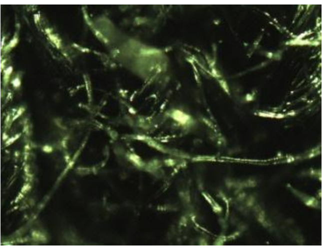
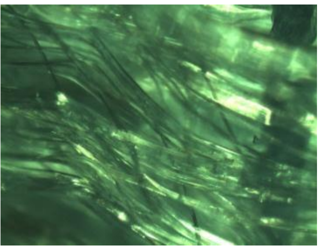
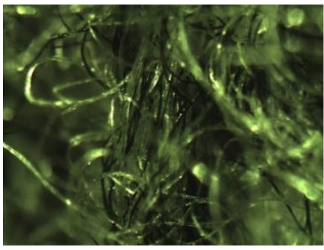
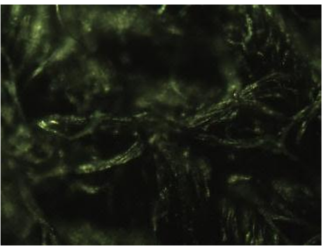
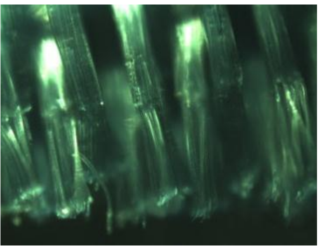
Source: http://en.wikipedia.org/wiki/SympaTex
Nomex (styled NOMEX)® is an aromatic polymer of polyamide. Due to its stable molecular structure it is used as a flame resistant fabric.

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 of fibres 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_2$0, 90 min. at 40°C pH = 10.74			
Mild detergent: Perwoll – care for fine fabrics (liquid) 5 ml in 250 ml $H_2$0, 110 min. at 40°C pH = 7.97			
soapsud: Fa Bar Soap Vitalizing Aqua 3 g in 250 ml $H_2$0, 180 min. at 40°C pH = 9.33			
soapsud: washing soda 2 tablespoons in 250 ml $H_2$0, 180 min. at 40°C pH = 11.26			
acidic solution: vinegar cleaner 5 ml in 250 ml $H_2$0, 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 such as coffee or red wine. During the washing process the bleach system consisting of a peroxide compound and TEAD (Tetraacetylethylenediamine) liberates 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 soaking 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 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 weakly 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 contain neither 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 harmful enzymes that damage the fibres.
There are some more special laundry detergents, e.g. 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 microbiologically 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, there have been several innovations in 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 germs or with people suffering from neurodermatitis, fear of pathogenic organisms, germs and body-odour. These antimicrobial textiles contain silver ions which stop the propagation of bacteria, hence removing bad smells of body odour (caused by caused by metabolites which are the result of the propagation of bacteria).

Some manufacturers use chemical additives such as quaternary ammonium salts, different kinds of the biopolymer (polysaccharide) Chitosan, or the antibacterial and antifungal agents as well as preserving agent. Triclosan is not used as a preserving agent 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, hence 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 affect the bacteria which gets into the textiles via sweat/perspiration. Hence, body-odour is prohibited as well as the settlement/colonization of pathogenic germs. The precious metal silver is known for its good skin tolerance and only rarely causes allergies. Although the textiles have been available for years, there are only a few studies regarding the effects and impacts on microbial particles. Up to now the question of the build-up of bacterial resistance, i.e. bacteria build-up of resistance to e.g. silver ions 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

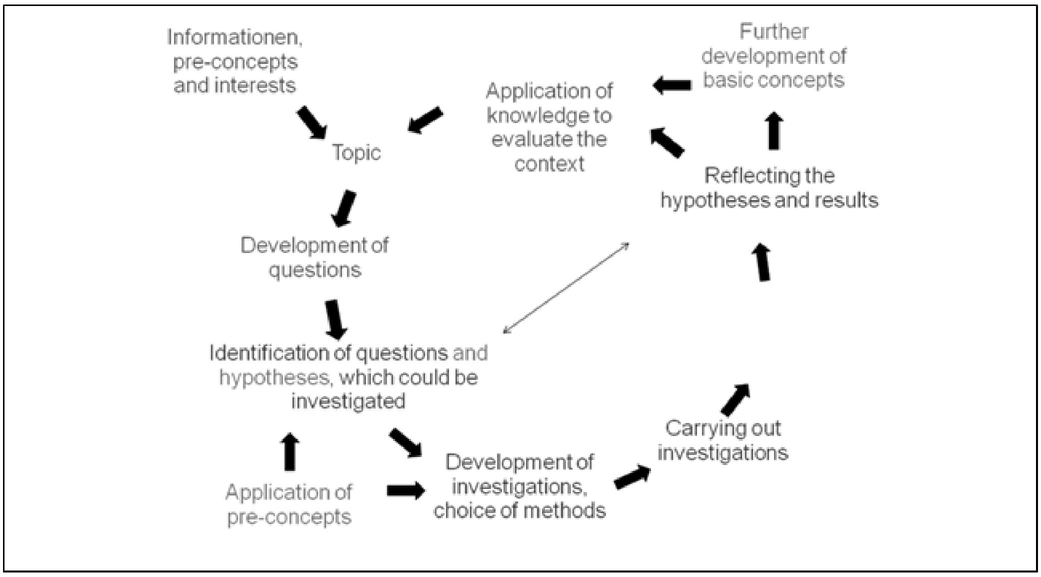
Henry Fountain “Anti-Odor Silver Exits Textiles in the Wash”. The New York Times. Published: November 2, 2009. http://www.nytimes.com/2009/11/03/science/ 03obsox.html

IV. Pedagogical Content Knowledge

The unit on chemical care aims 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.

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 places the activities in the students' home, this time focussing on cleaners and the use of chemical knowledge to their own and their families' health as well as care 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 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 retailing 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.)) to personal care products (shampoo, toothpaste, hair colorants etc. (Schauma, Fa, Diadermine etc.)) to adhesives, sealants and surface treatment products for consumer and industrial purposes.

In regard to possible links to industry, most activities deal with analyzing or working with an industrial product (either directly such as finding out about household cleaners or analysing different pieces of textiles, or indirectly such as consequences of acids on organic materials). Following are exemplary activities showing a connection to specific types of ICK:

- students are analysing household cleaners (subunit 1) as products from industry → ICK type 3
- students can discuss whether home-made cleaners (soaps) are “better” than industrial products (→ products made by chemical industry are often considered “bad” in the media; they will find out that home-made soaps cannot be “free of chemicals”, as is a popular advertising slogan) → ICK type 1 (link to industry, discussing social perception of products/science)
- possible visit to a community water treatment plant or production facility for cleaning agents → ICK type 2
- students will learn about how and why cleaners/fibres are produced and optimized in certain ways (subunits 2 & 3) → ICK type 5
- activities on acids → ICK type 1 (link to industry through using products for experiments)
- activities on designing the ideal fibre/cleaning agent → ICK type 4 (incorporating chemical knowledge and social/historical issues, dealt with in prior activities).

VI. Learning Path(s)

In all three sub-units, students are introduced to 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 behaviour 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 aims 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 will 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 the 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 will 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 informed arguments based on structure-property-knowledge, IBSE structure for engineers, and STS arguments.

Activity	Discipline	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 Further applications II	bounded inquiry	exploration
1.8 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
2.6 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:

Overall learning aims:

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 carried out chronologically by all students. Detailed material are available on the project website under classroom materials.

To start, divide the class into groups of “detective teams”. The following boxes gives 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.

The following activities are provided to illustrate opportunities for IBSE in the classroom. The optimal group size of 25 students is suggested. It is recommended that the student work cooperatively either in pairs or small groups. A textbook, the Internet or professional literature can serve as a source of information; digital technologies are an added value.

Activity 1.1: Formulating questions

Learning aims:

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.

Materials:

see classroom material

Suggestions for use:

The students can think about their questions in their detective team.

Activity 1.2: Formulating hypotheses

Learning aims:

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.

Materials:

see classroom material

Suggestions for use:

The students can present their hypotheses to the other teams.

Activity 1.3: Planning an investigation

Learning aims:

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.

Materials:

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 are used 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 aims:

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 carry out experiments responsibly as well as how to document them.

Materials:

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 aims:

Here students can link the chemical behaviour to household use. They learn to transfer their newly gained knowledge and apply it to daily life.

Materials:

see classroom material

Suggestions for use:

The students can solve this activity in team-work.

Activity 1.6: Further applications I

Learning aims:

Here students hypothesize which chemicals they could use to reduce risks in the household.

Materials:

see classroom material

Activity 1.7+1.8: Further applications II

Learning aims:

Here students investigate which chemicals can be used to remove different stains.

Materials:

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

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).

This activity 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. Heat the beaker 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).

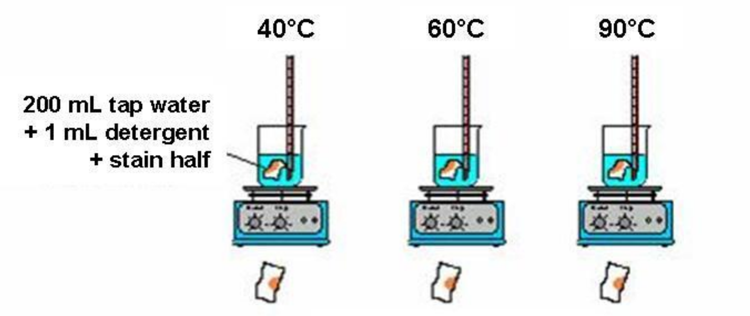
Regarding Worksheet 3:

Apparatus and materials:

3 beakers (250 ml); graduated cylinder (200 ml)l; 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 coloured 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 half of the stain will be washed and the other will be used for comparison. Mark the stain 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 time 40 minutes. Stir the liquid in each beaker by hand or with stirrer at medium.
- 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
Learning aims:
It depends on the facilities and regulations in each country whether the experiments with bacteria can be carried out. Here students investigate where potentially harmful bacteria can be found in the household and how they can be made visible. They transfer their knowledge to their household and reflect on this topic.
Materials:
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 to use 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 put into the dustbin or • contact hospitals or hygienic institutes to find out whether they will help with the disposal of them • burn outside and not in vicinity of people/schools.

SUB-UNIT 2:

Overall learning aims:

The students should learn how to apply and extend 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 are 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 described in sub-unit 1.

Activity 2.1: Which household products contain acids
Learning aims:
Here the focus lies on having the students state what they would like to find answers to.
Materials:
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 to 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. Providing an opportunity for incorporating ICT: students could use a pH-meter when dealing with household acids (quantify how acidic the solutions are; and for further activities how acidic it has to be to affect inorganic & organic substances, for example)

Activity 2.2: How much acid do we find in a household product?
Learning aims:
Here the focus lies on having the students state what they expect to find out.
Materials:
Experiment: see classroom material
Suggestions for use:
Students must be able to calculate volume-concentration-relations. Providing an opportunity for incorporating ICT: students could do titration with pH-meter to obtain digital neutralization curve (and use plotting software to digitalize results)
Possible questions:
Students formulate their own questions. A large amount of questions arise through this activity.

Activity 2.3: Why do companies include acids into cleaning products? – Intended effects
Learning aims:
Students explain the functionality of acids based on their chemical structure and reactions.
Materials:
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? – Unintentional effects

Learning aims:

Students learn to explain the functionality of acids based on their chemical structure and reactions.

Materials:

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.

For Activity 2.4.5:

- In the first research activity, students will check out companies (by a real or virtual visit or descriptions found online) and their treatment of acidic waste. Here, they might already find out about both neutralization and dilution as two options to decrease the concentration of acid in a solution.
- In the second part, students will themselves perform a neutralization and/or dilution. In both cases, the step-by-step change in acid concentration can be both measured and tracked by using pH-meters, for example, and/or calculated to visualize the change in acid concentration. In this activity, it would be nice to use acidic household cleaners, as they are the starting points of the students’ inquiry. A transfer to other acids used in the laboratory would also be possible.

Activity 2.5: Comparison of the effectiveness of different household detergents

Learning aims:

Students learn something about the effectiveness of household detergents because there are differences in their function, as e.g. only some are antibacterial.

Materials:

This activity is dependent on the facilities and regulations in each country whether the experiments with bacteria can be carried out.

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 the 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 exposure.

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 help with the disposal or
- burn outside and not in vicinity of people/schools...

Possible result after incubation:

Activity 2.6: The optimal cleaning reagent

Learning aims:

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.

Materials:

Results of Activities 2.1 - 2.5

Suggestions for use:

Students can assess both the desirable and undesirable properties of cleaners presented so far

SUB-UNIT 3:

Overall learning aims:

In this unit, students will use different types of fibres, both synthetic and natural ones. They will also become familiar with the fibres' synthesis, both in laboratory and in industry. While describing the use of fibres based on their properties, students will learn to differentiate between the macroscopic and the sub-microscopic levels.

Fibres in clothes:

Analyses of structures and properties including:

- Basic knowledge: classification of polymers
- Classification and structure (incl. pictures) of fibres (synthetic vs. natural fibres)
- Industrial production of fibres.

Activity 3.1: Analysing fibres

Learning aims:

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 analysed with regard to polymer mechanisms.

Materials:

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 sub-microscopic 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 analysed.
Students can also collect types of fibres from their own clothes and analyse them.
Providing an opportunity for incorporating ICT: students can make own pictures with digital microscopes.

Activity 3.2: The history of fibres

Learning aims:

This activity is to introduce students to the historical development of different fibres.

Materials:

Books or other resources, internet

Suggestions for use:

- Research activity in which students can gather information on the development 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
- Providing an opportunity for incorporating ICT: students can be shown historical movies or video clips on how fibres/fabrics were made historically; or research aspects for example about the historical development of a certain product can be included (industry websites)

Activity 3.3: Production processes of textile fibres

Learning aims:

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.

Materials:

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 carried out in groups
- Other processing methods (spinning and weaving methods) can also be covered.
- Providing an opportunity for incorporating ICT: teacher can use animations/simulations (video) on the process of making fibres or have a virtual visit to a plant producing a particular product
- Providing an opportunity for incorporating ICT: include aspect where students can create/watch 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, etc.

Fibres in products:

Interaction with weather (water, temperature), skin (moisture, temperature, skin) and washing detergents (different ingredients, temperature), including:

- 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 aims:

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.

Materials:

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 following experiments can be used as a starting point; encourage students to improve them, 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, e.g. a)each group performing the same experiments but with different textile samples or b) each group performing different experiments with the same material sample.

- Providing an opportunity for incorporating ICT: use (digital) temperature sensor for heating properties; (show video clip on properties of functional fabrics used for specific situations, e.g. from discovery channel: clip on marathon runner with normal clothes and with special running clothes in weather)

Experiments to examine the 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):

Activity 3.4a: Permeability regarding air

Materials

Plastic syringe (100 ml), stop watch, textile samples (e.g. cotton, polyamide, wool, silk, polyester, PVC); 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?

Activity 3.4b: Permeability regarding water (drops of water)

Materials

Plastic pipette, small beaker or small (marmalade) jar, textile samples (e.g. cotton, polyamide, wool, silk, polyester, PVC), 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?

Activity 3.4c: Permeability regarding water (jets of water)

Materials

Plastic syringe (100 ml), stop watch, textile samples (e.g. cotton, polyamide, wool, silk, polyester, PVC), 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?

Activity 3.4d: Permeability regarding 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); 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?

Activity 3.4e: 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); 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?

Activity 3.4f: 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); 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?

Activity 3.4g: Behaviour when heated

Materials

Hot plate, aluminium foil, marker, small pieces of textile samples (e.g. cotton, polyamide, wool, silk, polyester, PVC)

N.B. 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 aims:

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.

Materials:

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 defective 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 3.5a: 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:

- Find out about the underlying principle. Explain it. You may paint a model to explain the steps. (Search the internet for material and information)
- 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 their evaluations.

Activity 3.6: Keeping textiles clean

Learning aims:

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 analyse detergents in regard to their chemical composition.

Materials:

- Information material, such as textile care symbols and instructions
- Experiments investigating what happens when care instructions are not followed
- 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 to test. Instead of using beakers, students can use yoghurt cups but do not heat them!

- Students may work in teams of two: every team gets each type of sample fibre and tests their interaction with one detergent. They should prepare two different 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.

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 placed on either the current producers (producing countries) of different textiles or on working conditions in different countries, etc.
- Providing an opportunity for incorporating ICT: include aspect where students can create/watch podcasted interviews with experts working in the production or the management, giving information on how and why decisions are taken and new process initiated etc.

Activity 3.8: Ecological view on textile care

Learning aims:

Students learn about ecological consequences of detergents used to clean textiles.

Materials:

Variety of experiments

- 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

*for detailed experimental descriptions, see the following experiments

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.

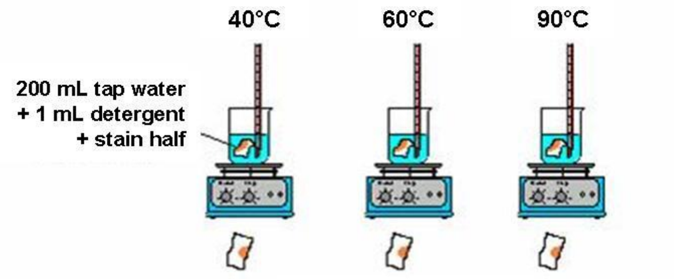
Worksheet 12: The influence of temperature on wash performance

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 coloured 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

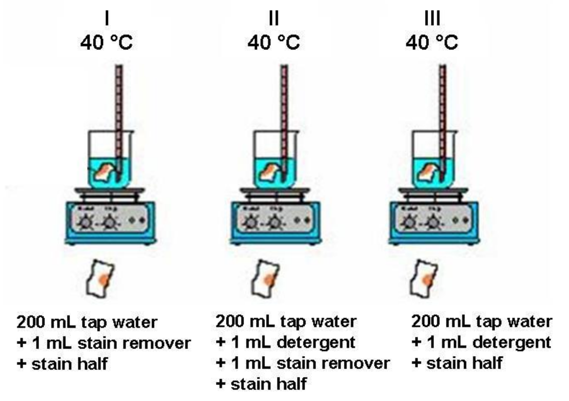
Worksheet 13: Improving wash performance by adding stain remover

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 coloured fabrics; 3 cocoa stains on cotton cloth; graduated cylinder (10 ml); stain remover

Procedure

- Cut out generous pieces of cloth, each with a stain in the centre, 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

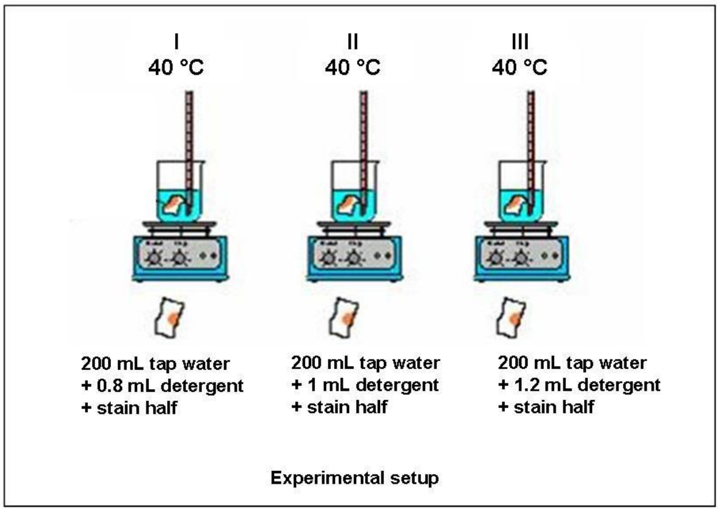
Worksheet 14: The effect of laundry detergent dosage and water hardness on wash performance

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 coloured fabrics; 3 cocoa stains on cotton cloth; graduated cylinder (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

Worksheet 15: The influence of laundry detergents on the growth of cress plants

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

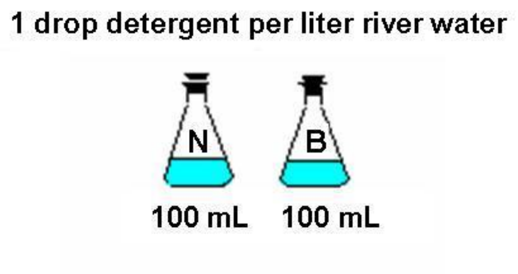
Worksheet 17: Part 2 Biodegradability of surfactants

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.



Experimental setup

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 aims:

Students familiarize themselves with the biodegradable fibres and discussed the possibility for their uses in textiles.

Materials:

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 aims:

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, or perfect detergent.

Materials:

Results of activities 3.1 - 3.9

Suggestions for use:

- Students can assess desirable and undesirable 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.

COSMETICS

The development of this unit has been led by the ESTABLISH partners:

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UNIT CONTENTS

I. Unit description

In this module, the students will explore the science behind cosmetic products (mainly that of emulsion creams): what are the main ingredients of cosmetic products, what is their effect on skin or their role in the product, and how cosmetics products are developed. Furthermore, the students themselves will develop a cosmetic product. Through this unit students develop their understanding of how the structure of matter is related to the properties of matter which is needed for understanding the technology of making cosmetic products. Moreover, students develop their understanding of possible advantages and disadvantages of industrial and home-made cosmetics.

- **Student level:** Students aged 16-19
- **Discipline(s) involved:** Chemistry, biology
- **Estimated duration:** 8 lessons

The cosmetics unit can be taught as an advanced course deepening the knowledge on organic chemistry, but also as part of the compulsory chemistry course under the topics of polymers and fats or, structure and properties of matter.

II. IBSE Character

In this unit students are given an opportunity to develop a variety of scientific process skills including aspects related to higher order learning:

- planning an investigation, discussing procedures, searching for relevant information,
- developing argumentation skills and/or making justified decisions, besides conceptual science acquisition,
- designing the product and developing tests in order to make a decision on the on the suitability of the product,
- discussing with peers.

III. Science Content Knowledge

Introduction

In order to develop a good cosmetic product, there are a number of different factors to consider: the purpose (is it meant to absorb unpleasant smell, moisturise the skin, clean the skin from grease, nourish the skin, etc.); whether the product is meant for men or women, what is the target age group, etc.

If the purpose and target group are already defined, then a number of other considerations must be taken into account: e.g. when the purpose is to moisturise the skin, then how to make it really moisturising, how can skin be moisturised for hours if we know that in normal conditions, water just dries off skin in less than half an hour. In addition, if the purpose is to nurture the skin, how can we guarantee that all active ingredients really penetrate the skin and reach to dermis. Therefore, it becomes very important to study the properties of skin and skin structure in order to develop a good product that would really “work“ as intended. The other important question is how to mix oils with water, common constituents of almost every cosmetic cream, if they are mutually insoluble, and even if shaken well, two layers will quickly separate: oil and water?

As every cosmetic product consists of tens of ingredients which must be dissolved beforehand whether in oil or water, the knowledge about principles of solubility of inorganic and organic substances is needed. There are a number of ingredients that are responsible for the “right“ thichness, certain durability, pleasant odor, needed effect, etc.

Different cosmetic industries worldwide contribute to the development of their products using the latest scientific achievements in order to improve the existing prodcuts and create totally new products to meet growing consumer demands. At the same time, probably, many of us have asked ourselves, whether these high-tech products are really better than those made by our ancestors from quite simple ingredients. Therefore, in this unit, students are invited to learn about the world of cosmetics and later given the oppotunity to develop their own products.

General principles of solubility

When a solid, liquid or gaseous solute is mixed with a solvent and it seems to disappear or become part of the solvent, we say that it has dissolved. The forces of attraction between the solute and solvent are the key to understanding their solubility. The general rule is "like dissolves like". In other words, a polar or charged solute will dissolve in another polar or charged solvent and a non polar solute will be insoluble in a polar or charged solvent. This means that ionic substances generally dissolve in polar solvents (like water) and non-polar molecules are generally soluble in non-polar solvents (like hexane).

Solubility of covalent molecules

To understand why "like dissolves like" the balance between the forces holding the solute and solvent particles together needs to be considered. Consider: (a) water (solvent) and (b) ethanol (solute):

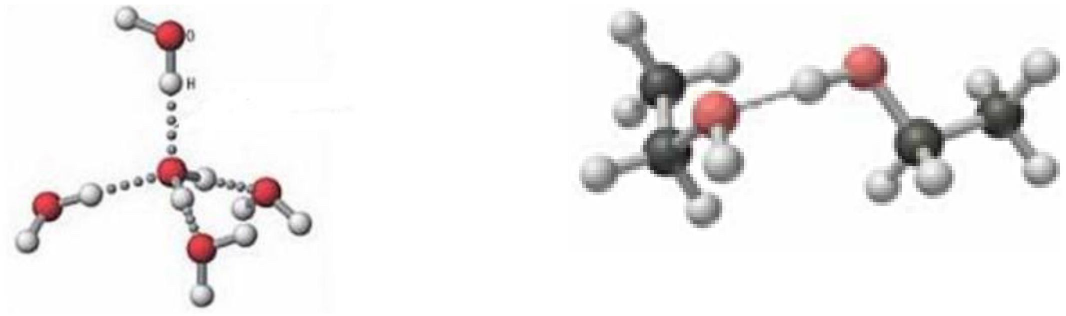


Figure 1. **Intermolecular forces between (a) water (left) and (b) ethanol molecules (right)**

Both molecules are polar which means that some part(s) of a molecule have positive and other part(s) negative charges. Molecular polarity, itself, is dependent on the difference in electronegativity between atoms in a compound. In the example shown in Figure 1, in both the water and the ethanol molecule, the oxygen is negatively charged and the hydrogen next to the oxygen, positively charged. Polar molecules interact through dipole–dipole intermolecular forces and hydrogen bonds. A hydrogen bond is the electromagnetic attractive interaction between polar molecules in which the hydrogen (H) is bound to a highly electronegative atom, such as nitrogen (N), oxygen (O) or fluorine (F). In the current example, the hydrogen bond exists between the positively charged hydrogen and the negatively charged oxygen and is marked by a dotted line in Figure 1. The hydrogen bond is not a true bond but an especially strong dipole-dipole force.

The force of attraction between water molecules and between ethanol molecules is weaker than the force of attraction between the water and ethanol molecules making ethanol soluble in water. For the dissolution process to take place, it is the hydrogen bonds between water molecules and the hydrogen bonds between ethanol molecules that are first broken. New hydrogen bonds are then formed between water and ethanol molecules, as illustrated in Figure 2.

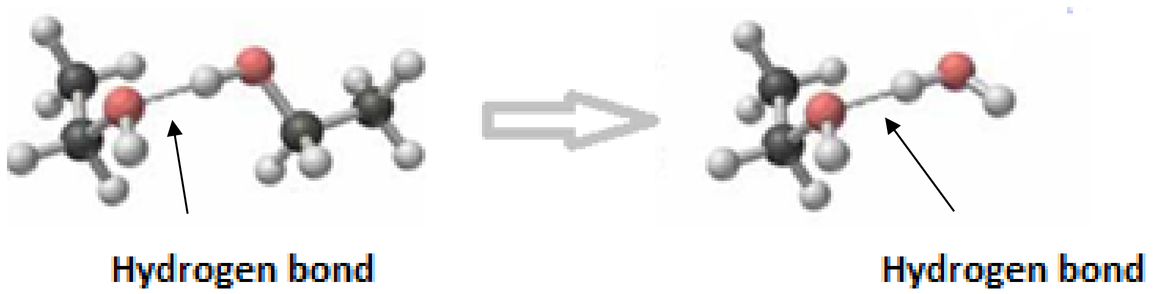


Figure 2. Hydrogen bond between ethanol molecules (left) and afterwards between ethanol and water molecules (right)

Short chained organic molecules with a polar head tend to be soluble in polar solvents like water. However, as the length of the non-polar hydrocarbon increases, the non-polar chain will eventually outweigh in size the polar *"head"* and the molecule will become insoluble in polar solvents. The molecule will now dissolve in non-polar solvents. Actually, small attractive forces, called van der Waals forces, exist even between non-polar molecules as a result of temporary internal shifts in the distribution of electrons within a molecule (Figure 3). The longer the chains the stronger the force between molecules.

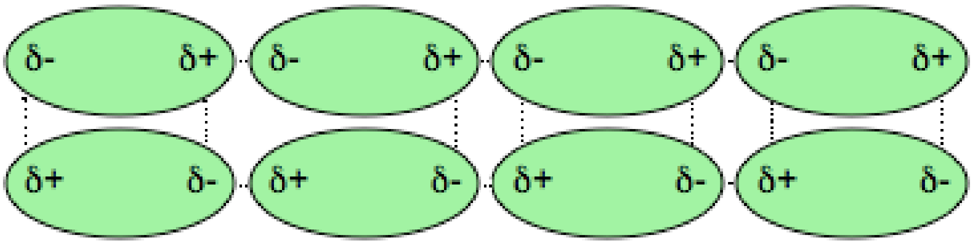
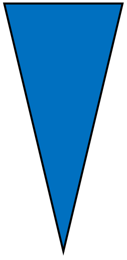
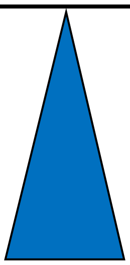


Figure 3. Van der Waals forces between molecules

Consider the table below which shows the solubility of alcohol in a polar (water) and nonpolar (hexane) solvent. All alcohols have a characteristic polar –OH functional group attached to the hydrocarbon chain.

Table 1. Solubility of alcohols in polar and nonpolar solvents

Alcohol	**Formula**	**Solubility in polar solvent (water) H_2O**		**Solubility in nonpolar solvent (hexane) C_6H_{14}**
methanol	CH_3OH	soluble		
ethanol	CH_3CH_2OH	soluble		
propanol	$CH_3CH_2CH_2OH$	soluble		
butanol	$CH_3CH_2CH_2CH_2OH$	insoluble		
pentanol	$CH_3CH_2CH_2CH_2CH_2OH$	insoluble		
....	...			
octanol	$CH_3CH_2CH_2CH_2CH_2CH_2CH_2CH_2OH$	insoluble		

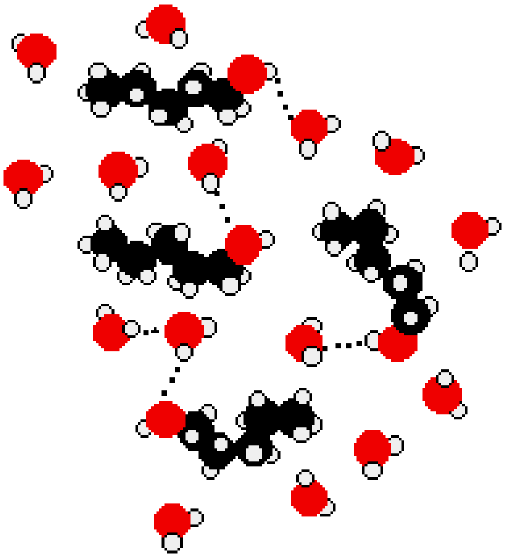


Figure 4. Hydrogen bond between molecules of pentanol and water

Consider what happens when alcohol pentanol is mixed with water (Figure 4). The hydrophilic OH end of alcohol molecules can form new hydrogen bonds with water molecules, but the non-polar hydrocarbon "tail" does not form hydrogen bonds. This means that quite a lot of the original hydrogen bonds being broken are not replaced with new ones. These attractions are much weaker meaning that pentanol will not mix with water and instead forms an insoluble layer on top of the water.

Therefore, when a polar solute dissolves in a polar solvent, the intermolecular bonds between the solute and solvent are broken and new intermolecular bonds are formed between the solute and solvent molecules. Nonpolar solutes at the same time, dissolve in nonpolar solvents. For example, relatively nonpolar oils and fats, while insoluble in water, are very soluble in nonpolar solvents (e.g. alkanes).

Solubility of ionic compounds

If an ionic substance dissolves in water, it means that the force of attraction that polar water molecules have towards ions is greater than the force of attraction that positive and negative ions in the lattice have towards one another. The partial negative charge of the oxygen atom of water is attracted to the positive metal ions of the giant ionic lattice and the partial positive charge of the hydrogen atoms of water are attracted to the negative non-metal ions.

Not all ionic compounds are soluble in water and most can be classified as either soluble, insoluble or sparingly soluble. As a general rule, a soluble substance is one where ≥ 1g of the substance dissolves in 100g of a solvent. In the case of an insoluble solute, ≤ 0.1g of a solute dissolves in 100g of a solvent. In the case of a sparingly soluble solvent, approximately 0.1-1g of a solute dissolves in 100g of a solvent.

In a chemical equation the process of NaCl dissolving in water is represented in the following way (Figure 5):

$$NaCl(s) + H_2O(l) = Na^+(aq) + Cl^- (aq)$$

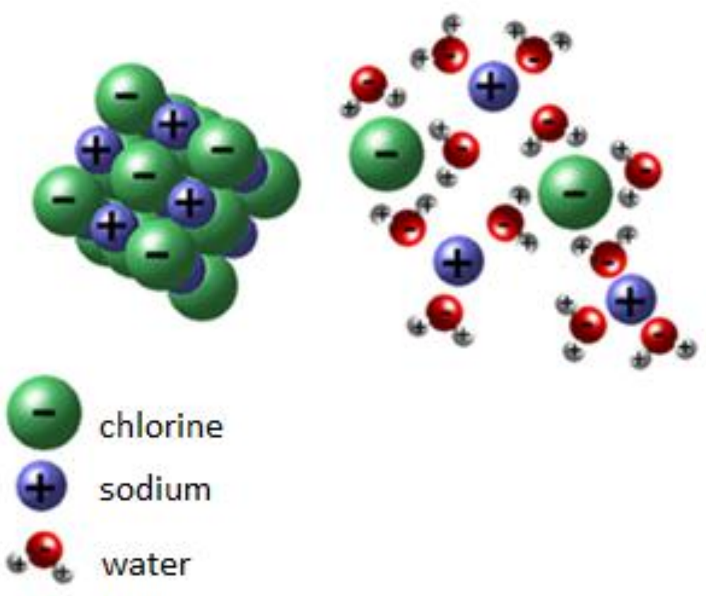


Figure 5. Process of NaCl dissolving in water

Table 2. The type of interations between solute and solvent

Solvent	Intermolecular forces between solvent molecules	Solute	Forces of attraction in solute	Solubility	Rationale
H_2O	Hydrogen bonds between solvent molecules	NaCl	Electrostatic attraction between Na^+ and Cl^- ions	Soluble	Soluble, because the force of attraction between Na+ and Cl- is weaker than the electrostatic force formed between polar water molecules and ions
H_2O	Hydrogen bonds between solvent molecules	C_6H_{14} (hexane)	van der Waals forces[1] between non-polar molecules	Insoluble	Insoluble because water molecules attract each other and hexane molecules attract each other more strongly than hexane molecules attract water molecules.
C_6H_{14} (hexane)	van der Waals forces* between non-polar molecules	C_6H_6 (benzene)	van der Waals forces between non-polar molecules	Soluble	Soluble because the attraction between non polar hexane and non polar benzene is stronger than the attraction between hexane molecules and benzene molecules.

References
http://en.wikipedia.org/wiki/Solubility
http://chemicalparadigms.wikispaces.com/file/view/4.5+Solubility.pdf

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[1] **van der Waals forces** are relatively weak electric forces that attract neutral molecules to one another in gases and in almost all organic liquids and solids.

The main ingredients of cosmetic creams

Cosmetic creams (lotions) are emulsions. Emulsions are dispersions where liquid substance(s) are dispersed or mixed with another liquid substance while the liquids actually do not mix microscopically. In cosmetic emulsions these are oils-fats as one part and water as the other part. This kind of a dispersion is not very persistent. Since oil drops are lighter than water, they accumulate quite quickly to the surface after shaking and form two separate phases: an oil phase and an aqueous phase. Therefore, emulsifiers are used to make the emulsion more persistent.

Oils and Fats: Oils and fats are composed of basically non-polar molecules (mainly C-C and C-H bonds) and are thus hydrophobic. Fats and oils are used to add to the lipid[2] layer on the skin. The lipid layer on the skin functions mainly as a barrier to protect the skin from the outside influences. It reduces the fluid loss from the epidermis by forming a thin film on the skin. It also fills the microscopic unevennesses and by that it makes the skin smoother and softer and reduces smaller wrinkles. Oils and fats with a low melting point are easily smeared onto the skin, whereas substances like wax that have a higher melting point can be quite solid; this, however, is useful in the case of lipsticks.

(a) Natural oils and fats

Herbal and animal oils and fats are triglycerides (esters[3]) that are formed of three fatty acid (usually composed of 16 or 18 carbon atoms) and one glycerine (alcohol) molecule. They are almost non-polar and hydrophobic substances. Natural oils and fats are never pure substances, rather they are a complex mixture of triglycerides and various additives.

When fatty acid residues in the fat molecule consist of double-bonded carbon atoms, they are called unsaturated fatty acids; when there is a single bond between carbon atoms then they are called saturated fatty acids. Fats composed of unsaturated fatty acid residues are more liquid-like than those composed of saturated fatty acid residues and are thus more appropriate to be used in a cream; at the same time it makes the fats more reactive to being

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[2] **Lipids** are biolmolecules with an ester-like structure. They are composed of at least two components: an alcohol and a fatty acid. Fats, oils, waxes, steroids and other water-insoluble compounds are lipids.

[3] **Esters** are formed as a result of a reaction between a carboxylicacid and an alcohol. The general formula is R-COO-R’

$$\text{R-COOH} + \text{R}'\text{OH} \rightleftharpoons \text{RCOOR}' + \text{H}_2\text{O}$$

oxidised by oxygen from the air. The latter process is called rancidification. As a result of rancidification, the smell, taste and/or the appearance of fats changes. In the Figure 6, one can see that the molecule is composed of two saturated and one unsaturated fatty acid residues.

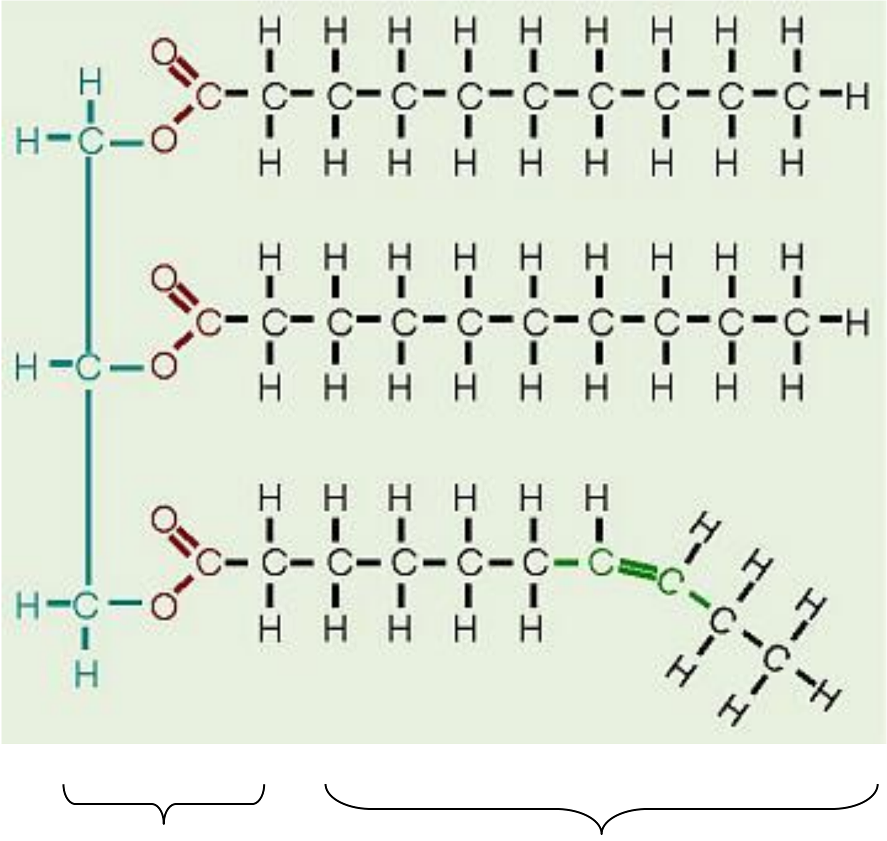


Figure 6. The structure of fats

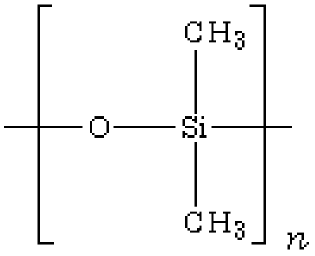
(b)Synthetic fats and oils

Synthetic fats and oils are much more tolerant to oxygen from the air since they do not contain multiple bonds like herbal fats/oils. However they do not break into essential fatty acids like natural fats. Hydrocarbons (paraffin, vaseline and other petroleum products) and silicones form an impermeable film on the skin and reduce the skins natural resilience when used for a long time.

Vaseline and mineral oils (paraffinum liquidum, petrolatum, petroleum jelly) – petroleum products; mixture of hydrocarbons, mainly that of alkanes, where the number of carbon atoms in the molecule is usually > 25. Vaseline and mineral oils soften the skin and dissolve other hydrophobic substances. They are often used in hand creams, but mainly still in cheaper products.

$$H(-CH_2-)_nH$$

Silicones are polymers containing silicon. Dimethicone is one example of a silicone. It forms an extremely efficient water-repellent film on the surface of skin or hair. Silicones are used a lot in hair care products.

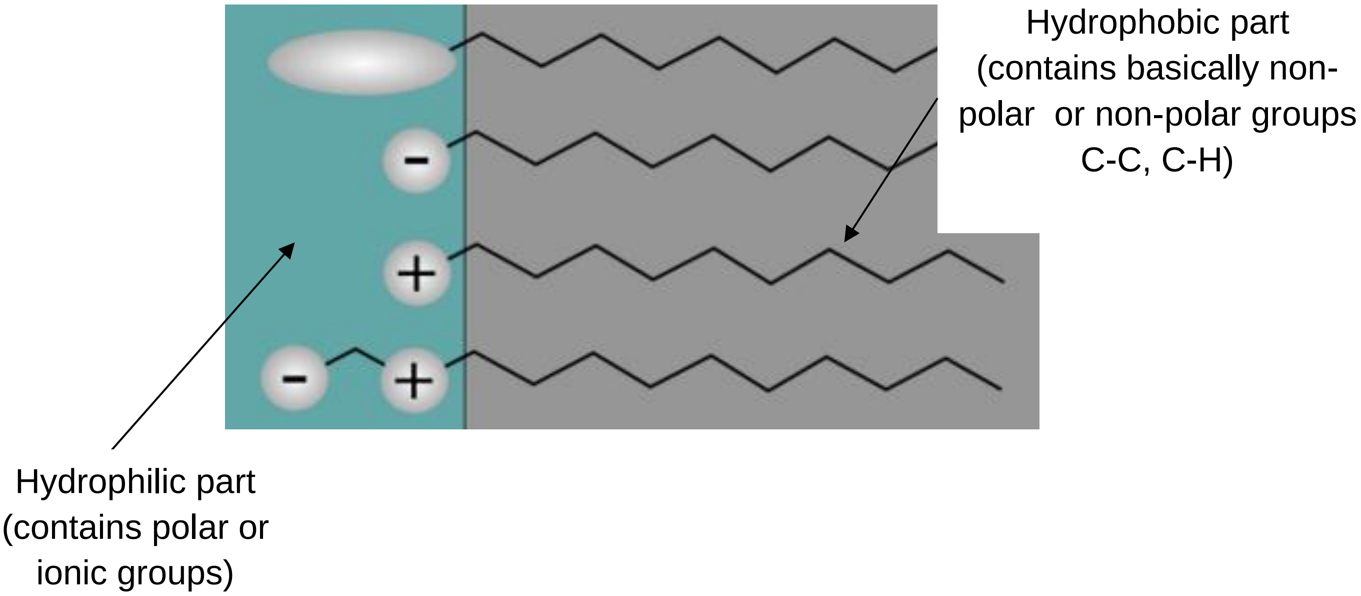


Polydimethylsiloxane (PDMS) or dimethicone.

Emulsifiers:

Emulsifiers are used in creams and other emulsions in order to mix two phases that do not mix: the oil phase and the aqueous phase. This makes the system more stable.

The typical emulsifier molecule is rather bulky and mostly non-polar making it hydrophobic and dissolvable in fat (directed towards the oil phase) Figure 7. The polar and hydrophilic end is directed towards the aqueous phase.



Hydrophobic part (contains basically non-polar or non-polar groups C-C, C-H)

Hydrophilic part (contains polar or ionic groups)

Figure 7. Comparison of different types of emulsifiers

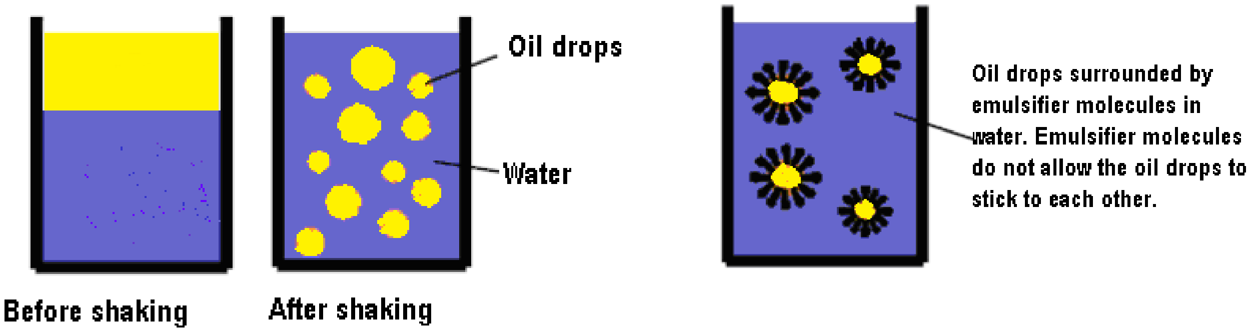


Figure 8. Emulsion without emulsifier (left) and emulsion with emulsifier (right)

(Source: http://www.makingcosmetics.com/articles/02-making-emulsions-for-cosmetics.pdf)

There are 2 types of emulsifiers (Figure 8, 9): oil in water (o/w) and water in oil (w/o). Night creams and sunscreens are often w/o- type of emulsions that are quite greasy. Body lotions and day creams are o/w-type of emulsions that are lighter and moisturise better.

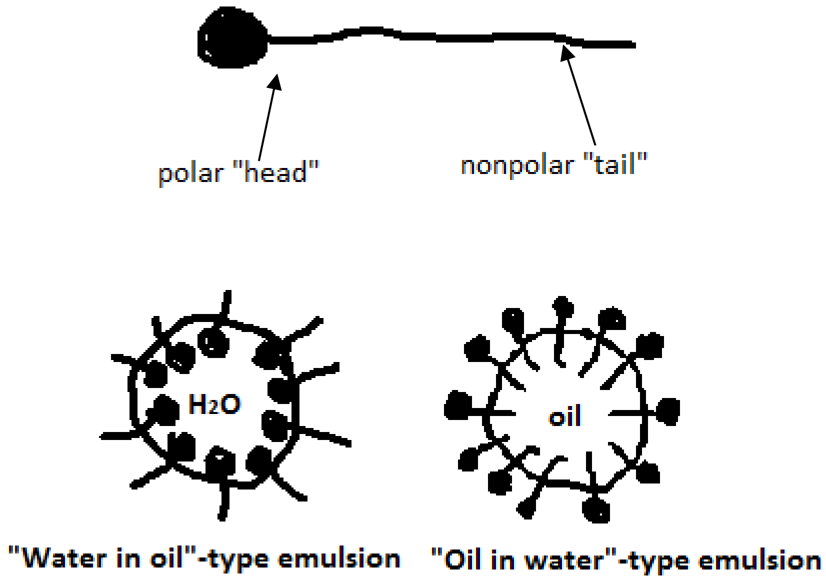


Figure 9. A comparison between water in oil and oil in water type of emulsions

Skin

Skin is very important as it covers and protects everything inside your body. Skin holds everything together. It also protects our body, helps keep it at just the right temperature and, through nerve endings close to the surface of the skin, allows us to have the sense of touch.
However skin can become infected with bacteria, viruses and fungi, and can be irritated by chemicals or other substances it is in contact with. Skin is also exposed to sunlight, and can suffer as a result.

Skin is composed of two parts (see Figure 10) – dermis and epidermis. The upper most layer of epidermis is called stratum corneum. Stratum corneum is made up of keratinuous dead cells. This is the part of skin and body that is peeled off daily. New skin cells are formed in the lower, e.g. basal layer, which is always forming new cells through cell division. The new cells gradually move towards the surface, which takes 1-2 months. As they move up they gradually die, become flattened and develop keratin and the outermost layer of flat dead cells is being continually worn away by friction.

The keratin and oil from the sebaceous glands help to make the skin waterproof. Keratin is the substance that hair, nails and horns are made of. The thickness of stratum corneum can easily be measured in cell layers — it is thickest under the heels, with some people having more than 100 cell layers. The thinnest stratum corneum covers the genital organs, for example the penis has only 6 cell layers.

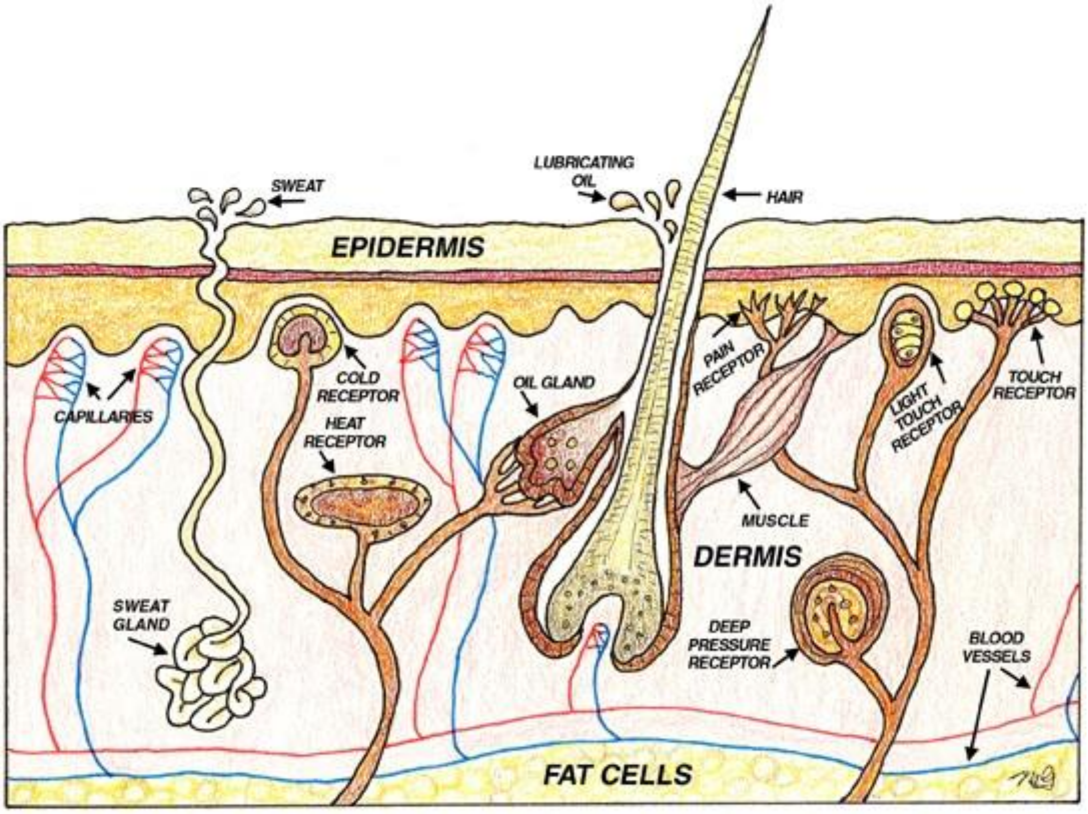


Figure 10. The cross-section of skin

(Source: http://www.infovisual.info/03/036_en.html)

The **dermis** is the inner layer. The following tissues and structures can all be found in the dermis:

Connective tissue – packs and binds the other structures in the skin.

Elastic fibres – make the skin resilient.

Capillaries – tiny blood vessels.

Muscle fibres – to move the position of the hairs.

Sensory cells – to sense touch, pressure, heat, cold and pain.

Nerve fibres – to activate muscles and glands and relay messages from the sensory cells to the brain.

Pigment cells which produce melanin, a very dark pigment.

Sweat glands which open onto the surface as pores

Hair follicles – pits in the epidermis in which hairs grow.

Sebaceous glands – produce oil to keep hair follicle free from dust and bacteria, and to help the skin become more waterproof.

There is a layer of fat underneath and in the lower regions of the dermis. The thickness of this layer varies depending on the part of the body and from person to person. A store of fat is useful to the body as insulation and it can be used for energy when the intake of nutrients is insufficient.

Skin has many functions:

- Control of body temperature
- Stops infection
- Acts as a waterproof barrier
- Protects delicate tissues underneath
- Heals itself when damaged

Temperature control

Body temperature is normally 37ºC regardless of the temperature of the surroundings. It is controlled by a feedback system, that is, information about the temperature of the body, for example from the temperature sensitive receptors in the skin, is fed back to the hypothalamus, the temperature-regulating centre of the brain. The brain then sends messages to parts of the body, including the skin, to keep heat in or to lose excess heat.

Other feedback systems are used in controlling the amount of glucose and water in the blood.

Keeping temperature, glucose and water at the right levels is known as homeostasis and is important for the chemical processes of the body to work properly.

A waterproof coat

Keratin in the epidermis and oil produced by the sebaceous glands help to make our skin waterproof. This means we do not “go soggy” in the bath or dry up in the sun.

Stopping infection

Millions of microorganisms live harmlessly on the skin and in the air around us. The skin forms a very effective barrier to stop them entering the body unless damaged, when infections can occur.

Skin colour

Melanin is a pigment that gives skin a colour from pink through brown to black. People are different colours because their skin contains different amounts of melanin. Melanin protects skin from ultra-violet (UV) radiation. When skin is exposed to the sun, more melanin is produced and the skin darkens. An albino person has skin which contains no melanin. Therefore they have no natural protection from UV rays. Their skin must be covered up in sunlight.

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IV. Pedagogical Content Knowledge

The most difficult part for students will probably be the understanding the relationship between the structure of matter and the properties of matter: what makes a molecule hydrophobic or hydrophilic; how to choose the right solvent for a particular substance, etc. The task for a teacher is to develop students' understanding that (1) there is a quite sophisticated science behind cosmetics, (2) science knowledge can contribute to the production of better products, and (3) there are always a number of pros and cons of industrial as well as home-made cosmetics.

Overall aims/competencies: The students are expected to be able to:

1. Propose ideas as to why we should make cosmetic products ourselves and what are related pros and cons.
2. Search for relevant information from the Internet and library resources.
3. Critically analyse the ingredients of cosmetic products and make decisions about their quality.
4. Understand the general principles behind the ingredients of cosmetic (emulsion) creams; based on his/her scientific knowledge be able to explain what role the ingredients play in the cream and explain their effect on the skin.
5. Make an emulsion cream from simple ingredients on their own
6. Work as a team in looking for information, analysing, planning the experiment and presenting the product
7. Present the product to others in a persuasive manner
8. Use the correct terminology related to the topic both orally as well as in written format.
9. Use creative thinking in designing the product, the commercial, and making up tests in order to be able to answer whether a self-made product is usable
10. Be aware of the careers related to cosmetics industry

The learning content as defined by the syllabus: Hydrophobic and hydrophilic substances, chemical bond, polar and non-polar substances, principles of solubility, emulsion, emulsifier, fats, the structure and functions of skin.

The types of activities: Searching for information from various sources, analysing the ingredients of cosmetic products, designing the product (from idea to implementation and marketing), producing a commercial and presenting it to the class, testing the properties of a product against determined criteria, making a decision on the suitability of the self-made product in place of analogous commercial products.

V. Industrial Content Knowledge

Cosmetic industry

The cosmetic industry is currently dominated by a small number of multinational corporations that originated in the early 20th century, but the distribution and sale of cosmetics is spread among a wide range of different businesses. The world’s largest cosmetic companies are The L'Oréal Group, The Procter & Gamble Company, Unilever, Shiseido Company, Limited and Estée Lauder Companies, Inc.

The cosmetic industry worldwide seems to be continuously developing, now more than ever with the advent of the Internet companies. Many famous companies sell their cosmetic products online also in countries in which they do not have representatives.

Besides well-known international companies, there is a growing trend in the World, to produce almost hand-made cosmetics with limited production using natural or almost natural raw materials and cosmetics manufactured in a way that is environmental-friendly. For consumers of this type of production it is important that they can buy good, unique and well-produced products, not available from mass market retailers. Each manufacturer brings their own design and creativity to their products. Sometimes, hand-made goods of a company become so popular that they outgrow from a small enterprise and become a well-known brand.

One such example is the UK’s company “Lush”, which was established in 1994 by Mark and Mo Constantine[4]. There are now 830 stores in 51 countries. Lush produces and sells a variety of handmade products, including soaps, shower gels, shampoos and hair conditioners, bath bombs, bubble bars, hand and body lotions and face masks.

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[4] The following text is adapted from http://en.wikipedia.org/wiki/Lush_%28company%29

Lush products are made in factories around the world (including Poole, Dorset and Vancouver, Canada), and are made in small batches based on orders from individual stores to ensure the freshness of the product. Stores do not sell products older than four months and most products have a total shelf life of approximately 14 months.

Lush products are 100% vegetarian, 83% vegan, and 60% preservative-free and feature grapefruit juice, vanilla beans, avocado butter, rosemary oil, and fresh papaya and coconut, etc. Typically, these products are free from packaging. Lush does not buy from companies that carry out, fund, or commission any animal testing. Lush tests its products on human volunteers before they are sold. Their aim is to have 100% of their packaging easily recyclable, compostable or biodegradable. Although many opponents exist because of their radical political actions related to animal rights, etc., their products are continually popular among consumers.

An Estonian success story is JOIK which is a small factory whose hand-made products quickly became popular amongst consumers. Their[5] story of success began in 2005, when company founder Eva-Maria Õunapuu was searching for high-quality scented candles that she could burn during dark and cold autumn and winter evenings. However, finding suitable candles turned out to be harder than expected. She did not want to burn petroleum-based paraffin candles and was constantly disappointed in the aromas of scented candles. The solution was to get into the exciting world of scented candles herself and thereby learn to make high-quality, clean-burning candles that are true to the promised aroma. She discovered that a suitable alternative to paraffin was natural soy wax. The next step then was to find the desired aromas. The process of getting the candles exactly right was long and full of nuances. However, it was worth the effort and eventually the candles turned out so good that other people also developed an interest for them. Therefore, the idea to start selling candles was born.

Step by step the hobby turned into a business and a successful company grew out of it. Over the years natural cosmetics products were added to the line, starting with soaps, body oils and body creams, bath products. Later a hand and foot care as well as a facial range were added. The most important

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[5] The following text is adapted from http://www.joik.eu/our-story/the-company/

aspect of JOIK products has always been the high-quality ingredients that are as natural as possible. A long process of research and testing precedes the launch of all new JOIK products – all for the satisfaction of their clients.
JOIK is now the most successful Estonian natural cosmetics brand. JOIK products are sold in stores all over the country, but also in Europe and in Asia.

Careers related to cosmetic industry

Different types of jobs in the cosmetics industry include production, research, testing, sales and application. Like any industry, there are also a number of management positions. Various career paths in the cosmetics industry more related to science, are introduced below.

Scientists in the cosmetic industry[6]

There are literally thousands of scientists working in the cosmetics industry and the number of jobs continues to grow. This is an industry that continues to sell products even in uncertain economic times. There are various types of companies that employ cosmetic scientists and chemists. These include manufacturers of finished goods, contract manufactures, raw material suppliers, and testing laboratories. The most common degree required of a cosmetic scientist is a Bachelors' degree in Chemistry, Chemical Engineering, Biology or Microbiology, and to a lesser extent a degree in Physics; bigger companies like Procter & Gamble or L'Oreal tend to favour students who have a Masters or a PhD degree in cosmetic science.

A person looking to work as a scientist in the cosmetic industry, has a wide range of jobs to choose from:
a. **Cosmetic Formulator** – If one likes inventing and creating (e.g. the newest lipstick formula, or a biodegradable nail polish), the position of a formulator is probably the best choice. Most of these jobs are with finished goods and contract manufacturers[7]. Some raw material suppliers employ formulators in their technical services departments.

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[6] Adapted from http://chemistscorner.com/how-to-become-a-cosmetic-chemist/

[7] A contract manufacturer is a type of manufacturing business that specializes in producing goods for a client, based on specific criteria that is provided by that client.

b. **Quality Control Chemist –** This position is ideal for someone who likes gas chromatography, infra-red spectroscopy, and mass spectrometry. Every company in the industry hires this type of scientists.

c. **Analytical Services** – This area of work is closest in the industry to scientific research. Most raw material suppliers and finished goods manufacturers have analytical departments.

d. **Process Engineering -** This profession involves work very similar to building things and engineering. Almost any cosmetics company with manufacturing facilities will hire PE scientists.

e. **Synthesis Chemist** – For those who love organic chemistry, raw material synthesis is an appropriate career choice. Most of these jobs will be with raw material suppliers.

f. **Regulatory Scientists** – For people who like science but do not like to be in the lab, working as a regulatory scientist is a suitable alternative. Nearly all companies hire regulatory scientists and even more jobs are being added, because more governmental regulations make it more complicated to create innovative cosmetics.

g. **Marketing (sales)** – A career in marketing is suitable for somebody who likes communicating to peole and at the same time wants to work with cosmetics in the cosmetics industry. Professionals in cosmetics marketing manage research focus groups, promote the desired brand image, and provide other marketing services (sales forecasting, allocation to different retailers, etc.).

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The main ingredients of cosmetic creams

As manufacturers have to present the ingredients of a cosmetic product according to the requirements of INCI (International Nomenclature for Cosmetic Ingredients), the ingredients' names below are given according to INCI (in latin). This will also be helpful in looking for information from the internet. The list of ingredients on the package of the product must be presented in the order of decreasing content percentage.

Most often used natural fats and oils in cosmetic products

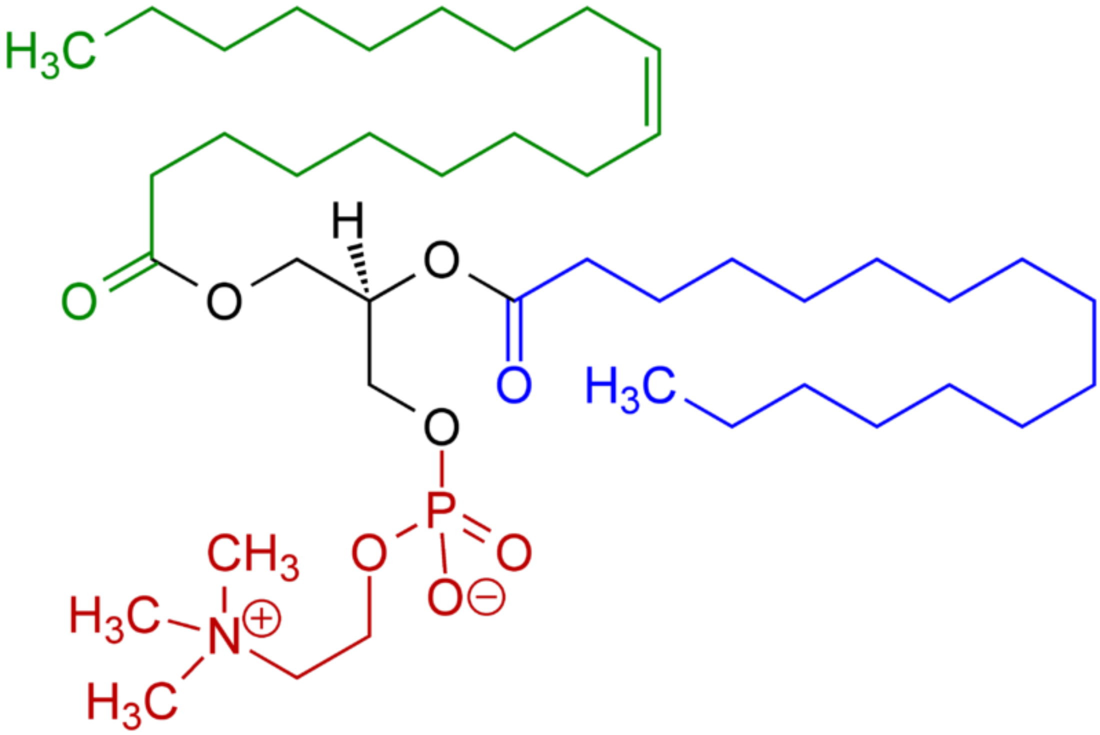
- Cocoa butter – a liniment with a balmy chocolate smell, heals, moistens and softens (rough, dry) skin and is thus recommended to be used for smoothing scars, spots and other skin defects and treat sunburn. It has an anti-wrinkle effect and makes the skin more elastic. Cocoa butter is a natural cream thickener that stabilizes an emulsion. Creams usually contain 3-6% and balsams 6-60% of cocoa butter.
- Grapefruit seed oil – it is known as a natural preservative and is sometimes added to the soap mixture in cold process soap making. Since it contains antioxidants, it is an antibacterial oil and is suitable for problematic and sensitive skin. Because it contains a lot of vitamin C, it is good for making creams (including anti-acne), lotions and serums.
- Coconut oil – coconut oil is one of the basic ingredients of soap and cream. It adds firmness (strength) to soap and makes it foam nicely as well as softens and smoothens skin. It is used in making creams, emulsions, soaps and shampoos, and in ointments, baby care products, protection creams and bath oils.
- Shea butter – shea butter is good for skincare; it is moisturizing, smoothening, anti-ageing and anti-inflammatory; it has a calming effect, treats micro wounds; to some extent protects against UV-radiation. It is added to emulsions, creams, sunscreens and after-sun lotions, moisturizing creams, body liniments and to ointments in the range of 3 to 100%.
- Sweet almond oil – it is one of the most popular oils for making cosmetics. It is squeezed from the fruit cores of the almond tree. It is suitable for dry and sensitive skin, has a wonderful skin moisturizing and smoothening effect, vitalizes and absorbs well into the skin, treats chapped skin. It is added to creams, emulsions, ointments, bath oils and baby care products.

- Raspberry seed oil – cold-pressed raspberry seed oil contains a lot of E- and A-vitamins that make the oil a wonderful skin care product. It protects the skin from free radicals and offers protection from sun radiation. Because of this, the oil is used in eye creams, lip balms and face creams.
- Castor oil – castor oil has a diverse skin softening and smoothening effect. It is used in creams, emulsions, hair care products, bath oils, sunscreens, lip balms and lip balsams.
- Avocado oil – this oil contains A, B1, B2, D and E vitamins. It has a healing effect on skin diseases such as psoriasis and eczema. It is a natural sunscreen and contains natural antioxidants. It is used in creams, emulsions, body liniments including lip liniments (lip balm), products usually contain 4-20% of avocado oil.
- Olive oil – olive oil moisturizes the skin, increases its elasticity, reduces signs of aging and rejuvenates skin. It can be used by itself or in mixtures with other luxury oils to make a perfect face serum.
- Grape seed oil – this oil absorbs well and is slightly astringent; it is a non-greasy softener with a tonic effect. Because of these characteristics the oil works best for problematic and impure skin. It can be added in the amount of 1-100% to creams tonics, massage oils and bath oils.
- Rose hip seed oil – it is a wonderful softener and moisturizer, helps treat surgical wounds, burns, eczema, reduces wrinkles and is ideal for stressed skin. In an undiluted form it is used as a massage oil. In creams, emulsions, bath oils, tanning and baby care products it is used in the range of 1-100%

Emulsifiers

a) Water/in oil type of emulsifiers

- **Lecitine** – it is added to the oil phase before mixing. Used in creams, ointments, body gels, shampoos, sunscreens, body liniments and decorative cosmetics.
- **Egg yolk**
- **Sorbitan monostearate**
- **Triglyceryl monooleate**

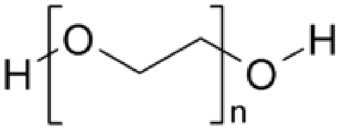


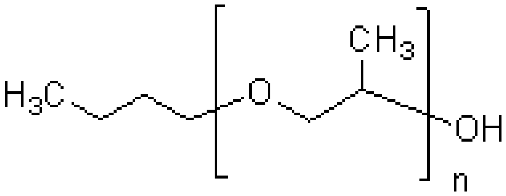
Lecitine (Source: Ju)

b) Oil/ in water type of emulsifiers

Stearic acid – emulsifies and thickens, gives the skin a slightly waxy feel and a shiny and cooling effect. It is usually added in the range of 2-10%. Extensively used in soaps, creams, emulsions, in protection and shaving creams and other skincare products.

Polyethylene glycols (PEG) and polypropylene glycols (PPG)





They can act both as emulsifiers and as fat-like substances. The number behind the abbreviation represents the number of elementary links in the molecule. For example, PEG-40.

Polysorbate

Cetearyl alcohol – contains molecules consisting of 8-22 carbon atoms. Makes up 1-5 % of the total mass of a cream. It is added to both w/o as well as to o/w type of emulsions

Octane-1-ol

Waxes

Waxes are complex mixtures of alcohols, fatty acids and esters. They are harder, less greasy and highly resistant to humidity, oxidation and microbiotic degradation. Waxes are very useful ingredients in cosmetic products due to their protective, softening and thickening properties as well as for the fact that they form a film. They increase the persistence and viscosity of cosmetic products and make them more even.

- **Bee wax** – non-congealing thickener, emulsifier, forms a film, slightly anti-bacterial, softens the skin. Melted by heating to a temperature of 61-68^{o}C. Products can contain 2-40% of bee wax. Used in creams, emulsions, pomades, liniments, lipsticks, mascaras, eye shadows, ointments, protective creams.
- **Carnauba wax**
- **Candelilla wax** etc.

Thickeners and constituents of the base

Fats and fat-like substances as well as emulsifiers already act as thickeners. Nevertheless, special thickeners can be added—usually polymers, e.g. carbomers, corn starch, modified starch, xanthan gum, cellulose gum etc. Some salts such as calcium chloride, sodium chloride and magnesium sulphate also have a thickening effect.

Sunscreens

UV- light is essential for humans since it creates vitamin D that helps develop bones. Melamine in the skin might not protect the skin enough from harmful UV-radiation. Sunscreens either reflect or absorb UV-radiation. Substances that reflect radiation are for example (powdered):

- TiO_2 – titanium dioxide
- ZnO – zinc oxide

Humectants

Humectants are important ingredients of cosmetic products that help avoid and maintain the moisture loss of the skin. Strateum corneum can protect the skin efficiently only when it contains enough water. Skin becomes dry and develops cracks when the water level decreases. Microbes can enter via the cracks and the dryness of skin causes itching. The moisture content of skin can decrease when a person is smoking or due to dry air and of course when the skin ages. The natural humectants between two skin cells are amino acids and sugars. The main characteristic of a humectant is the ability to strongly bind water (via hydrogen bonds). Humectants are not only added to skin care products but also to hair care products, to add volume to hair. This group includes a number of proteins, acids, polysaccharides and some smaller molecules: polyhydroxyl alcohols such as glycerine, hexane-1,2,3,4,5,6-hexaol (sorbitol), propylene glycol, but also urea and amino acids such as aloe vera juice.

Preservatives

Cosmetics are a good surface for bacteria, viruses and fungi since the products contain water, oils, peptides and sugars. Because of this, various cosmetic products require preservatives or have a short life span.

- **Grapefruit seed oil** – (look at previous pages). This can be added to warm or cold mixtures before adding the odour. Products usually contain 0.5-1% of the oil (2-3% in the case of more complex mixtures). It is not enough for long term preservation and is thus combined with different parabens.
- **Potassium sorbate, sodium sorbate**
- **Sodium bensoate**
- **Parabens** – commonly found in cosmetic products from stores. They are absorbed easily and quickly through the skin and get into the blood circulation within tens of minutes after use. Studies have shown that they mimic the body`s own hormones and can thus interfere with the endocrine systems. The best known parabens are methylparaben and ethylparaben.

Antioxidants

Antioxidants are active components of cosmetic products. Generally they help to stop oxidation reactions and bind free radicals (e.g. peroxides). Both of these processes ruin the functions and integrity of natural substances. Antioxidants are useful in two ways: they prevent the degradation of natural ingredients (proteins, carbohydrates, fats) in a cosmetic product; and at the same time they protect the skin cells and slow down aging-related processes.

Antioxidants have become useful substances that help make the skin more shiny and decrease signs of aging.

- **Vitamin E** (tocopherol) and its derivatives – besides having an antioxidant effect they also moisturize, are anti-aging, repair the skin relief, soften and are anti-inflammatory. They also stimulate the growth of skin cells and the activeness of enzymes. They are added in the range of 0.5-2.5% to have an effect on the skin and in the range of 0.1-0.5% to stabilize the fat- and oil-containing product. Used in various skin and hair care products. Added to the oil phase.
- **Vitamin C** (L-ascorbic acid) and its derivatives – besides having an antioxidant effect it is also anti-aging: it repairs skin elasticity and stimulates the formation of collagen, avoids over-pigmentation, is anti-inflammatory. Added to the aqueous phase, usual content of 0.2- 4%. Used in emulsions, creams, post-tanning products etc.
- **Vitamin A** – promotes skin regeneration. Promotes epithelium and keratin formation, anti-wrinkle properties. It is useful to freeze it in order to preserve it. Should be put into a warm-water bath to melt and add to the product as the final ingredient. Average amount of 10 drops per 100g of cream. Used in all sorts of skin care products, especially in nutritive and sunburn creams.

Skin peeling agents

Skin peeling agents work in two ways: via mechanically and chemically removing dead skin cells. Various herbal flours, but also sugar and salt crystals are mechanical peelers. Weak acids such as lactic acid, citric acid and malic acid are chemical peelers and they dissolve in the space between two cells—this causes the release of the cells on top. As a result of the peeling, the skin becomes more shiny and the effect of other cosmetic products increases as they can get deeper into the skin. The top layer of skin recovers very quickly.

Alpha hydroxy acids (AHA’s)

AHA’s most commonly used in cosmetic applications are typically derived from food products including glycolic acid (from sugar cane), lactic acid (from sour milk), malic acid (from apples), citric acid (from citrus fruits) and tartaric acid (from grape wine). For any topical compound to be effective, including AHA, it must penetrate into the skin where it can act on living cells. Bioavailability (influenced primarily by small molecular size) is an important factor in a compound's ability to penetrate the top layer of the skin. Glycolic acid, having the smallest molecular size, is the AHA with greatest bioavailability and penetrates the skin most easily; this largely accounts for the popularity of this product in cosmetic applications. They have a peeling effect, keratolytic effect, added in the range of 5-15% to the aqueous phase.

Odours

Nowadays most lotions contain odours. The purpose of these added odours is to make the product more attractive, while at the same time they might also be used to conceal the smell of the original components, which might not be so pleasant. Odours can be natural as well as synthetic. The best known natural odours are essential oils, which constitute complex mixtures of compounds. The best known synthetic odours are geraniol, citronellol, citral and others, which simulate natural odours.

Other components

- **Citric acid** – acidity regulator, gelatine formation, neutralises certain minerals in order to increase the efficacy of antioxidants and preservatives, has buffer capacity (helps maintain a pH between 2.5 to 6.5), higher concentration has exfoliating properties (like with AHA acids), moisturizes, exfoliates, softens, has an anti-wrinkle effect. The safe use of citric acid should not exceed 10% and not be at a lower pH value than 3.5. Citric acid is added to creams, shampoos, shower gels, bath pearls (along with sodium carbonate).
- **Salicylic acid** – proven anti-acne effect due to its anti-septic properties, very effective keratolytic effect (exfoliating effect extends to the pores of the skin). Used in exfoliators, anti-dandruff products, anti-psoriasis products and in products meant for problematic skin: for acne – 0.5-3%; for dandruff – 1-3%, for warts – 5-25%. Products containing salicylic acid may smell on the skin. When salicylic acid is attempted to be used together with other exfoliators such as benzoyl peroxide, recorcinol or soaps and other cosmetic products that dry your skin one must be aware of an excessive exfoliating effect.
- **Aloe Vera juice** (extract, gel) – moisturizes, rejuvenates, heels, penetrates easily through the skin while stimulating the blood circulation and the immune system, increases the elasticity of the skin and stimulates collagen synthesis, found in various products.
- **Allantoin** – heals (sun) burns, abrasions, works well for chapped skin, leaves a soft and dry feeling (for example in the case nappy discomfort), usually added to an aqueous base in the amount of 0.2 - 2%. Added to a great variety of products.

References

- http://www.makeyourcosmetics.com
  a comprohensive page where a lot of different information can be found: recipes, components, the content of the components, effect etc.
- http://www.naturalnews.com/022113.html
  the effect of parabens
- http://lifestyle.blogtells.com/2009/03/17/home-made-skin-creams-and-ointments recipes/
  home-made creams
- http://www.vitaminstuff.com
  a lot of information about vitamins
- http://www.essentialwholesale.com
  here one can buy substances, but it also gives information about the ingredients and their effect
- http://www.makingcosmetics.com
  articles about cosmetics and a whole book about the ingredients of cosmetic products, the effect and how much and where to add something
- http://www.joik.ee/?section=et/2033&class=shop_order_center&action=show_items&id=203
  ideas to experiment with different mixtures
- http://allnaturalbeauty.us/emulsions.htm
  a lot of information about emulsifiers

Labelling

The list of labels that may or may not be taken into account before buying a product or ingredients to make ones own cosmetics

- No animal ingredients (100% vegetarian ingredients or Vegan)
- No animal testing (also known as Cruelty free products)
- No artificial colours, sweeteners or flavours
- Containers are recyclable
- Fair trade

Fair trade is an organised social movement that aims to help producers in developing countries to make better trading conditions and promote sustainability. The movement known as fairtrade indicating the certification advocates the payment of a higher price to exporters as well as higher social and environmental standards.

Certified organic ingredients

Organic certification is process for producers of organic food and other organic agricultural products. In general, any business directly involved in food production can be certified, including seed suppliers, farmers, [food] processors, retailers and restaurants.

Requirements vary from country to country, and generally involve a set of production standards for growing, storage, processing, packaging and shipping that include:

- no human sewage sludge fertilizer used in cultivation of plants or feed of animals
- avoidance of synthetic chemical inputs (e.g. fertilizer, pesticides, antibiotics, food additives, etc.), genetically modified organisms, irradiation, and the use of sewage sludge;
- use of farmland that has been free from prohibited synthetic chemicals for a number of years (often, three or more);
- keeping detailed written production and sales records (audit trail);
- maintaining strict physical separation of organic products from non-certified products;
- undergoing periodic on-site inspections.

Biodegradable

Biodegradation (biotic degradation, biotic decomposition) is the chemical dissolution of materials by bacteria or other biological means. Biodegradable means to be consumed by microorganisms and return to compounds found in nature. The term is often used in relation to ecology, waste management, biomedicine, and the natural environment (bioremediation) and is now commonly associated with environmentally friendly products that are capable of decomposing back into natural elements. Organic material can be degraded aerobically with oxygen, or anaerobically, without oxygen. Biosurfactant, an extracellular surfactant secreted by microorganisms, enhances the biodegradation process. Biodegradable matter is generally organic material (plant and animal) and other substances originating from living organisms, or artificial materials that are similar enough to plant and animal matter to be put to use by microorganisms.

References

Diaz, E. (editor). (2008). Microbial Biodegradation: Genomics and Molecular Biology (1st ed.). Caister Academic Press. ISBN 1-904455-17-4.

Measuring Biodegradability", The University of Waikato, June 19, 2008

Agamuthu, P. Biodegradability and Degradability of Plastic Waste, International Solid Waste Association, November 9, 2004.

Paraben free

Parabens are a class of chemicals widely used as preservatives by cosmetic and pharmaceutical industries. Parabens are effective preservatives in many types of formulas. These compounds, and their salts, are used primarily for their bactericidal and fungicidal properties. They can be found in shampoos, commercial moisturisers, shaving gels, personal lubricants, topical/parenteral pharmaceuticals, spray tanning solution, makeup, and toothpaste. They are also used as food additives. They are becoming increasingly controversial, however, because they have been found in breast cancer tumours (an average of 20 nanograms/g of tissue). Parabens have also displayed the ability to slightly mimic estrogen (a hormone known to play a role in the development of breast cancer). No effective direct links between parabens and cancer have been established, however. Another concern is that the estrogen-mimic aspect of parabens may be a factor in the increasing prevalence of early puberty in girls. Most known parabens are methylparaben and ethylparaben.

Mineral oil free (Petroleum free)

A mineral oil is any of various colourless, odourless, light mixtures of alkanes in the C15 to C40 range from a non-vegetable (mineral) source, particularly a distillate of petroleum. The name mineral oil by itself is imprecise, having been used to label many specific oils over the past few centuries. Other names, similarly imprecise, include white oil, liquid paraffin, and liquid petroleum. Most often, mineral oil is a liquid by-product of the distillation of petroleum to produce gasoline and other petroleum-based products from crude oil. A mineral oil in this sense is a transparent, colourless oil composed mainly of alkanes and cyclic paraffins, related to petroleum jelly (also known as "white petrolatum").

One of the common concerns regarding the use of mineral oil is its presence on several lists of comedogenic substances. These lists of comedogenic substances were developed many years ago and are frequently quoted in the dermatological literature. At the same time it is reported that highly refined and purified mineral oil found in cosmetic and skincare products is noncomedogenic (does not clog pores).

References

DiNardo, J. C. (2005), Is mineral oil comedogenic? Journal of Cosmetic Dermatology, 4, 2–3.

Free of chemical preservatives

The meaning of such a label is that the product is made without synthetic preservatives. Due to controversy surrounding the use of synthetic preservatives in food and cosmetics, some companies are turning to other options to help extend products' shelf life. Some are switching from synthetic to natural. Unfortunately all natural preservatives may not be as good as they sound, especially if taken in excess. But on a positive note they are not as toxic as synthetic preservatives. The best option would be no preservatives at all, but products would not be able to stay fresh for too long.

The issue with manufacturing products entirely without the use of preservatives is that, besides taking a lot of time to be made, they are very expensive. Products manufactured without preservatives need to be fabricated in a sterilized environment using a flow hood similar to that found in hospitals and laboratories. They should also be refrigerated immediately after their first use. Because of this some companies are considering making products using natural preservatives.

There are ways of reducing microbial activity (such as using essential oils) in a more natural way. Antioxidants can help in this task as well. They will protect the oils, which become rancid when hit by light or air, from spoiling and becoming susceptible to contaminants. This is a process that cannot be stopped 100%, but antioxidants have the ability of slowing down this process.
Antioxidants and essential oils are completely natural ingredients. Antioxidants, as the word implies, are substance such as Vitamin E, Vitamin C or beta carotene that protect cells from the damaging effects of oxidation. In the case of essential oils, these are powerful antiseptics that kill most of the harmful bacteria and fungi without causing any damaging effects to the human body. Essential oils are derived from plants, flowers, leaves and grasses. The discovery of the antiseptic properties of these oils was made in France during the cholera epidemic when it was observed that workers in perfume factories seemed to be almost fully immune to the disease while the rest of the population perished.

References

http://www.chemicallyspeaking.com/archive/2011/04/15/preservatives-in-cosmetics.aspx

VI. Learning Path(s)

This unit consists of 10 activities. The exemplary sequence of activities, in which all activities are used, is given in the table below.

Activity		Discipline	E-emphasis
1	Capturing students' interests	Interactive discussion	Engagement
2	Exploring the science behind cosmetic creams	Structured inquiry	Exploration
3	Exploring the ingredients of and their role in cosmetic creams	Structured inquiry	Exploration/ Explanation
4	Analysis of the cosmetic cream	Interactive demonstration/ Guided inquiry	Exploration/ Explanation
5	Preparations for making an emulsion cream	Guided/structured inquiry	Elaboration/ Extension
6	Experiment: making	Guided inquiry	Exploration
7	Estimating the suitability of the self-made product	structured inquiry or open inquiry	Evaluation
8	Presenting the product	Interactive demonstration/ discussion	Evaluation
9	Decision-making	Argumentation and reasoning	Evaluation/ Extension
10	Exploring careers related to the cosmetics industry	Guided inquiry	Exploration

VII. Assessment

Students will be assessed in many different ways throughout the course, including both science process skills, general competences, and topic-related content knowledge. Types of assessments will include formative assessments including observation, participation and summative assessments such as a final project.

Assessments that could be done throughout the project:

Formative	**Summative**
Formats and objects	
❖ Oral/written feedback from teacher (based on obseravtions, questions asked, etc.) throughout the unit, during the experiments and other formats of group work ❖ Peer assessment (during the final presentation) ❖ Individual worksheets	❖ Product presentation (measured through performance, questions asked) ❖ Group portfolio on the product development (extended recipe, results of tests) ❖ Individual worksheets

VIII. Student Learning Activities

Activity 1: Capturing students' interests

Learning aims:

Students are expected to

- Express their previous knowledge regarding the topic;
- Generate and share ideas for further exploration with their group members.

Materials:

Internet Resources:
http://www.youtube.com/watch?v=mYt0v0v19eM (an example of a large scale enterprise)
http://www.youtube.com/watch?v=PvaeTb38TJc (an example of a small factory)
http://www.youtube.com/watch?v=bj0XooeMFcs (an example of a home-made production)

Suggestions for use:

After presenting video excerpts, group discussion is carried out where students are asked to think about reasons why one would want to make cosmetics while supermarkets are full of all imaginable cosmetic products. In addition, students are asked to think about the possible benefits and risks of (a) industrial, (b) home-made cosmetic products.

We propose 7 possible reasons that can be used to help guide the students if needed:

- **Cheaper -** cheapness is of course relative, but if one is skilled enough (knows how to get the ingredients, how to mix and preserve the product) then the outcome can really be much cheaper compared to similar products from the store.The beginner often has the problem of not knowing exactly what needs to be used in the product and thus many constituents will go to waste.

- **To use more natural raw materials** – especially in the cheaper cosmetic products, petroleum-derived materials are very often used. These are not very skin-friendly, eg. vaseline leaves a very greasy feeling, but it does not actually absorb through the skin, it is hydrophobic; at the same time, a longer usage of vaseline can cause the skin to dry; this is a problem with hygenic lip balms. The advantage of vaseline and silicone is that they do not have multiple bonds making them more chemically stable. At the same time, the last property speaks in favor of natural cosmetics, as natural oils are more easily biodegradable.

- **Design products according to one`s own taste**
  We would be able to choose the odour we like or have no odour at all. Still, since compounds from the nature have their natural odour then a cream with no specific flavouring could still have an odour.

- **To make products that are more effective**
  Commercial products often do not include enough of the beneficial substances that have an effect on the skin. Rather the additives written on the package have a psychological effect, e.g. “ Vitamine E helps reduce the signs of ageing on the skin“.

- **To make especially natural products for children**
  There is no need to add substances that add odour, colour or increase preservation time. The cream does not have to be kept on the shop shelves for months; it can be mixed together and be used straight away.

- **To make products for one’s own company**
  And why not? – the so called hand-made products with a short preservation time are becoming a growing trend in cosmetics. Many spas and beauty salons offer skin care using products made on the spot (eg. coffee grounds mixed with honey as a body scrub etc.)

- **To make cosmetic gifts for close friends**
  It is often said that the best gift is one that is made by yourself. Adding a bit of heart to it makes the gift better than any other, often a more expensive gift.

People who choose to make their own cosmetics, however, should be aware that whatever recipes they dream up at home will most likely not resemble the highly processed and largely synthetic products that they are used to buying in stores. Additionally, people who venture to make homemade cosmetics should take into consideration the effects that natural products might have on the skin and always be careful not to let products expire or spoil.

Commercial products often contain significant amounts of synthetic ingredients that can be irritating or damaging to skin. The positive side is that these synthetics, as well as the ample preservatives in commercial cosmetics, extend the shelf lives of these products and prevent them from spoiling or harboring bacteria. Homemade cosmetics, although they are free of synthetics such as parabens, will more quickly go rancid. As a result, homemade cosmetics can be made only in very small batches, and they need to be stored properly and used quickly to prevent contamination. Failing to do so can cause spoiling or the growth of bacteria that can cause infections.

Possible questions:

- What do you think, why would anybody want to make their own beauty products?
- What could be the advantages and disadvantages of home-made cosmetic products?
- What should you know before starting to make a beauty product on your own?

Activity 2: Exploring the science behind cosmetic creams

Learning aims:

It is expected that students will:

- Develop further an understanding of the general principles of solubility of nonpolar and polar substances; emulsions and emulsifiers.
- Predict solubility of known and unknown substances in different solvents.

Materials:

Internet Resources:
http://www.elmhurst.edu/~chm/vchembook/170solutions.html
http://www.elmhurst.edu/~chm/vchembook/
Appendix 4 Classroom Materials

Suggestions for use:

As in the following lessons students are invited to make a cosmetic product on their own and moreover, deal with product development (why, to whom, how, the probable price, the scientific explanation of the effect etc.), students will investigate the science behind cosmetic creams.
At the very beginning teacher should recall or, when not learned before, introduce students to the key concepts and principles related to polar and non-polar substances, general solubility rule concerning the polarities of a solute and solvent (“like dissolves like”), and emulsions and emulsifiers. Students may also read through Appendix 4. After that students fill the worksheet on solubility (Table 1) – classroom materials

Possible questions:

What are the general principles in predicting the solubility of a particular solute in a particular solvent?

Activity 3: Exploring the ingredients of and their role in cosmetic creams

Learning aims:

Student are expected to

- Search for information from different sources.
- Cooperate within groups where each member will explain the role and structure of skin or the role of different ingredients in cosmetic creams, to their group members, ask questions when needed from group members.
- Understand the composition of cosmetic creams and the role of different ingredients in the mixture.

Materials:

Appendix 1, **Internet Resources**: http://www.makingcosmetics.com
The ingredients of cosmetics, the purpose of the ingredients and their function; you can also download the whole catalogue, where the classification of the ingredients, the most famous representatives and their effect can be found.
http://www.davidsuzuki.org/publications/downloads/2010/homemade-cosmetic-ingredients.pdf
The list of most common ingredients of home-made cosmetics, their purpose, properties, where to get them and where they are used, is given on this web-site.

Suggestions for use:

In this activity, students will investigate the composition of cosmetic creams and the role of different ingredients in the mixture.
Within the group, topics are divided so that each group member will look for information about the topic from the Internet, recommended literature and/or from the materials given by the teacher (e.g. Appendix 1 – classroom materials). Afterwards, each group member should be able to present their topic to the others.

Topics:

I. The structure and functions of skin.

The main ingredients of cream (role and/or effect on skin):

II. Oils and fats (natural and synthetic), waxes
III. Emulsifiers, humectants
IV. Preservatives, antioxidants
V. Other substances (nutritive, exfoliation, bleaching, anti-inflammatory, anti-wrinkle etc. ingredients, odours (essential oils)

Possible questions:

- What are the main functions of skin?
- What is the role of different ingredients in a cosmetic cream?

Activity 4: Analysis of the cosmetic cream

Learning aims:

Students are expected to:
Analyse the consistence of a given cosmetic product using the science knowledge gained from the previous activities.

Materials:

Appendix 1 and 2.

Internet Resources:

- http://www.makingcosmetics.com/articles/07-essential-role-vitamins-in-cosmetics.pdf about the role of vitamins in cosmetic products
- http://www.makingcosmetics.com/articles/01-how-to-use-preservatives-in-cosmetics.pdf suggestions related to preservatives
- http://www.makingcosmetics.com/articles/13-humectants-moisturizing-agents-in-cosmetics.pdf suggestions related to humectants and moisturisers

Suggestions for use:

In the next lesson, based on the knowledge gained about skin and creams, students will be able to analyse and assess the consistence of one cosmetic cream.
Each group will receive a description of the ingredients of one cosmetic cream. For example, a daily cream “Intensive Care“ that promises to moisturise and provide nutrients to the skin.

Ingredients: *Aqua, paraffinum liquidum, PEG-6, sweet almond oil, cetyl alcohol, glycine, glycerine, citric acid, calcium chloride, vitamin A, vitamin E, linalool, propyl parabene*

Cruelty free product.

Students classify the substances in the recipe according to their function:

- oils and fats;
- emulators;
- waxes;
- humectants;
- preservatives;
- antioxidants;
- special agents (nutritive, exfoliation, bleaching, anti-inflammatory, anti-wrinkle etc. ingredients);
- odours (essential oils).

The use of each ingredient in the product should be explained: why is it added to the product, what kind of properties does it give to the product. The analysis does not have to be in a tabular format, but the same issues should be still addressed. Based on the analysis, students make a poster or fill the table as given in student work sheet (Table 2) – classroom materials

In order to be more knowledgeable in different markings related to cosmetic products (e.g. “cruelty free” or “paraben free” product), students should familiarise themselves with Appendix 2 where the meaning of such labels is provided – classroom materials

Activity 5: Preparations for making an emulsion cream

Learning aims:

Students are expected to

- Work as a team in looking for, and critically analysing, relevant information;
- Plan the experiment;
- Use creative thinking in designing the product.

Materials:

Internet Resources:

- http://www.makingcosmetics.com/How-to-Market-Your-Own-Cosmetics-149.html
- http://www.makeyourcosmetics.com
- http://lifestyle.blogtells.com/2009/03/17/home-made-skin-creams-and-ointments-recipes/
- http://www.makingcosmetics.com
- http://www.davidsuzuki.org/publications/downloads/2010/homemade-cosmetic-ingredients.pdf

The list of most common ingredients of home-made cosmetics, their purpose, properties, where to obtain them from, where they are used.

Materials and equipment:
We offer the following list of the ingredients easily found from trade:

- Oils and fats: Cocoa butter/cocoa oleum, coconut oil, olive oil, almond oil, ricinus oil (castor oil), shea butter, grape seed oil, liquid parafine, avocado oil, apricot kernel oil,
- Vitamines: E-vitamine, A-vitamine.
- Emulsifiers: stearic acid, bees wax.
- Essential oils, rose water.

Some essential ingredients can also be found at home, eg. honey, vitamins, essential oils to add the odour, herbs that can be used to make water-based extracts and be used in the recipes instead of (rose) water etc.

Supplies that are needed include electronic weights, (wand) mixer or hand whisk, a cooker or at least hot water that can be used as a waterbath to melt the ingredients. It is convenient to use small bowls made of stainless steel or enamel-coated. These small bowls can be put into a pot or into a bigger bowl to be used in the waterbath to melt the ingredients together and mix them. Empty jars for the cream are also needed.

Suggestions for use:

In this part, students will choose, based on their Internet searches, the recipe of a favourite cream (preferrably it should be an emulsion cream), and start to develop their own product. Before the next activity it would be useful four groups to read through the Internet article “How to Market Your Own Cosmetics” (http://www.makingcosmetics.com/How-to-Market-Your-Own-Cosmetics-149.html) getting the necessary knowledge for the following activities.

As a result of this activity, students have to present the list of necessary ingredients and the plan and rationale of the following activities to the teacher.

Possible questions:

- What are the main steps of making an emulsion cream?
- What ingredients are the most essential for making an emulsion cream ?

Activity 6: Experiment: making the product

Learning aims:

Students are expected to:
- Make an emulsion cream from simple ingredients on their own.
- Cooperate as a member of the team.

Materials:

Equipment: Given by the activity 5.
Internet Resources:
http://www.makingcosmetics.com/articles/02-making-emulsions-for-cosmetics.pdf

Suggestions for use:

The amounts suggested in recipes are often quite large. Since all the groups (optimal group size would be 4-5) need to be able to use the materials available, it should be noted that the amount of the product that is to be made should not exceed 50ml (50g). The amounts of the ingredients should be proportionally reduced if needed.

Student’s attention should be brought to the safety issues: Using a water bath for melting waxes and fats may be related to the risk of getting burned by hot water or oil.

Students will be able to mix emulsion cream together within one lesson if all necessary ingredients and tools are provided beforehand and students have a clear understanding of what should be done.

Water-soluble substances should first be mixed with an aqueous phase; oil-soluble substances with an oil phase. Both of these mixtures should be heated simultaneously to 75-80°C while stirring constantly. To heat the fat basis of the cream, the dish containing it should be placed in a water bath (a larger bowl half filled with water, into which a smaller tin bowl can be fitted). When both cream bases reach the required temperature, remove the container with the water base from the heating plate, the bowl with the fat base along with the water (in the bath) should be kept warm (in the case of an electrical stove, keep it at the lowest temperature level).

Next pour the fat base into the water base in a thin stream, at the same time stirring the mix constantly. For mixing purposes a mixer or a whisk is ideal. The mixer should be working at a medium speed. Keep on stirring and place the cream mixture back on the water bath, to avoid its rapid cooling. Continue stirring for the next 5 minutes. The mixture should be evenly creamy.

Next remove the cream base from the water bath and cool it down to 40°C while stirring at the same time. The mixer should now be working at the lowest possible speed. The less the cream comes into contact with air, the better the end result. The thickness of the cream depends on the length and intensity with which the mixture was stirred. If necessary, remove the thicker mass of the cream from the walls of the dish. At 40ºC preservatives, E-vitamins, moisturisers, etc. can be added one by one without stopping the stirring. If the additives are of different thickness, start with the thickest one.

Possible questions:

- What are the main risks when making a cosmetic cream?
- How to decide, which ingredients should be dissolved in water and which in oil phase?

Activity 7: Estimating the suitability of the self-made product

Learning aims:

Students are expected to:

- Establish the criteria in order to assess the suitability of the self-made product in place of analogous commercial products (only by activity 7b).
- Carry out a number of tests.
- Draw conclusions based on the results of the tests.

Materials:

Equipment:
pH-sensor or universal indicator paper
the self-made product (from the previous activity)
Internet Resources:
http://www.makingcosmetics.com/Stability-Testing-of-Cosmetics-148.html

Suggestions for use:

After making the product, students are expected to establish their criteria in order to assess the "goodness" or quality of the product. Students will carry out the experiments where the self-made product is tested against the pre-determined criteria while presenting gathered data in a tabular format. Some tests, which are actually quite important, cannot be conducted within limited classroom time (e.g. determining the shelf life of a product). Still, some tests may be applicable like measuring pH, estimating qualitatively the feeling on the skin left by the product, the odour, appearance and viscosity. Based on the findings, students draw conclusions about the product. This learning activity may be organised in a way using more open or more structured formats of student inquiry. Based on Bianchi and Bell (2008)[8] students' inquiry may be conducted as:

- Confirmation inquiry: Students are given a question, the procedure, and the results are known in advance. Teachers use activities at this level to introduce a tool or practice a procedure such as observation, measurement, or data collection.
- Structured inquiry: questions and procedures are provided, but students develop their explanation supported by their collected evidence

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[8] Bianchi, H. & Bell, R. (2008). The many levels of inquiry. Science and Children, 46 (2), 26-29.

- Guided inquiry: Students are provided with the question, but students design the procedures and develop explanations of the results (with teacher guidance and feedback).
- Open inquiry: Students develop their research question, design procedures, carry out experiments and communicate the results.

It would be probably reasonable to implement an open inquiry with students who already have sufficient experience with other formats of inquiry. More or less, it depends on a teacher’s decision which format to use taking into consideration his/her students and their previous experiences. Compared to more structured formats, more open formats certainly take more time to carry out this activity.
Therefore, the two different ways suggested to carry out this activity are: (1) using a structured inquiry, and (2) using an open inquiry.

Activity 7a. Structured inquiry

Using this format, students are provided with the research question and criteria to assess the self-made product plus, the description of procedures to follow.

They are asked to find answers to the following question:

> *Does the self-made product meet the predetermined criteria regarding its: (a) pH, (b) viscosity, (c) outlook, (d) smell, (e) feeling on skin? Is the self-made product comparable with analogous commercial products?*

Probable tests:

1) pH

The usual pH of a cosmetic cream may vary between 5 – 8. Normal skin has a pH level of about 5.5. Skin or at least the outermost layer of it is slightly acidic. The acidic layer helps your skin retain moisture and keeps germs out. To help maintain the skin's fatty protective layer cosmetics should be a pH level similar to that of the skin itself. For example, soap that is too alkaline pH≥8, will break up the acid in skin, causing dryness.
However, the cosmetics that contain alpha hydroxy acids (AHA’s) may be more acidic than other. Alpha hydroxy acids found in skin-care products work best in a concentration of 5% to 8% and at a pH of 3 to 4. Beta hydroxy acid, salicylic acid, is a topical exfoliant that can reverse some of the effects of photoaging such as fine wrinkles and discolored skin. Currently, salicylic acid is the only beta hydroxy acid used as an exfoliant.

2) Feeling on skin

The product can be tested on skin, too. Volunteers should be warned to apply cream only on a very small area on skin. They should also be aware of the ingredients in order to minimise possible allergic reactions. Does it leave the skin soft, smoothe, and not very greasy? The last may be even OK when the product is meant for rough hands and/or frosty whether.

3) Odour and appearance

Odor and appearance may also be very important factors when buying a product. At the same time, the sense of smell may be quite subjective, therefore, it is suggested to use a number of "expert noses" to estimate the attractiveness of the smell. The same issue is related to the appearance of the product.

4) Viscosity

Viscosity of different products may broadly vary depending on its purpose, still it cannot be too runny and therefore inconveniet to use, and the other way around – if it is too thick, it will be difficult to spread on skin. Students probably are not expected to measure quantitatively the viscosity, rather, they give their qualitative estimation on viscosity.

5) Shelf life

This may be a case for individual inquiry as it takes time to become rancid even for a product made without preservatives.

How long may be t**he shelf-life**[9] **of homemade cosmetics?** Products can be preserved for a couple of weeks or for three to four years depending on three factors: 1) how clean one works (disinfection is very important); 2) what kind of container one uses (dispensers are preferable because contamination is minimised); 3) the concentration of anti-microbial agents (essential oils, vitamins, and preservatives).

How do you know that the product is spoiled?

Besides a gray-green layer of mold on the surface of a product, there are several other factors indicating that a cosmetic product is severly contaminated with microbes:

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[9] **Shelf life** is the length of time that foods, beverages, pharmaceutical drugs, chemicals, and many other perishable items are given before they are considered unsuitable for sale, use, or consumption. In some regions, a *best before*, *use by* or *freshness date* is required on packaged perishable foods.

- Loss of viscosity (product becomes thinner)
- Emulsion break (separation of water and oil)
- Cloudiness of previously clear products
- Loss or change of color or bad smell
- Drop in pH (product becomes more acid)

Activity 7b. Open inquiry

This is an alternative to Activity 7a following the open inquiry format where students are expected to develop their own research question(s) and criteria for deciding whether the product is applicable in place of analogous commercial products. Although it is expected that students make up tests on their own, they may need the teacher's help to decide whether the criterion is met (e.g. what is actually the normal pH of cosmetic creams).

Possible questions:

- What are the control variables when carrying out the tests in order to assess the suitability of self-made product?
- What is the usual pH of cosmetic creams? What may be the consequences when the normal ranges of pH in cosmetic products are exceeded?

Activity 8: Presenting the product

Learning aims:

Students are expected to:

- Use creative and critical thinking when producing a commercial.
- Present the produced commercial to the other groups.
- Analyse critically and put forward suggestions for improving the commercials made by the groups.

Materials:

Internet Resources: http://en.wikipedia.org/wiki/Advertising
Overview of different types of advertising; effects; criticism and ethical issues related to advertising.
The equipment needed for this activity depends on the chosen format of commercial: from paper and pencils to video cameras and digital media.

Suggestions for use:

In this activity, students will develop an advertisement: a booklet or an advertisement in the style of “TV Shop”: the product is introduced by a specialist (cosmetician, dermatologist, scientist), or a consumer; the scientific content is strongly emphasised.

The advertisement should include the description of both the target audience as well as the effect of the product, its ingredients and their function. Furthermore, it would be good to think about what kind of advantages to emphasise in the given cosmetic product (see Appendix 2). For example:

- Are the ingredients natural (from so called clean nature)
- Bring forth the advantages of the product compared to other products that might include preservatives such as parabens, triclosan or sodium lauryl sulfate e. SLS.

After producing the advertisement (this may take 1-2 lessons or more, depending on the format), the rest of the class could be the judges, giving their opinions about how convincing the presentation of the product was: what was done well, but also giving suggestions for any improvements that could be done.

Moreover, the ethical issue (were the ways in which a possible consumer was influenced ethical?) could be posed and discussed after watching a presentation.

Possible questions:

What may be the causes why labels indicated below have been used in marketing cosmetics (see Appendix 2):

- No animal ingredients (vegetarian ingredients or Vegan)
- No animal testing (also known as Cruelty free products)
- No artificial colours, sweeteners or flavours
- Containers are recyclable
- Fair trade
- Certified organic ingredients
- Biodegradable
- Paraben free
- Mineral oil free (Petroleum free)
- Free of chemical preservatives

In your opinion, which of these qualities are important for you? Explain!

Activity 9: Making the final decision on the suitability of self-made cosmetic products (emulsion creams)

Learning aims:

Students are expected to:

- Analyse critically the possible pros and cons of self-made cosmetic products (emulsion creams) based on the knowledge and experiences gained from this learning unit .
- Make a (individual) decision on the suitability of self-made products in place of analogous commercial products

Suggestions for use:

Based on the information gathered (inc. the experiments carried out), each student will fill in a table where they should write down the advantages and disadvanatges of home-made creams. Having regard to the table the student should make an individual decision about the viability of home-made creams.

Possible questions:

- What are the advantages and disadvantages of self-made cosmetic products, and more specifically, of emulsion creams?

Activity 10: Careers related to cosmetics industry

Learning aims:

Students are expected to:

- Find relevant information related to the careers in cosmetics industry.
- Make a summary of one of the jobs related to the cosmetics industry and share the findings within a group or class.

Materials:

Internet Resources:
http://en.wikipedia.org/wiki/Cosmetics#Cosmetic_careers
http://en.wikipedia.org/wiki/Prosthetic_makeup
http://chemistscorner.com/how-to-become-a-cosmetic-chemist/

Suggestions for use:

After introducing themselves to the text given in Appendix 3, students will search for information from the Internet about (at least) one job related to the cosmetics industry. They then write a summary based on what they have found. Students' share their findings within a group or class.

PLASTIC & PLASTIC WASTE

The development of this unit has been led by the ESTABLISH partners:

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UNIT CONTENTS

I. *Unit description*

The unit is focused on studying plastic and plastic waste. It is divided into three subunits.

The first subunit **(Subunit 1)** deals with getting to know plastic, the markings on it, separation and recycling. Due to its properties, plastic has a wide range of use in all spheres of human activity. In competition with classical materials, mainly metals, polymers have succeeded mostly because of their ease in processing, low density and a convenient ratio of utility qualities and price. Students acquire knowledge of plastic from everyday life and they will deepen it in this subunit. They will learn to identify symbols used to mark plastics and 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 naturally, therefore it accumulates in the environment.

Subunit 2 deals with plastic waste. Within these activities, students have to think about the issue of waste disposal, discuss it with classmates and propose possible solutions. Students 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 **subunit 3,** students study various polymers, their physical and chemical properties and then, on the basis of this experience, they examine their potential for future exploitation in both existing and possible applications. They consider polymers in their surroundings, suggest reasons for the application of the given polymer (why PVC was used for the particular toy), test properties of particular polymers using several tests (flame test, polymer density, etc.) and propose further 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 discipline: Chemistry

II. *IBSE Character*

The lessons develops students' ability to look up information on the Internet, identify problems, create mind models, discuss, communicate with peers, propose hypotheses, and distinguish alternatives.

By carrying out activities and completing worksheets, students develop their understanding of scientific research. The activities are designed in such a way that Students work in groups, discuss, reason and propose solutions to the problems. Problems are stated either by the teacher or by students themselves. Thus the research is managed and confined in these activities.

For example, in activities 1.2 "Plastic Properties" and 3.5 "Properties of polymers", problems are stated by the teacher while the experiment that will address the problem is proposed by either the teacher s. Students should determine combustibility of plastic, its thermal and electrical conductivity, reaction with acids, alkalis or with solutions of salts. Students write the results into tables. They improve the following skills necessary for research – data collecting and recording, data processing, carrying out experiments, stating hypotheses. In groups, students discuss conditions for conductivity of plastic and compare the conditions with conductivity of other substances.

While working on the activity 3.1 "Re-solubility of waste in the Environment", students 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 are" and 3.13 "Pointing out the importance of polymers in everyday life" give space to communication, reasoning and developing explanations. Students tackle tasks focused on properties of plastic, its recycling, processing, separation of waste. A project-based method is used in this activity.

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.

Pedagogical Content Knowledge

Discussion methods – discussion, managed discussion

Students discuss, e.g. the issue of produced waste from the point of view of the environment. A teacher together with students discusses recycling of different materials as well as plastic and its use. Students discuss the results of the experiment and conclusions drawn from it.

Problem-based teaching

A teacher consistently gets students involved in the process of looking for and finding solutions to problems – e.g. students 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 students. A task for the group: How is plastic made? Find at least two ways of its production. Students present conclusions 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 students' 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, e.g. Draw a simple comic ”From the life of PET bottles”.

Practical methods

They include carrying out chemical trials by which students not only observe phenomena but also affect them in an active way – they prepare, manage and evaluate chemical process themselves. Based on experiments carried out, students acquire knowledge on properties of plastic in the lesson.

III. Science Content 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 the 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 their origin the following polymers are distinguished:

a) natural – e.g. polysaccharines, proteins, nucleic acids,

b) synthetic – e.g. polyethylene, polyesters, polyvinyl chloride, Teflon,

c) modified – chemically modified natural substances, e.g. celluloid, viscose.

Synthetic polymers (plastics) can be classified in different ways:

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 (Figure 11):**

a) linear,

b) branched,

c) reticular,

d) spatially reticular.

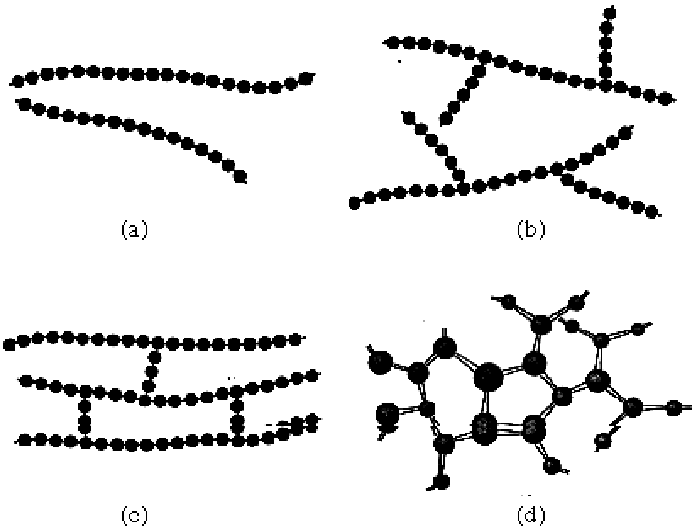


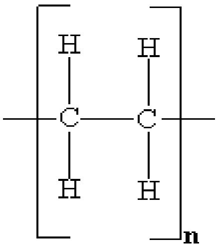
Figure 11. Different structures of macromolecules classified by shape

Characteristics of selected plastics capable of being recycling

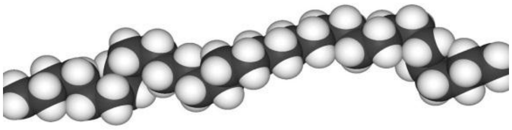
We will focus on polyethylene, polypropylene, polyvinyl chloride and polystyrene. All these plastics are made by polymerization. It is a polyreaction in which two identical monomers with multiple bondings react. If different monomers with multiple bondings react, it is called copolymerization.

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 and H_2O. In the figure below a) t is a structural model of polyethylene b) shows the spatial chain of polyethylene.



a)



b)

Polyethylene, a well-known polymer, is produced by polymerization of ethene (figure .12).

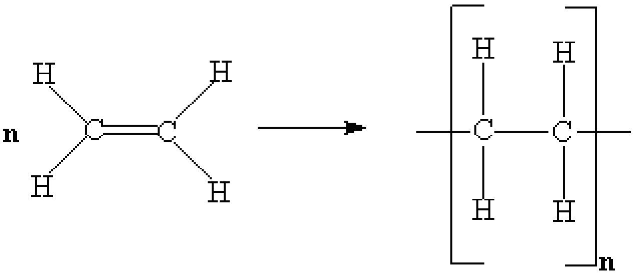


Figure 12. Polymerization of ethene

According to the way of production, type of initiation agent, and catalyst, polyethylene with different properties can be produced:

- HDPE – high density PE
- LDPE – low density PE

Use of HDPE

- Hollow objects in moulds, eg. different high volume vessels,
- crates
- bottles for detergents

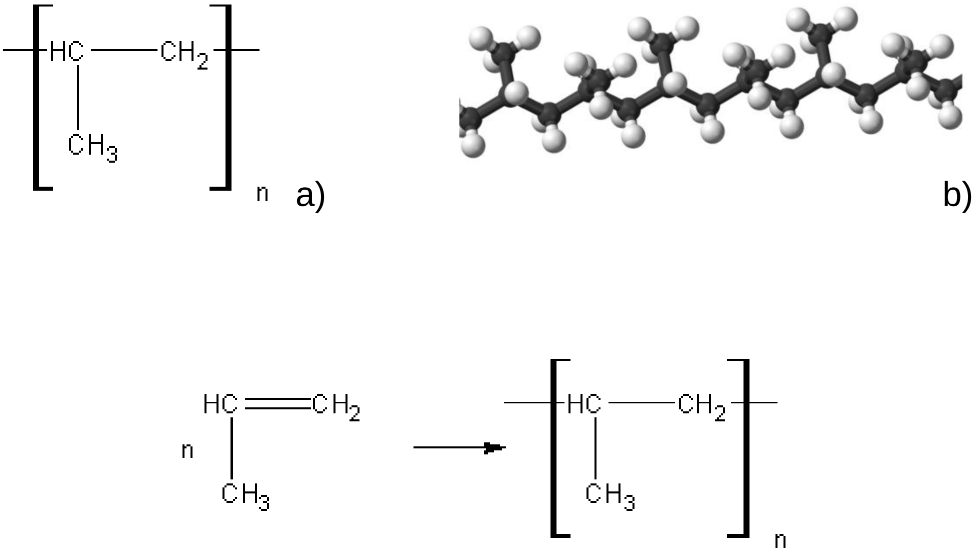
- bottles for mineral water,
- bottle lids.

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)

Shown in a) as structural formula and b) as a spatial chain, polypropylene is produced by polymerization of propene (Figure 13).



a) b)

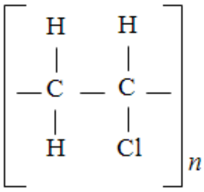
Figure 13. Polymerization of propylene

Uses of polypropylene

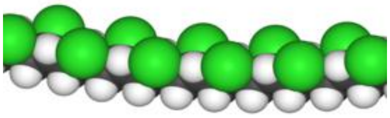
- it is used as a part of machines and equipment, e.g. in car making industry (parts of dashboards and fans, bumpers) and in consumer industry (parts of vacuum cleaners, kitchen appliances) because polypropylene has outstanding mechanical properties,
- it is used for making syringes and other medical 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)

Together with polyethylene and polypropylene, polyvinyl chloride belongs to the most widely produced synthetic plastic. The structural model of polyvinyl chloride and its spatial chain are shown below.



$$\left[\begin{array}{ccccc} & \mathrm{H} & & \mathrm{H} & \\ & | & & | & \\ - & \mathrm{C} & - & \mathrm{C} & - \\ & | & & | & \\ & \mathrm{H} & & \mathrm{Cl} & \end{array}\right]_n$$



Preparing polyvinyl chloride

Vinyl chloride is synthetised from natural gas, petroleum and sea water salt (Figure 14). 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.*.

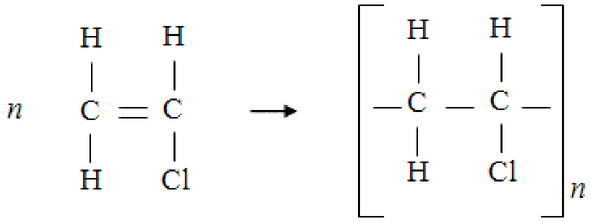


Figure 14. Polymerization of chloroethane

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

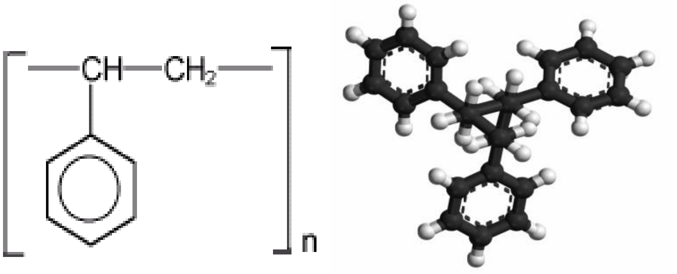
- production of floor covering,
- food foils,
- toys,
- protective gloves, raincoats,
- hoses, bottles, tablecloths,

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 are shown.



Preparing polystyrene

Polystyrene is made by polymerization of styrene (Figure 15).

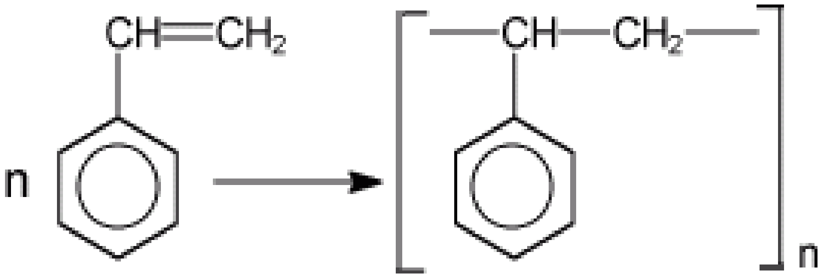


Figure 15. Polymerization of styrene

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, e.g. 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 decompose 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 plastics which are better for the environment are now being produced, e.g. plastic enriched with starch, non-toxic plastics.

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 in this way. Plastic similar to glass and porcelain does 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 as the most convenient solution because part of its vapours may be aggressive (eg. in polyvinyl chloride incineration toxic emissions, i.e. polychloro dibenzo-p-dioxins, polychloro dibenzofurans are released).
3. **Recycling** is the best way today 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. Other methods carried out in special facilities are magnetic separation and separation based on density. Physical properties of plastic are used here as magnets do not effect it, although they effect steel objects, and plastics have a 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 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), e.g. a plastic bench costs €150 and weighs 65 kg.

IV. *Industrial Content Knowledge*

Production and processing of plastics in the Czech Republic covers 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 finish 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 are worth mentioning:

- 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.
- 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.
- FV plast, a.s., 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).

A large number of companies are involved in this area as the technology of plastics processing is relatively easy. For this reason, even the companies from other industries have their smaller production lines for plastics processing, e.g. in food industry. For example Coca Cola ČR (http://www.cocacola.cz/) produces 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%).

References:

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

V. *Learning paths*

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 define more exactly (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 organise the information/knowledge gained. 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 economic and aesthetic parameters. These considerations also include the students' ideas about the product such as. the stability 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 inform discussions with other students on 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.

VI. *Assessment*

It is desirable to ask the students to write down their hypotheses in paper or electronic form. Although 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).

VII. *Student learning activities*

Activity 1.1: Kinds of packaging plastic materials and their labelling

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 with possible questions:

A teacher brings different kinds of plastic waste to the class. They are pieces of the following plastic: linoleum, pipes, plastic bags, polystyrene, plastic containers, pens, covers of books and exercise books, packages of chemicals, milk, juice, plastic bottles. Students recognise different kinds of plastic. They either look up the necessary information on the Internet or ask the teacher. In the second part of the lesson, students can work with worksheets in which they will look for answers to important questions concerning labelling plastic packages.

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. Students formulate hypotheses about expected properties based on their previous knowledge and verify them consequently by experiments.

Learning aims:

- acquire knowledge of properties of plastic materials based on experiments,
- apply the acquired knowledge of plastic materials properties in practice

Materials & Procedure:

See worksheet

Activity 2.1: Re-solubility of waste in the environment

Learning aims:

- get students interested in waste-related issues,
- discuss the issue of produced waste from environmental point of view,
- look for possibilities of waste disposal,
- think about re-solubility 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:

Students 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. Students 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 students try to write all the things that could influence the length of decomposition of different materials.

Activity 2.1b: Re-solubility of plastics and different materials in the soil

Materials:

One worksheet per group

Suggestions for use:

At the beginning, the teacher gets students interested by asking problem-based questions. The teacher states a problem and tries to get all students involved. In the following stage, students become part of the investigation. Students work in groups and use worksheets - they gather information, ask questions, formulate hypotheses without teacher‘s direct instructions.

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 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 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 over _20–100 years_. During the time of decomposition animals or people looking for relaxation in the country can be injured. These 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** 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 it can be there for as long as _4000 years_ until it is decomposed.

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 with possible questions:

A teacher asks problem-solving questions to students and finds out the level of their knowledge of the issue. In the next part of the lesson, students work in groups and use worksheets. They look up the necessary information on the Internet or ask the teacher.

Activity 2.3: Effect of acid rain on plastic products

This activity is focused on plastic waste that is in contact with acid rain. A question arises whether acid rain has an effect on the decomposition of plastics. Students have acquired knowledge about acid rain, their reasons and impact on the environment. Based on experiments they have to decide if acid rain has an effect on decomposition of plastics.

Learning aims:

- know the cause of acid rain and their impact on the environment,
- based on experiments decide if acid rain has any influence on decomposition of plastic materials.

Materials

Pictures of muscles in the body, from a textbook or from the internet.

Suggestions for use with possible questions:

A teacher asks questions concerning causes of acid rain. A discussion follows focusing on impact of acid rain on different materials, including plastic. Students formulate hypotheses and write their answers into worksheets.

Students 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.

Activity 2.4: Recycling plastics – using project-based method

This activity is focused mainly on team work of students. 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 students have enough time to gather necessary information. The result of students‘ work is not only the answers to the questions in the worksheet but also their PowerPoint presentations or poster presentations in front of other students.

Materials

See worksheets.

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 with possible questions:

Procedure and 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, 12-15% of components are plastic (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.)

A majority of products around us contain 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 actually is 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". The concepts of polymer and plastic often coincide with a given product, but the polymer is a more general concept. We refer to plastics from 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 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 (see also previous list):
    - *☑ chair –e.g. polyethylene or polypropylene,e and a cover, which is often made of synthetic fibres*
    - *☑ car –share of plastics reaches 12-15% such as polyethyleneterephthalate (PET), polystyrene (PS) polyethylene and many others.*
    - *☑ rucksack –synthetic fibres*
    - *☑ jacket –synthetic polymeric fibres*
    - *☑ cup of yogurt - often polystyrene (PS).*
    - *☑ 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 –can be made of synthetic polymeric materials*
    - *☑ spectacles –frames of synthetic polymers*
    - *☑ handkerchief –synthetic polymers are not so far commonly used for the production of handkerchiefs*
    - *☑ school bag –often made of synthetic fibres and synthetic polymers*
    - *☑ Notice board –there are 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 activity outlined in the worksheets

Activity 3.2: Polymerization – polycondensation

Learning aims:

- To show one way of polymer preparation.
- 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 rod, tweezers

Suggestions for use:

Procedure:

1) Pour solution of adipoylchloride in hexane into narrow high 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 rod.

Possible Questions:

Polymers can be prepared by three different processes. They are polymerization, polycondensation and polyadition. Polymerization is addition of monomer on double bond of monomer (by a macro-ion 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 their chlorides) and diamines, when water or hydrochloric acid are removed.

$$H_2N{-}(CH_2)_6{-}NH_2 + ClOC{-}(CH_2)_4{-}COCl \xrightarrow[-HCl]{} \left[HN{-}(CH_2)_6{-}NH{-}CO{-}(CH_2)_4{-}CO \right]_n$$

What are the mechanical properties of this polymer?
It is a hard and solid fiber.

What group of polymers does this polymer belongs to?
Polyamides.

Activity 3.3: Cross-linking of polymers

Learning aims:

- Understanding of the process of cross-linking of polymers and the consequent change in the mechanical properties of polymer

Materials

borax, two beakers (one smaller and one bigger), white glue, balances, hot water, glass rod, dyes, spoon, cloth

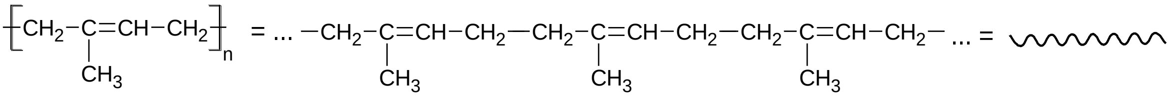
Suggestions for use:

Procedure:

1. Dissolve ca 4 g of borax in 100 mL of hot water in a beaker and stir well 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 a few drops of the selected dye. Mix well.
3. Add 2 spoons of borax solution to the water/glue mixture in the second beaker and stir.
4. A glue of polymer is formed. Remove it, dry it and compact it in palms of hands for a few minutes.
5. Feel and move the polymer in your hands; what mechanical properties does it have?

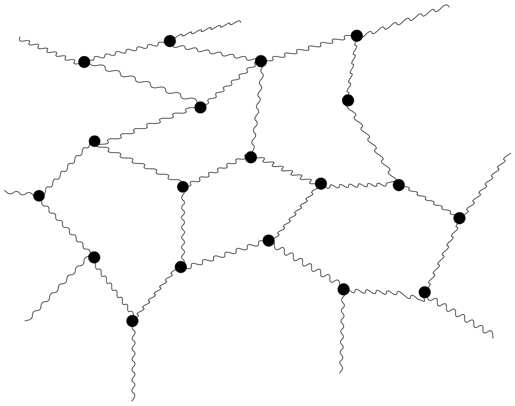
Possible Questions:

Synthetic polymers are substances which consist of long chains of big molecules – macromolecules. Their structure is similar to a chain. The macromolecules are composed of a large number of smaller periodically repetitive units like segments of a chain.



$$\left[\mathrm{CH_2-\underset{CH_3}{\underset{|}{C}}=CH-CH_2}\right]_n = \ldots \mathrm{-CH_2-\underset{CH_3}{\underset{|}{C}}=CH-CH_2-CH_2-\underset{CH_3}{\underset{|}{C}}=CH-CH_2-CH_2-\underset{CH_3}{\underset{|}{C}}=CH-CH_2-} \ldots = \sim\!\sim\!\sim\!\sim$$

Linear polymer
White glue is a mixture of polymer and water. Molecules of the polymer are stacked like small pieces of spaghetti. The tangled molecules give the white glue its sticky character but it is not a liquid. If we put the white glue in air, the water from the glue evaporates from the polymer and the polymer chains are stacked to the surfaces and connect them together.
If we add Borax, which contains borate ions, the ions can form a connection between the chains of 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. Of course, Gluep is also less sticky and elastic than the original white glue.



You know that white glue is a 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 are the properties of the polymer that you made changed from the starting material?
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 are the mechanisms of glue effect?
White glue is a mixture of polymer and water. Molecules of the polymer are stacked like small pieces of spaghetti. The tangled molecules give the white glue its sticky character but it is not a liquid. If we put the white glue in air, the water from the glue evaporates from the polymer and the polymer chains are stacked to the surfaces and connect them together.

Activity 3.4: Preparation of polymers, influencing their properties

Learning aims:

On the basis of this 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 prepare polymers carefully.

Materials

Polyurethane foam (spray), two empty matchboxes, a lamp, and a watch

Suggestions for use:

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 (PUR) 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 structures of PUR foam.

Possible Questions:

- Why did you wet the box and what were the results on the formation of polymer?
- According to the structure of the polymer, what uses do you recommend for this polymer?

Polyurethane (PUR) foams in spray form can be one–component (prepolymer) or two-component (two monomers). In the polyaddition –NH– groups are formed, which can, to a smaller extent, convert into isocyanate groups. During this reaction, an intermediate product is formed – aryl carbamic acid, which leads to the elimination of carbon dioxide, that foams up the polyurethane.

$$\underset{\text{isocyanate}}{\ldots\text{–}R{=}N{=}C{=}O} + H_2O \rightarrow \underset{\text{aryl carbamic acid}}{\ldots\text{–}R\text{–}NH\text{–}COOH\ldots} \rightarrow \underset{\text{amine}}{\ldots\text{–}R\text{–}NH_2} + CO_2\uparrow(\text{gas})$$

The amine formed reacts with isocyanate (monomer or also a newly formed group) and a polyurethane polymer is formed.

$$\ldots\text{–}R{=}N{=}C{=}O + NH_2\text{–}R\text{–}\ldots \rightarrow \ldots\text{–}R\text{–}NH\text{–}CO\text{–}NH\text{–}R\text{–}\ldots$$

PUR foams are used as insulation; their advantage is that they are waterproof but also absorb moisture in the air, thus ensuring "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 is cut in half. The presence of water will speed up 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.

Prepared polyurethane foam, on the left PUR foam formed on the wet box.

Activity 3.5. Properties of polymers

Learning aims:

Through their own exploration, students should explain that polymers are substances of very diverse properties. Their properties are due to the chemical structures of the polymers. This can be used for the selection of a suitable material for design and production of the given product but also for the identification of unknown samples of polymers.

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 and 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, 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, 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), 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

Suggestions for use:

We will try to explore the properties of some synthetic polymers. Several tests will be carried out on samples of polymers and from which we will 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.

The range of observed properties can be broad, but certainly the following are important:

- *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 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 – at common operating temperatures, the*

product should not 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 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 so as 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.
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; place a text about 1 cm behind the sample and determine the transparency depending on visibility through the sample

Plastic	Foil (F), fibre (VL), moulding (VY)	optical properties Transparent (TP), translucent TL), opaque N)	Colouring Transparent (P), coating (K)	opacity-bright (L), matt (M)	roughness-smooth (RS), rough (RR)	adhesiveness sticky (SK), non-sticky (NS)	feel-waxy (V), soft(M), hard (T)
PE							
PP							
PS							
PVAc							
PMMA							
PC							
PA							
PUR							
PET							
PVC							
PTFE							
MF							
Poly isoprene							

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 more than one category (option) in the table 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 provided. 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 into the other (work in a fume hood!!!). Put 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·cm^{-3}**	**0-1.50 g·cm^{-3}**	**>1.50 g·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
Poly isoprene		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 a lower density. However, the density of polymers exceeds 1.5 gcm^{-1} in only a few samples. Synthetic polymers are therefore relatively light materials (e.g. of about. 5-6 x lower density than steel or about 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 quantitative test is complex, but we can arrange the chosen samples of polymer according to the needle tip penetration into the polymer sample (qualitative test).

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 is 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 (softe PVAc, PUR, PET*
Group II, higher pressure necessary	*PP, PVC, PS, PTFE*
Group III, difficult to penetrate	*PMMA, PC, PA*

<u>Resistance to chemicals, solubility test</u>:

We are looking for a chemical or solvent in which the polymer sample can dissolve.

Procedure:

We sprinkle the sample of plastic with a solvent and observe (after about 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**	**Cyclo-hexane**	**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								
Poly isoprene	X		X			X		

What conclusions can be made from the data above?

The synthetic polymers tested are materials of diverse chemical properties, according to its structure soluble in different solvents, which are mainly non-polar. In the majority of cases, these substances are resistant to water and ethanol. Particularly resistant to these solvents 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:

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. (according to http://ufmi.ft.utb.cz/texty/kzm/KZM_05.pdf). 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, follow the procedures below 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
    - a. Luminous flame without a blue or green base (SVB)
    - b. Luminous flame with a blue or green base (SVZ)
    - c. Non-luminous blue flame (Z)
- Smoke – throughout burning, smoke may or may not be produced; if produced the properties of the 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: The chemical composition and structure of the polymer influences the nature

of substances that are released during burning or depolymerisation or degradation of a 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 behaves depending on 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,*	*N*	*N*	*DH*

			sparks			
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 specific 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 a particular 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. The temperature of the plate is 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 three times. 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 address this concept.

What conclusions can be drawn from the experiments carried out?

The aim of the experiments is to show that synthetic and natural polymers are substances with different properties (e.g. high and low 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 is clear that the selection of a suitable monomer and the reaction conditions (from which the structure of polymer often results) allow the preparation of a range of materials that are suitable for use (kitchenware, covers for electronics, chairs, cars, etc.). It is desirable to *note that a combination of polymeric materials (and the production of the so-called composite materials) can lead to more applications, but these are not experimentally tested here. Therefore, only a few products and applications do not allow the use of a polymer in their production; therefore, the use of polymers is widespread and can be found in nearly all products or in the 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.*

The experiments also show that if the individual polymers differ from one another, the particular experiments can also be used as identification tests for determination of the polymers. This is also the subject of the following activity.

Activity 3.6: Properties of polymers – elasticity and cross-linking

Learning aims:

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

Suggestions for use with possible questions:

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 the polymer

Procedure:

1. Inflate the balloon and tie it.
2. Dip the skewer into Vaseline and spread it over the entire length of the skewer.
3. Push the skewer with a slow and gentle rotation through the top knot of the balloon. Continue a gentle rotation of the skewer and push it towards 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.

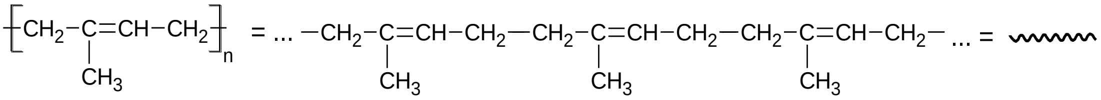
5. During the passage of the skewer through the balloon wall you can start pulling the skewer faster.

Possible Questions:

Explain the balloon behaviour, why it bursts in one case but why in principle it is possible to draw the skewer through.

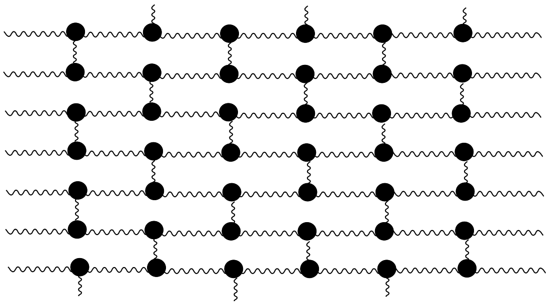
Due to lower tension of the balloon near the top and the knot, it is possible to pull the skewer through the balloon without damaging it since the structure of polymer is not affected by the rupture of chains but only by their extension. During a “rougher” use of the skewer, a rupture of the polymer chains occurs, 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:



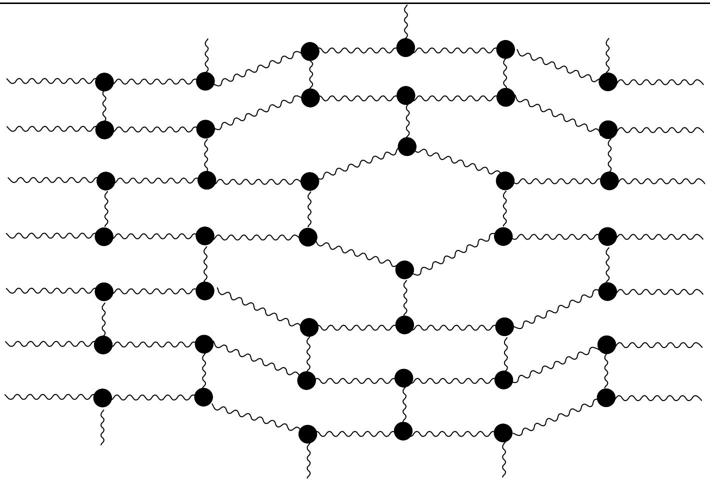
$$\left[-CH_2-\underset{CH_3}{\underset{|}{C}}=CH-CH_2-\right]_n = \ldots -CH_2-\underset{CH_3}{\underset{|}{C}}=CH-CH_2-CH_2-\underset{CH_3}{\underset{|}{C}}=CH-CH_2-CH_2-\underset{CH_3}{\underset{|}{C}}=CH-CH_2- \ldots = \sim\sim\sim\sim$$

Linear polymer

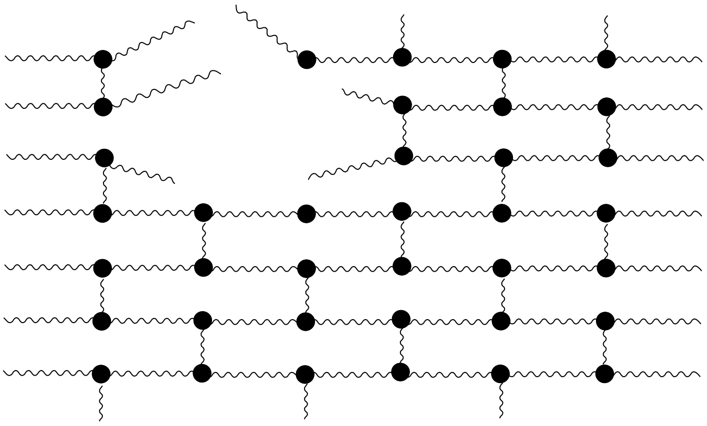


Reinforced polymer

This bond keeps the polymer molecules connected and allows the polymer to extend up to a certain point, when the force or tension on the lateral ligaments is too high and it leads to their breaking and the rupture of the polymer.



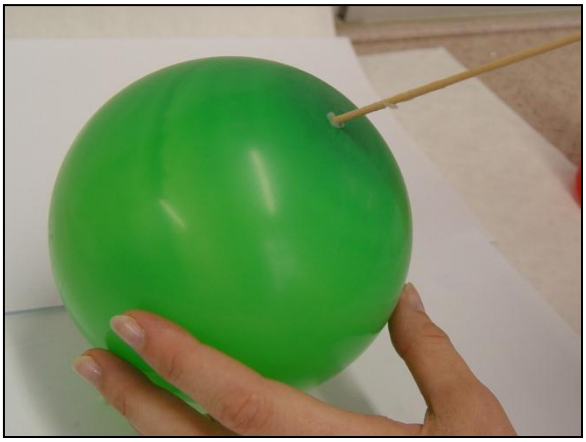
After extension of reinforced polymer



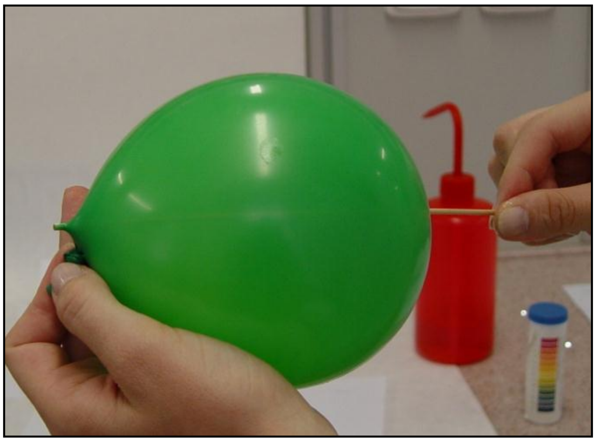
After rupture of reinforced polymer

Experience from implementation: the balloon should be to a diameter of less than 10 cm (or shorter than the length of the skewer). The skewer should be pulled through very carefully.

a) Skewer through the balloon wall

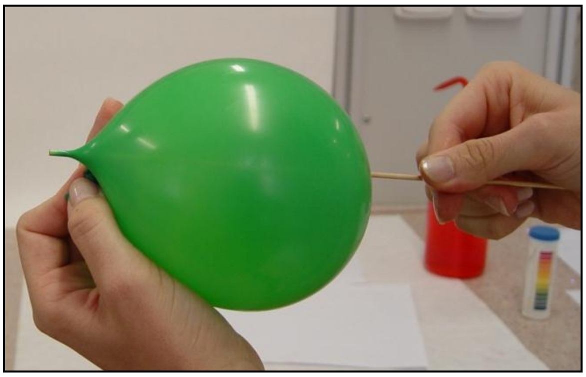
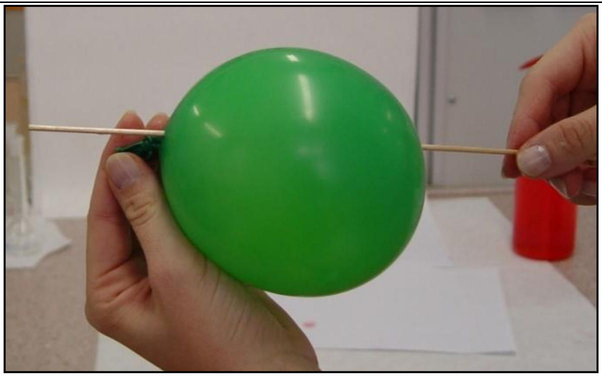
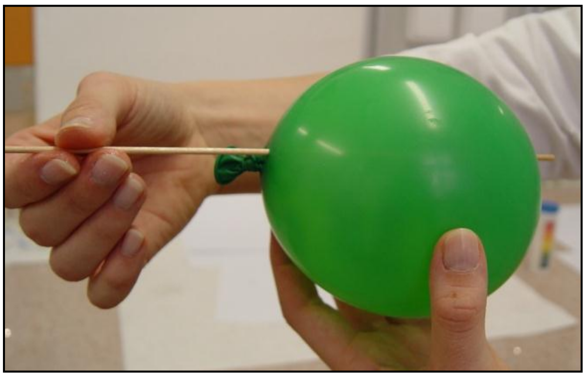
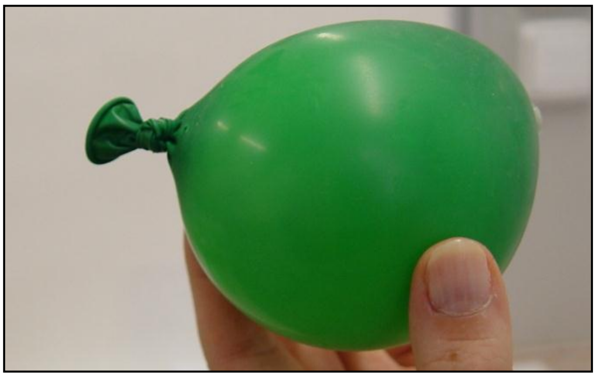


b) Slow rotation of the skewer to penetrate through the wall



c) Skewer passage through the

d) Skewer through the balloon

balloon wall 	
e) Removing the skewer out of the balloon 	f) After the passage of the skewer the balloon slowly leaks 

Activity 3.7: Properties of polymers – dissolution of polymers

Learning aims:

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

Suggestions for use with possible questions:

Task: Explore, whether the polymers are soluble in some solvents and what is responsible for the solubility.

Procedure:

1. Chew the chewing gum and divide it into three parts, two smaller and one bigger. Put the bigger part away safely as 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 chew it. Chew the chewing gum and then add a chocolate. Chew them together. What happened? Write down the results.

Possible Questions:

Polymers usually are not very soluble and their dissolution takes longer, because whole macromolecular chain have to be surrounded by molecules of solvent. However, it does not mean that polymers are insoluble. Some of them are soluble. 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 this activity, the chewing gum is soluble in oil, but, it is not soluble in water. On the other hand, sugar, having 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 chewing gum made of? 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 did the chewing gum dissolve in chocolate?
Polyisoprene is nonpolar substance, hence, it is soluble in nonpolar solvents like oil, petrol etc. In the case of this activity, 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.

Activity 3.8: Identification of polymers

Learning aims:

On the basis of previous results the students will take a different material and identify the particular polymer present

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)

Suggestions for use with possible questions:

Task – identification of polymer: Within the previous activity, due to a number of experiments, you have discovered 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:

Title of protocol: What is the subject of your work (e.g. Identification of unknown sample of polymer)

Procedure of 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. its density, how it reacts in the flame – type of smoke, colouration of flame, etc.

Possible Questions:

What type of polymer is it and justify your choice

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 tests.

Activity 3.9: Application of polymers

Learning aims:

On the basis of knowledge of polymer properties, the students should be able to deduce their application or vice versa, i.e. considering a particular application, they should be able to find a suitable polymer.

Materials

Literature, the Internet, notes on activities 2 and 3.

From the selected products containing synthetic polymers, choose any 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 units 2 and 3 and possibly from other sources, try to find a polymer that would be appropriate for your application. Justify your choice. Refer both to positives and negatives of your choice.

Suggestions for use with possible questions:

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 the 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 envisaged (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 are however eliminated due to a higher price; the cheapest polymers of appropriate properties are PE (indeed the cheapest) or PP. PP has a higher strength than PE.

Possible Questions:

Discuss your choices with other groups. Try to debate the choices of other groups.
Discussion can range over the properties, acceptability of price, aesthetic qualities of the product, etc.

Activity 3.10: Pairs

Learning aims:

To reinforce the knowledge on polymers and polymer substances using a popular game.

Materials

Print the cards available on the worksheets 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!!!

Activity 3.11: Where can I find the polymer?

Learning aims:

On the basis of knowledge of polymer properties, the students should be able to deduce their application or vice versa, considering an application, they should be able to find a suitable polymer.

Materials

Literature, internet, notes to the preceding activities, worksheets.

Suggestions for use with possible questions:

Procedure:
Match the corresponding polymer and its application or product, available in the worksheets. Write the names of the polymers into the boxes below the corresponding product:
Polymethymetacrylate, polyisoprene, polystyrene, polyethylentereftalate, polyethylene, polyvinylchloride, melaminoplastics, Nylon or Silicon

Activity 3.12: Estimate and discuss some information regarding polymers

Learning aims:

Extend the knowledge of the importance and applications of polymers in everyday life.

Materials

Literature, internet, notes to preceding activities, worksheet.

Suggestions for use with possible questions:

Procedure:

Find or estimate the answers to the following 6 questions; write down your answers and give reasons for the answers. After this, can you find supporting evidence on the internet. Discuss your answers

Question 1: When did European people meet natural rubber for the first time?

In 1493, when Christopher Columbus and his sailors followed Indians to play with an elastic ball made from sap of Hevea braziliensis tree.

Question 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 quickly became a commercial hit in 1939, especially with ladies, when nylons substituted stockings from nitrocellulose. In 1941, USA entered WWII, and the whole production of Nylon was used by the war industry (parachutes, tires, tents, ropes etc.).

Question 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, about. 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. The majority of plastics is used in the CR for this purpose.

Question 4: What is (approximately) the worldwide production of plastics (in years around 2010)? Is it a large production or not? Compare with other commodities!

World production of synthetic polymers is about 240 million tons. Production of iron is much bigger, ca. 1,414 million tons. On the other hand, polymers have much lower (about 8x) density, and so 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 5: Polymers are used in the following area: cars, constructions and buildings, wrapping, special applications. Range these applications based on the use of polymers, and estimate their usage.

wrapping 38%, construction, buildings - 21%, cars – 7%, special applications (OLEDs etc.) – 2%. 40% are short-term applications and 60% are long-term applications.

Question 6: Rank the following polymers in decreasing order of consumption in one year: polyethylene, polyetylentereftalate, polyvinylchloride, polystyrene, polypropylene.

polyethylenes 28%, polypropylene – 18%, PVC – 12%, PS – 8% a PET – 7%.

Activity 3.13: Pointing out the importance of polymers in everyday life

Learning aims:

In a creative way to express and comprehend the importance of polymers in human society.

Suggestions for use with possible questions:

Task: Write a text or essay of 2-4 pages entitled “Life with polymers” or “Life without polymers”.

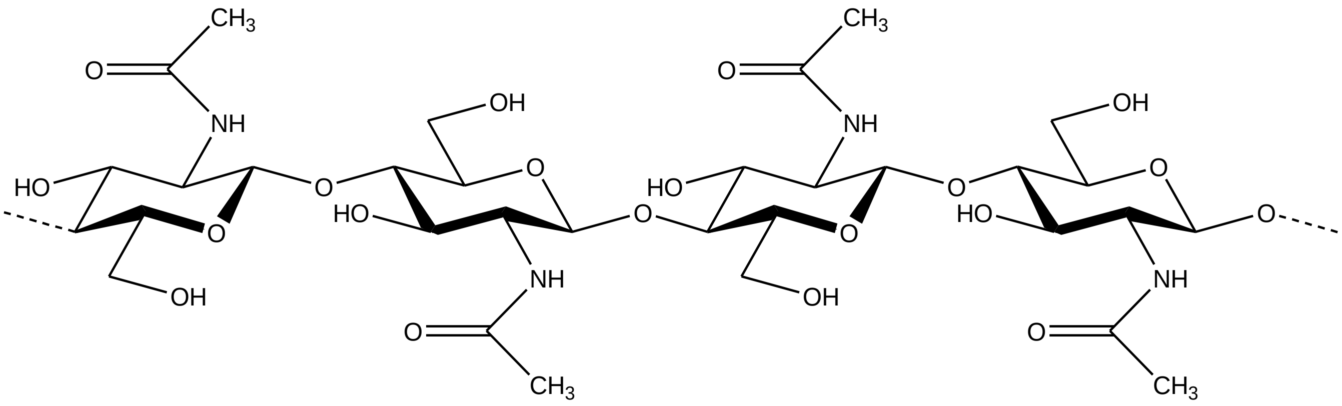
Read each other’s essays and discuss the world of polymers. Are they really so important for our lives or could we do without them? Which items made of synthetic polymeric substances would you gladly give up and which, on the contrary, you would not. Which materials would you recommend to replace them? What would it mean for us?

CHITOSAN – FAT MAGNET?

The development of this unit has been led by the ESTABLISH partners:

Wolfgang Graeber.

Leibniz- Institute for Science and Mathematics Education (IPN)



UNIT CONTENTS

I. Unit Description

There is a lot of advertising on chitosan (Poly-β-1,4-D-glucosamin) as a fat magnet but 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 their own experiments. They learn about how to produce chitosan, its properties and several of its applications. The knowledge gained and then forms the basis 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 unit can be taught as an advanced course deepening the students' knowledge of carbohydrates, but can also be extended to more everyday topics such as 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 analysis (area 9). The sequence can suit each of the following topics:

- Carbon hydrates
- Structure-property Relationships

II. IBSE Character

The skill of argumentation is developed in this unit. To introduce the topic, the teacher may initially introduce the problem; for example, s/he has found advertisements referring to chitosan as a slimming agent: "Chitosan: Fat Magnet! or perhaps presents a product to the students or. While showing how s/he has found the information from the internet the class is also presented with information claiming the uselessness of chitosan for reducing weight. So there are two opposing opinions; one in favour of chitosan as slimming agent, and another describing that it does not work. This is the leading question for this unit: "Who is right?" which is the starting point for the class' inquiry process.

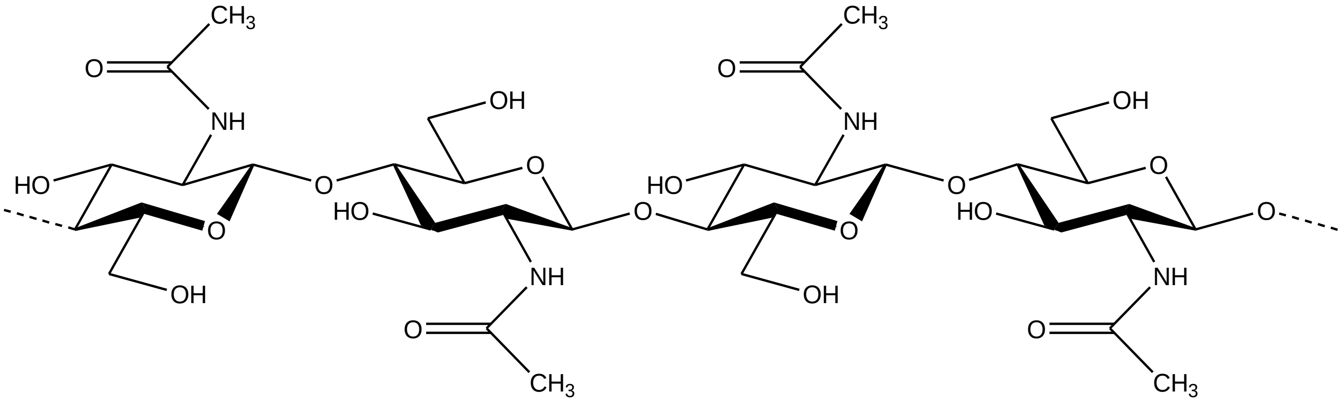
The students will:

- define the problem,
- develop and carry out a plan of how to investigate the problem (which includes:
    - searching for further information
    - formulating and testing hypotheses
    - planning and carrying out experiments
    - communicating and discussing their findings with peers)
    - and creating coherent arguments supporting their findings

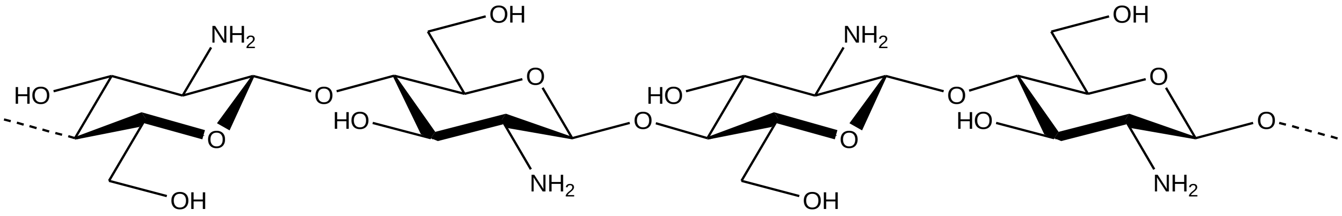
In addition students are asked to make and discuss their own decisions on whether to use chitosan themselves or recommend it to others.

III. Science Content Knowledge

Many nations with coastal regions that are 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 of the shells of chitosan (from chitin) to solve this environmental problem, producing valuable products from the waste. This unit focuses mainly on the application of chitosan as a slimming aid.



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



Chitosan: Poly-β-1,4-D-glucosamin

The effectiveness of chitosan is a good problem for chemistry classes. Chitosan can easily be prepared from chitin, the structural substance of crab or shrimp shells. From the structural formula it is clear that chitosan is very similar to cellulose: there is only one –OH group per glucose unit replaced by an amino (-NH_2 group). After cellulose, chitin is the second most common naturally produced polymer worldwide, so it‘s not an exotic substance but is quite common, with many applications. In teaching chemistry, chitin is also important in that it can easily be used to demonstrate structure-property relationships.

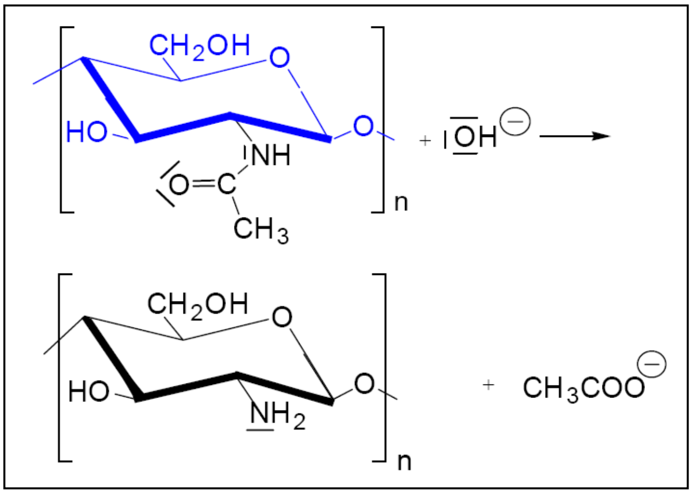
Bader and Birkholz in their contribution to the Chitin Handbook (R.A.A. Muzzarelli and M.G. Peter, eds. (1997): Chitin Handbook. European Chitin Society) wrote*: “The use of polysaccharides as renewable materials is a new subject in chemistry courses. Like in other cases the aim is to show the origin 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): see process next page.

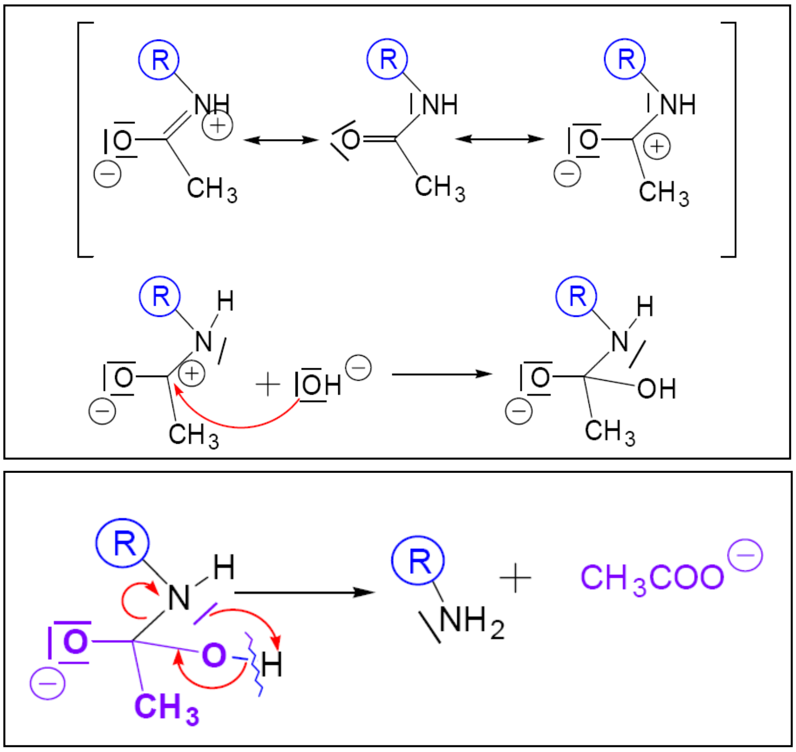
The crab/shrimp shells have to be initially washed with water, dried and ground into powder. In its second step, the protein is removed with sodium hydroxide solution, and the calcium carbonate with hydrochloric acid. The chitin is then deacetylised with sodium hydroxide solution, washed with water and dried. The product is a lifgt pink-beige chitosan which looks very similar to chitin.

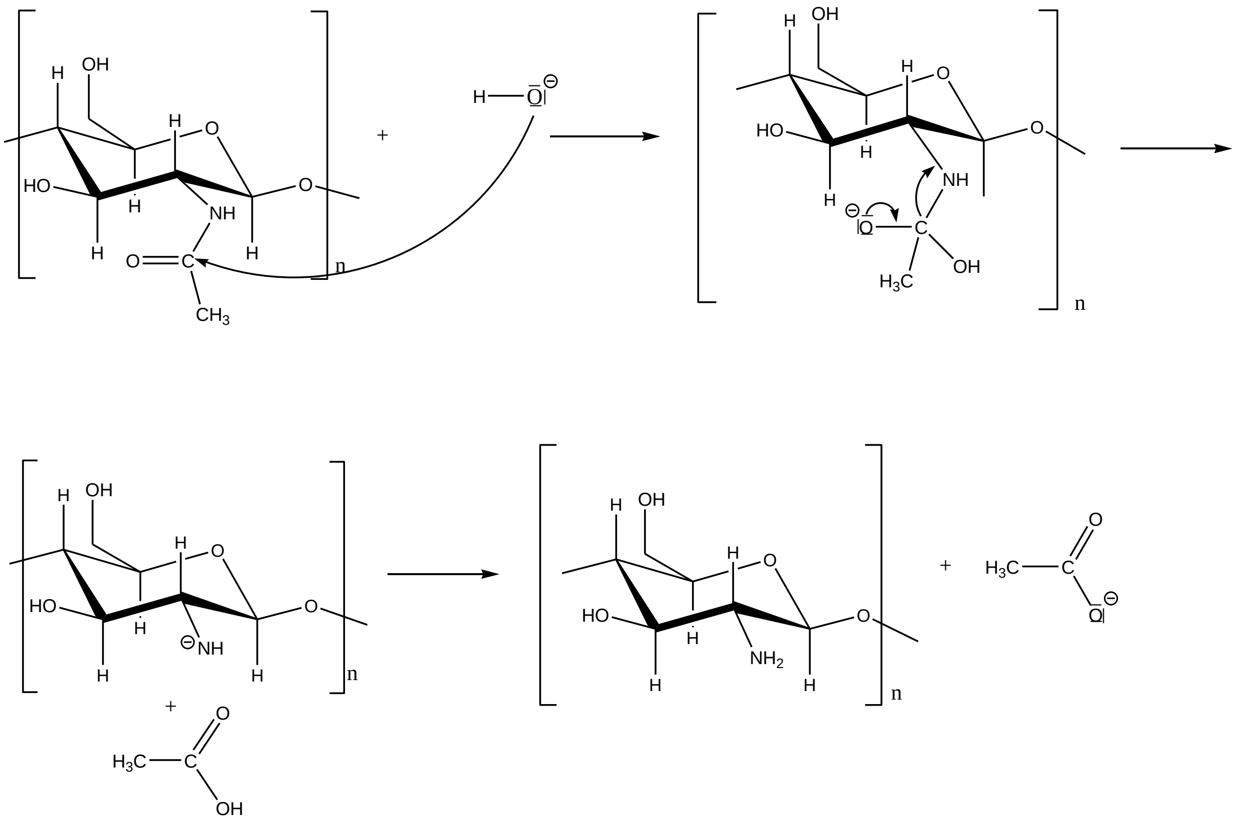
Deacetylation of chitin:

Summary:



Mechanism:

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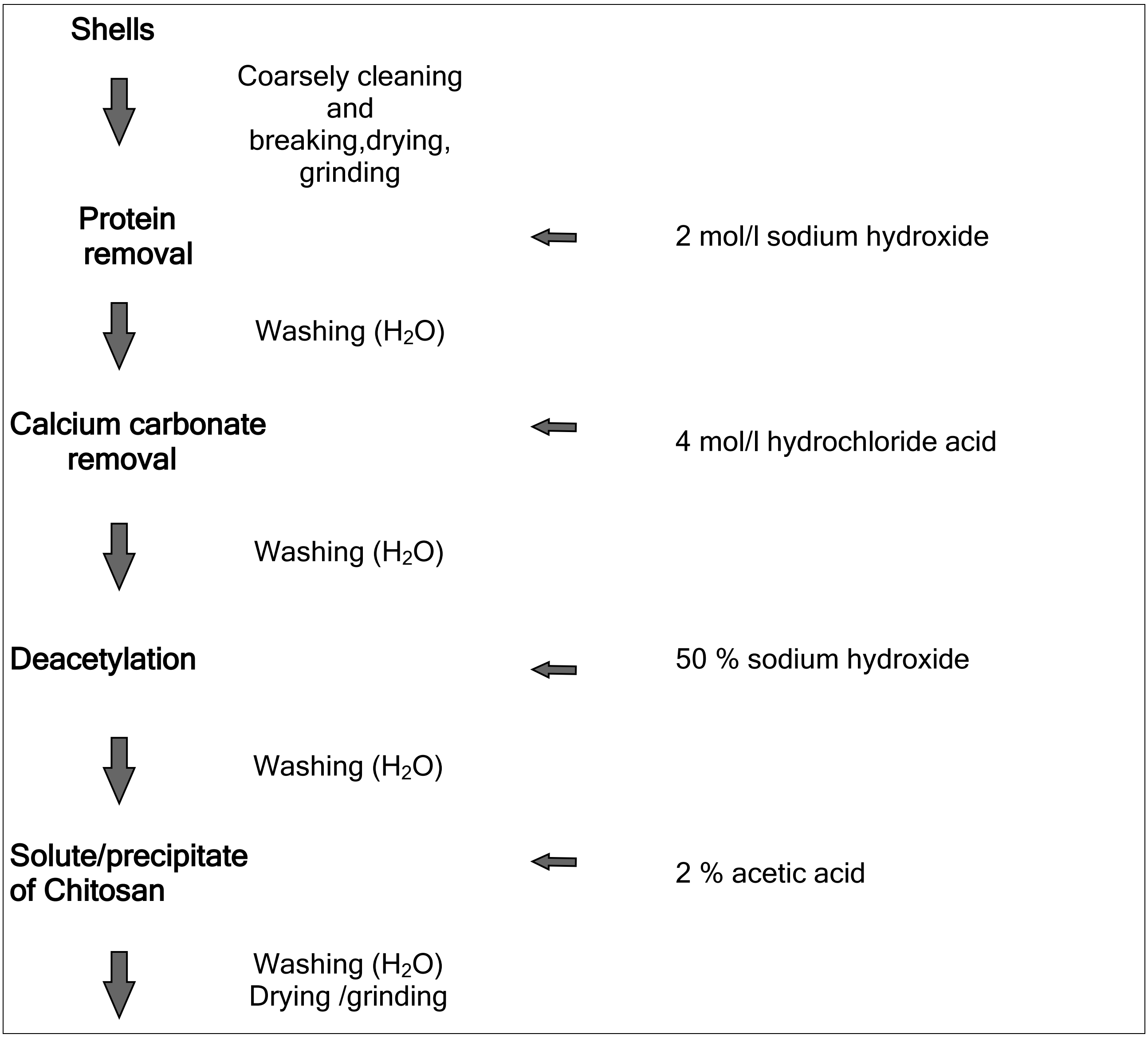


Chitosan has many applications due to its structure and properties. Bader and Birkholz (1997) published the following applications:

- The clarification and cleaning of protein-containing waste water of the fruit, meat, fish and milk industries and of breweries was once the biggest and for a long time the only, use of these polysaccharides. Chitosan causes the coagulation of the proteins found in the waste water. As a naturally occurring polymer, the chitosan is degradable and non-toxic, and so it should be preferable to synthetic polymers.
- Similarily, fruit and vegetable juice are clarified with the aid of chitosan.
- Chitosan and chitin are chelating agents showing complexation 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. dilute 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 significantly 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. Currently, 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, such as those listed below:

- 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 applications such as suture materials, wound dressings as well as synthetic skin.
- Recently, derivatives of chitosan are used in hair-care products, thanks to their setting and conditioning 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 industry.
- 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 guarantees 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 areas of application. During this unit, we will focus on chitosan as a 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 protonated and thus charged positively. These poly-cations are able to bind the negatively charged fatty acid anions, irreversibly 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.” (http://www.nutraingredients-usa.com/news/ng.asp?id=54318-chitosan-fails-to, accessed 24.08.2004)

IV. Pedagogical Content Knowledge

Teaching/Learning goals

Scientific concepts: Chemical structures of chitin and chitosan and their properties, the possible reactions of chitosan in the human body, applications of chitosan in different areas (biochemistry/medicine, cleaning water, preparing fruit juice ...) and its reactivity 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(s), 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 ideas, communicating with partners from industry, making own decisions based on scientific knowledge and personal values.

Prerequisite Knowledge:

Contents:

The students should already have some knowledge of carbon hydrates and about cellulose as a poly-saccharide;

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

Skills:

The students are familiar with conducting experiments on their own. They can use computers, and are able, at least to some extent, 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 has been on learning facts and concepts, while the promotion of the competencies have been neglected. This is changing since the new education standards have been introduced in 2004, where explicit foci are set on four areas of competencies: discipline knowledge, nature of science, communication and evaluation.

V. 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 section, 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 significantly 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 in 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 areas such as 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 too 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 also received 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 this 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 had a relevance to everyday life and life beyond school.

VI. 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)

- Can we find 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 a fat magnet, about the structure, formation and properties of chitosan. They 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 their 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 a fat blocker giving differing information. Does it work or does it not work? They reflect on their findings, discuss them with their classmates and prepare a public presentation with posters, experiments and slides.

Extension

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

Evaluation

After discussing the results and extending the chemical knowledge 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 in favour and against the use of chitosan and defend their decision, such as those listed below

In favour	Against
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 environments, but the intestine is basic
You avoid unhealthy overweight	Fat soluble medications can be compromised in its effectiveness (oral contraceptive, estrogen)
Creative method of using waste	The missing fat will also hinder vitamins from entering the metabolism
	Producing more shrimps in Asia will destroy mangrove woods
	It‘s much more healthy to eat balanced diet and do exercises

Activity	Experiment	Discipline	E-emphasis
1 Chitin from Crab Shells	1	Guided inquiry	Explanation
2 Chitosan from Chitin	2	Guided inquiry	Explanation
3 Solubility of Chitosan	3	Guided inquiry	Exploration
4 Chitosan binding Fat	4	Guided Inquiry	Exploration
5 Preparation of Chitosan Films	5, 6	Guided/open inquiry	Exploration
6 Clarification of Fruit Juices	7, 8	Guided inquiry	Extension

VII. Assessment

Assessment is very much dependent on the way the unit is taught and on the content chosen. This will differ in each school, each level and each country. Assessment tasks have to be constructed together with the teacher in charge.

VIII. Student Learning Activities

The student learning activities can be grouped as follows:

A. School experiments on chitin and chitosan
B. Student worksheets related to the experiments (available on website and e-platform)
C. Articles with more background information about chitosan as slimming agent (found on the internet)

Section B and C can be downloaded from the project website.

A. School experiments on chitin and chitosan

The following experiments are adapted and informed by 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
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: Isolating Chitin from crab shells

Learning aims:

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.

Duration:

First step: 20 minutes without drying time; second step: 2 hours; third step: 30 minutes without drying time.

Materials:

Classroom Materials: Experiment B worksheet

Equipment: beaker (400 ml), strainer (mesh size 3 - 4 mm), magnetic stirrer with heating plate, stirring rod, evaporating dish (diameter 14 cm), drying oven, balance, mortar with pestle, suction flask (500 ml), buschner flask and funnel, water pump or vacuum pump, thermometer, retort stand material, filter paper (diameter 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 a few minutes. Then the shells are filtered off. This process is repeated until sand and other soil are removed. The cleaned crab shells are dried overnight in the drying oven at 80°C.

Second step: Protein removal

15 g of the dried shells are ground in a mortar and transferred to a beaker. Then 250 ml of sodium hydroxide solution is added and the mixture is heated with 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 until neutral with demineralized water. To save time 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 is slowly added to the shells and the mixture is stirred at room temperature until no more gas evloves. 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 pre-cleaned 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

Duration

First day: 70 minutes; second day: 30 minutes without drying time.

Materials

Classroom Materials: Experiment C worksheet

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, vacuum pump, Buchner funnel and flask, filter paper, evaporating dish (diameter 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 is added to 2 g of chitin. The apparatus is flushed with nitrogen and then it is closed air-tight with a nitrogen-filled balloon. Now the mixture is heated under stirring to 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 until neutral 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.

Analysis of chitin and chitosan

Like starch, chitosan forms an inclusion complex with iodine, 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.

Materials:

Classroom Materials: Experiment D worksheet

Equipment: 2 watch glasses, 2 Pasteur pipettes.

Reagents and materials: Chitin, chitosan, I_2/ KI solution

(0.2 g I_2 is added to 100 ml of KI 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 mixture is acidified with 2-3 drops of sulphuric acid.

Observation: After addition of iodine/potassium iodide 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.

In contrast, 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.

Materials:

Equipment: 2 round-bottom flask (250 ml), 2 cork rings, measuring cylinders (100 ml and 10 ml), 2 reflux condensers, 2 heating mantles, 2 magnetic stirrers, 2 stirring rods, tubing, retort stand material, filter rack, filter paper, glass filter.

Reagents and materials: Chitin, chitosan, dilute hydrochloric acid, w(HCl) = 7%, concentrated hydrochloric acid, w(HCl) = 24%, acetic acid, w($C_2H_4O_2$) = 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 is added to each mixture. The flasks are heated under 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 a few 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 hydrolytes of experiment 4 by chromatography

Duration:

40 minutes.

Materials:

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).

Procedure:

Observation (see. 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 – see A and B in Figure 1 (both in position and brownish colour). The chromatograms of the filtrates (A and E below) show further spots below the main spot which are paler in intensity. Those indicate different oligomers of N-acetylglucosamine and glucosamines of 2 to 4 sugar units.

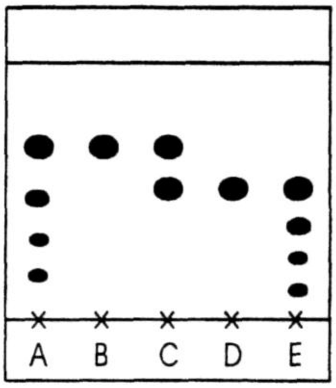
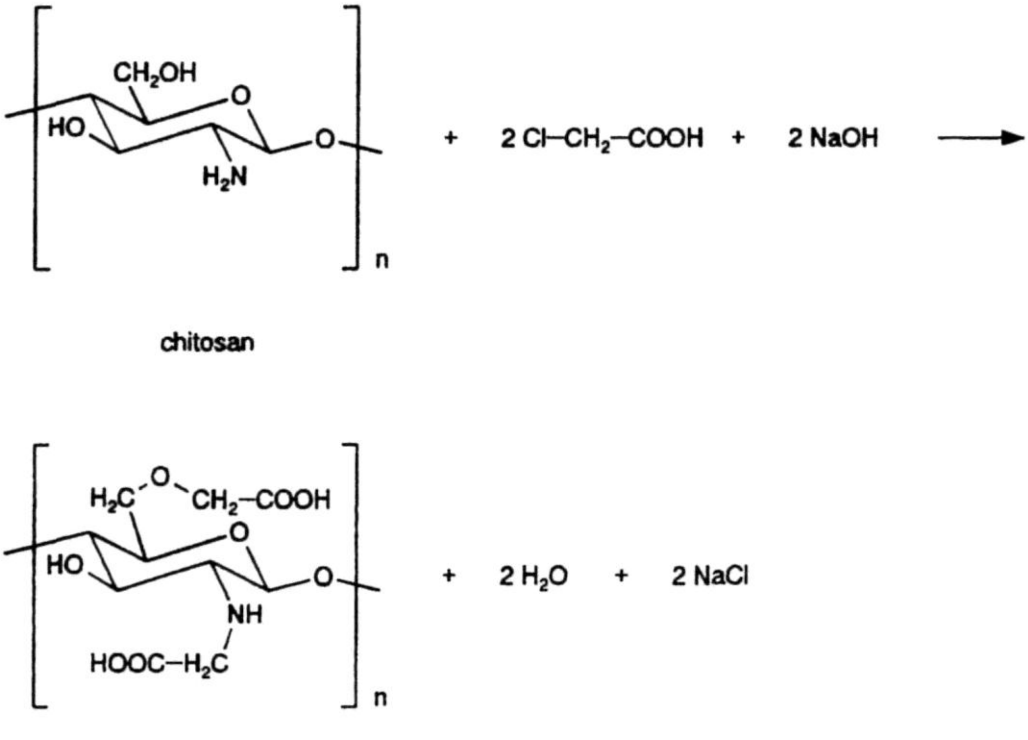


Figure 1. Chromatogram of products obtained in hydrolysis of chitin and chitosan. A: Filtrate of acidic hydrolysis of chitin, B: N-acetylglucosamine reference, C: N-acetylglucosamine/glucosamine reference, D: glucosamine reference, E: filtrate of acidic hydrolysis of chitosan.

Practical Use 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 flocculation can occur. 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 ionic macromolecular complexes with those compounds which can be removed by centrifuge.



chitosan

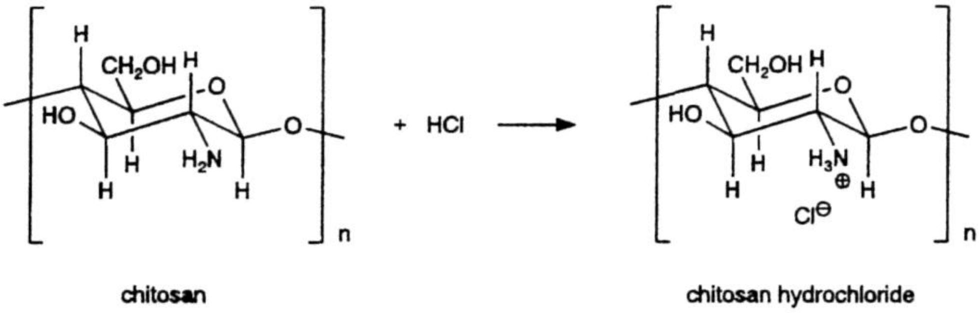
N,O-carboxymethyl chitosan

In alkaline medium, chitosan reacts with monochloroacetic 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. The coating is easily removed by washing before consumption. Fruits treated in this way keep well for more than three months when stored in cool environments.

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



When paper is treated with a solution of this hydrochloride, a film is formed on the surface, which 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.
Materials:
Classroom Materials: Experiment E worksheet *Equipment: 2* beakers (250 ml), magnetic stirrer with heating plate, stirring rod, Pasteur pipette, small-meshed strainer, 2 plastic plates or rinsing bowl. *Reagents:* Chitosan, acetic acid, w($C_2H_40_2$) = 12 %, tetraethylene glycol.
Procedure:
Procedure: Two beakers are filled each with 2 g of chitosan and 100 ml of acetic acid. With 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 a few 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 evaporate overnight.
Observation: After the solvent has evaporated 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 a strainer, it is possible that the chitosan particles not dissolved completely will cause areas of thickness and uneven patches. Also, 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.

Materials:

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/L, acetic acid, $c(C_2H_4O_2) = 0.2$ mol/L.

Procedure:

Preparation of chitosan solution: With slight heating, 1 g of Chitosan is dissolved in 50 ml of dilute acetic acid (w ~ 1.2%). The solution is diluted with demineralized water to a volume of 200 ml, resulting in a 0.5% chitosan solution in 0.3% acetic acid. This solution shows no Tyndall effect.
50 ml of demineralized water are added to 1 g of fresh egg-white. After stirring for a few minutes, 0.5 g of chitosan is 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 is 7. The centrifugate is clear. The biuret test is negative. 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/L 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.

Materials:

Classroom Materials: Experiment F worksheet

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.

Procedure:

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).

Materials:

Equipment: 2 beakers (100 ml), magnetic stirrer, stirring rod, filter, filter rack, filter paper, pH paper, evaporating 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 dilute 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 highly 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 fumehood and protective gloves have to be worn. If stirring time is shortened, possibly not all of the chitosan will have 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.

Materials:

Equipment: Beaker (250 ml), magnetic stirrer with heating plate, stirring rod, Pasteur pipette, small-meshed strainer, plastic plate (30 cm^2) or rinsing bowl.
Reagents and materials: N,0-carboxymethyl chitosan, demineralized water.
Procedure: 2 g of N,o-carboxymethyl chitosan is dissolved with 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 evaporate overnight.

Procedure:

Observation: After the evaporation 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, that are not dissolved completely will cause areas of thickness and uneven patches. Also, 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.

Materials:

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

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

Procedure:

With 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 each put onto a clock glass in the refrigerator and are observed over 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, looking more wrinkly and after two weeks, the first moulding is observable. In contrast, the treated fruits do not show any changes.

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 such 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.

Materials:

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 is 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 with boiling. On cooling, a fine, white and crystalline precipitate is formed.
Faults and precautions: Chitosan hydrochloride only dissolves completely at boiling temperatures. 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.

Materials:

Equipment: 2 evaporating dishes (14 cm), 2 pincers, hair-drier, balance.
Reagents and materials: Chitosan hydrochloride, demineralized water, paper (ca. 8 x 8 cm), ink.

Procedure:

In an evaporating dish, 1 g of chitosan hydrochloride is dissolved in water. Some pieces of paper are then 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 more 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 ink spots formed.
Waste disposal: The treated paper is added to the waste jar for solids. The dipping solutions are poured down the sink.

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