3

PLASTIC EXPERIMENTS

Plastic is an important part of our everyday lives, yet for a long time the problem of plastic waste has been an underes timated threat to our environment. Mountains of plastic waste still present us with a great challenge today. This teaching module addresses this problem through practical experiments from school pupils' everyday surroundings and makes a valuable contribution to education for sustainable development.

Laura Thiel, Corinna Hößle,
Holger Winkler, Antje Wichels

TASK

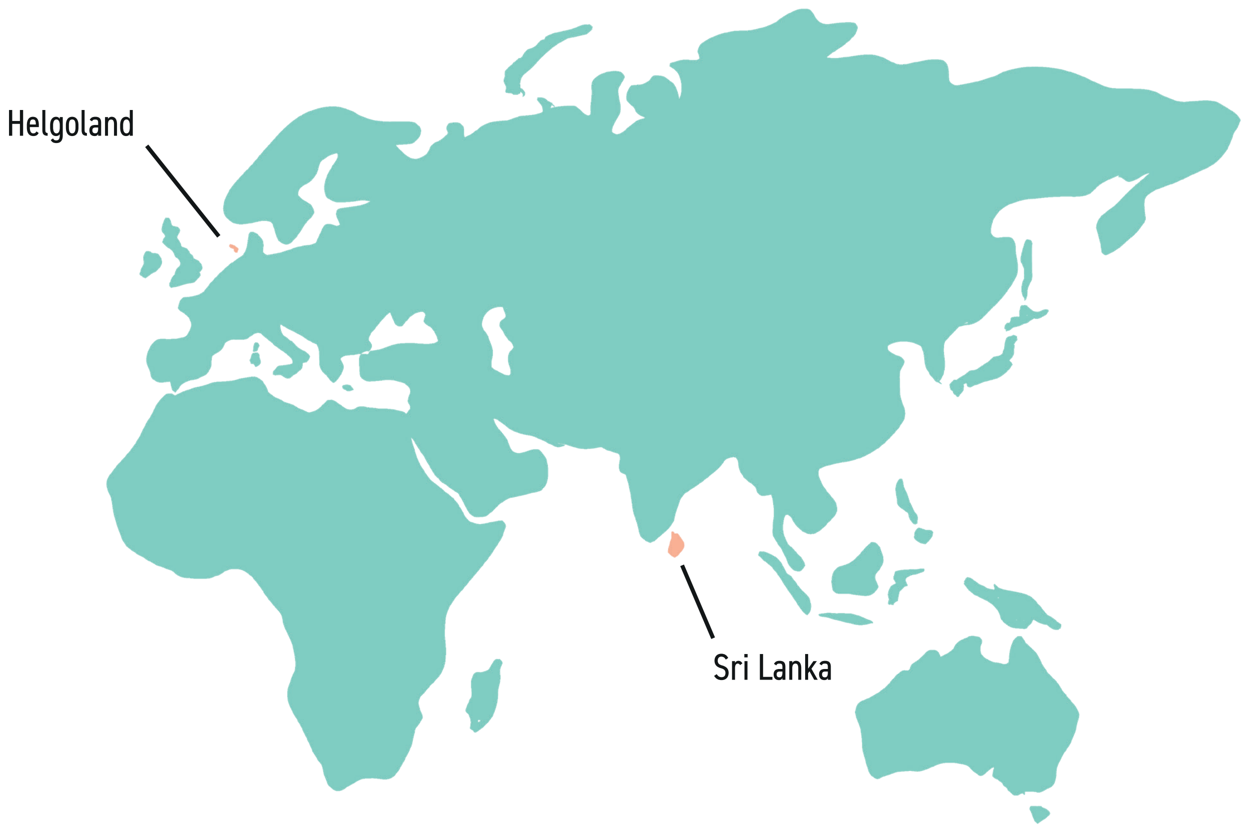
Do research and perform experiments on plastic as part of our everyday lives. How many plastic products do you handle every day? Do you know how much microplastic a fleece sweater sheds in one wash? Gather ideas on what can be done about plastic waste and pollution!

Info on the Biological Institute Helgoland

This educational material was developed for school clases by a team from the Biological Institute Helgoland at the Alfred Wegener Institute Foundation, Helmholtz Centre for Polar and Marine Research, which studies biotic communities in the North Sea. Helgoland is Germany's only deepsea island and is located about 70 kilometres from the mainland. The rocky mudflats and the submarine rocky landscape covering more than 35 square kilometres are home to the richest marine fauna and flora on the German coast in a kind of oasis. Research has been conducted here since 1892 and the Biological Institute Helgoland has been part of the Alfred Wegener Institute since 1998.

Plastic Experiments: Laura Thiel, Corinna Hößle, Holger Winkler, Antje Michels

https://www.awi.de/en/focus.html



LEARNING MATERIALS & EXPERIMENTS FOR YEARS 7 AND 8

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Microplastic Contamination in the Weser-Wadden Sea National Park Model System: An Ecosystem-wide Approach. These learning materials and experiments were developed to raise awareness of plastic waste in the FONA joint project PLAWES in cooperation with the AWI and the University of Oldenburg and provide learners in years 7 & 8 with specialist knowledge on the topic of plastics and plastic waste. BmBF FKZ-03F0789B

CONTENTS

THE PROBLEM WITH PLASTIC

Plastic is everywhere – and it is inconceivable to imagine our everyday lives, not to mention our newspaper headlines, without it. Its useful properties, such as longevity and stability, are precisely what makes it hazardous to the environment when it is not disposed of correctly.

Everywhere we go, we are faced with headlines like "Plastic waste: The polluted planet" (Hecking et al, 2018) and "The fight against plastic – can we still save the oceans?" (Schlag & Wenz, 2019), yet it seems that living our lives without using plastic would be verging on the impossible. Many school pupils are also confronted with this dilemma and this learning module provides them with the opportunity to intensively delve into this topic.
This learning module presents methods to help assist in making decisions concerning how to best deal with plastic. Furthermore, pupils will gain the knowledge necessary for participating in societal discussions on the subject. They will work through much of the thematic content independently, using exploratory and discovery-based learning. All learning modules have been designed with education for sustainable development in mind, within the scope of the Microplastic Contamination in the Weser-Wadden Sea National Park Model System: An Ecosystem-wide Approach project (PLAWES for short). The core aspects of this project, the point sources, the entry paths and the spread of microplastics in rivers and the ocean, have been focused on.
The pupils will also critically assess their own consumption of plastic and suggestions for good ways to manage plastic will be provided to the pupils.

LEARNING REQUIREMENTS

Pupils do not need any specific prior knowledge about plastic or the plastic waste problem. All learning material can be worked through independently by pupils using the integrated experiments and the tasks for developing specialist knowledge. Pre-existing knowledge about the river-ocean system, food chains and globalisation are beneficial fo being able to holistically assess the scope of the problem.

THE TERM PLASTIC

The term plastic refers to the complete group of plastic materials including thermoplastics, thermosets (more on this later) and elastomers. These include finished products and waste products (plastic bottles and plastic waste) as well as the raw materials used in the plastics industry and the chemistry of plastics.

STRUCTURES OF PLASTICS

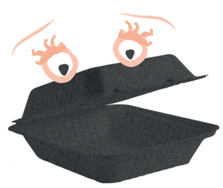
Plastics are technical materials that consist of macromolecules. They are mainly produced from crude oil, natural gas and coal. Macromolecules consist of many small molecular building blocks called monomers (mono=one). These are linked together to form long or large molecular chains.
These are called polymers (poly=many) and consist of 100 to over 10,000 monomers (Braun, 2012). The most common chemical elements in plastics are carbon (C), hydrogen (H), oxygen (O), nitrogen (N), chlorine (Cl), silicon (Si) and sulphur (S).
In addition to basic polymers, substances can be added to plastics to change their properties. These additives contribute to the specific properties of the plastics and can improve durability, strength, weight, corrosion resistance, as well as thermal and electrical insulation properties (Gächter & Müller, 1990).

THEORETICAL BACKGROUND TO PLASTICS

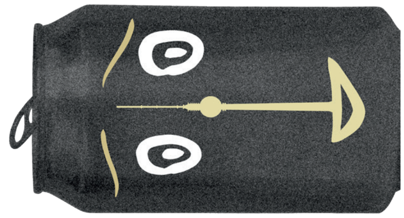
Modern life is inconceivable without plastics. Countless technical parts, clothing, packaging materials, furniture and so much more is made of plastic. Yet plastics are a relatively new invention. It was not until 1905 that the Belgian chemist Leo Baekeland (1863-1944) discovered that phenol and formaldehyde could be combined in experiments to form long molecular chains and hardened under heat and pressure to form a solid mass. In 1907, he patented his invention under the name Bakelite (Crespy, 2008), the first plastic was born and the heat-resistant Bakelite is still used for the production of light switches, sockets and telephones, for example.
The German chemist Hermann Staubiger (1881-1965) also researched the composition and structure of plastics. His findings on the macromolecule, as he called the plastic, are still valid today.
In 1953, he was awarded the Nobel Prize in Chemistry for his work. The triumphal march of plastics began in 1955, when the Ziegler-Natta catalyst (Braun, 2017) was developed for the synthesis of polymers. In the 1970s, the boom of plastics began through industrial production (2 million tonnes) and with it the advance of plastics into people's everyday lives.
A thousand new types of plastic have been developed since then. In 2017, 348 million tonnes of plastics were produced worldwide, 64.4 million tonnes in Europe alone, (PlasticsEurope, 2018). This is a worldwide increase of ca. 370% between 1950 and 2019 (Statista 2020). The largest share (39.7%) of the plastic produced is made into packaging. Other important sectors are household goods (about 5%), electronics (6%) and medicine (16%), as well as the construction industry (about 20%).

BIOPLASTICS

A new trend in the plastics industry is the development of bioplastics. This term is ambiguous and is sometimes criticised for not being precisely defined. Bioplastics are materials that can be made from renewable raw materials (such as corn, rubber or potatoes).
The cultivation of these raw materials leads to an increased use of soil, often accompanied by over-fertilisation of the cultivated areas. A study by the German Environment Agency (UWA) has shown that the ecological footprint of bioplastics is worse than that of fossil plastics. These bio-based plastics mostly have the same chemical structure as synthetic plastics.
They also often occur in a mixed form (20% bioplastics, 80% fossil plastics) (Thielern, 2013). These materials are not biodegradable and they can be recycled in the same way as conventional plastics.
On the other hand, the term bioplastics refers to their degradation properties. These biodegradable plastics can theoretically be completely biodegraded under optimal conditions (Ißbrücker, & von Pogrell, 2013). The biodegradable plastics are made from both crude oil and renewable raw materials. However, if such biodegradable plastics enter the recycling loop, there is often a reduction in plastic quality and thus rejects. Our current bioplastics therefore only represent a more sustainable alternative to conventional plastics to a limited extent (Detzel, et al, 2012).



SYSTEMATISATION OF PLASTICS



Plastics can be classified according to the chemical properties of the polymers. Depending on the type of molecular cross-linking, they are divided into thermoplastics, thermosets or elastomers.

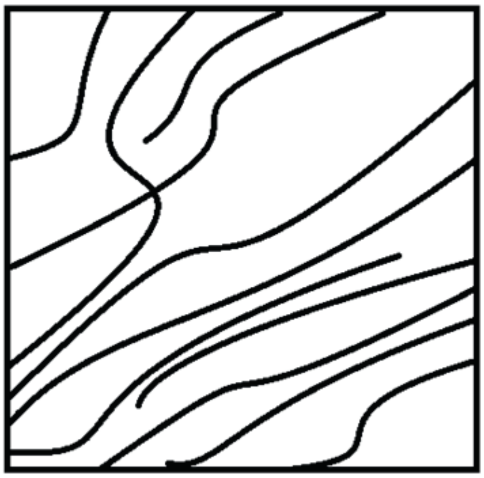


Illustration 2: Molecular structure of thermoplastic

THERMOPLASTICS

Thermoplastics are characterised by their long linear structure. They are easily to mould by heating. They consist of different lengths of polymer strands and are held together by physical interactions (Van der Waals forces and hydrogen bonds). The heating process causes the molecules to vibrate so that the interactions are cancelled out and the plastic becomes mouldable. Thermoplastics are often used in technical processes because of these properties.

Examples: Packaging material, fishing lines, hoses

THERMOSETS

Thermosets are characterised by the net-like structure of their monomers, which are all linked together. In addition to physical interactions that connect the polymer strands, there are atomic bonds. As a result, thermosets remain dimensionally stable, even at high temperatures. At very high temperatures, thermosets carbonise and the original structure can no longer be produced. In addition to their high stability, thermosets are also characterised by their high chemical resiistance.

Examples: Irons, insultaing material, sockets.

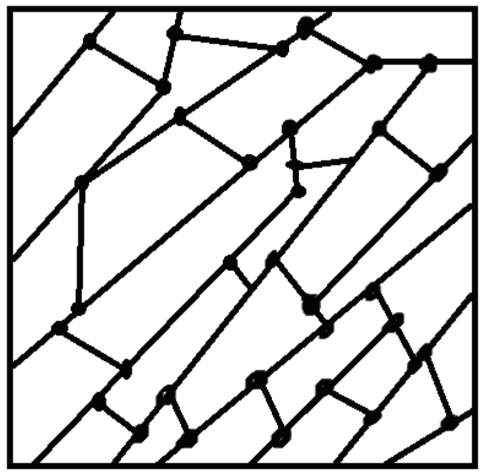


Illustration 2: Molecular structure of thermosets

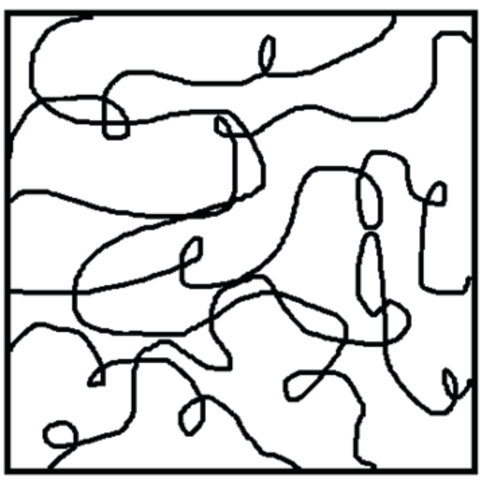


Illustration 2: Molecular structure of elastomer

ELASTOMERS

The structure of elastomers is similar to that of thermosets. Their polymer strands are connected with atomic bonds, but their net structure has larger meshes. When heated in a tensioned state, the plastic contracts as the mesh threads vibrate more and the mesh nodes move closer together. This means elastomers can be deformed by pressure and tension. After deformation, they return to their original shape.

Examples: Mattresses, shoe soles, table tennis bats, rubber bands.

Manufacturing of plastics

Plastics are usually produced completely synthetically. This process is called polyreaction and can take place in three ways:

• **Polymerisation:** Monomers are continuously linked to each other. No waste products are produced.

• **Polycondensation:** Monomers are linked together in stages with the elimination of a lowmolecular product (condensation) such as water or hydrochloric acid.

• **Polyaddition:** Monomers are linked together in stages. No waste products are created.

Plastic in the ocean

Most plastic enters the ocean via two pathways, the majority (80-98 %) being land-based, e.g. via rivers, tourism, littering in nature and landfills. The driving force is often the wind, which blows the particles towards the ocean. In contrast, only about 2-20% of plastic enters the oceans
directly via ships and fisheries (sea-based; Newman et al, 2015). Approximately 4.8 to 12.7 tonnes of plastic are discharged into the ocean annually through improper waste disposal (Jambeck, et al, 2015). Plastic can be found everywhere in the ocean, and it can be found at all depths. Only a small proportion of the total amount of plastic floats on the ocean's surface. Scientists have discovered that about 0.7 g/m2 of plastic floats on the sea surface (Lebertton et al, 2017). In contrast, they found about 70 g/m2 on the seabed. Ocean currents cause particularly large amounts of plastic to accumulate in some regions. These areas are called garbage patches. In the largest of them, the Great Pacific Garbage Patch, researchers have found up to 80 g/m2 of plastic floating at and below the surface. It covers an area of 1.6 million square kilometres (more than 4 times the size of Germany and 24 times the size of Sri Lanka). The ocean current causes comparatively large amounts of plastic to accumulate here (Kaiser, 2010).
Due to its chemical properties, plastic is not biodegradable. It breaks down into smaller and smaller pieces through chemical and physical processes such as UV light, abrasion and temperature fluctuations (Primpke et al, 2017).

Complete decomposition can take many hundreds of years. During this time, pollutants such as toxins or heavy metals can accumulate on the plastic waste. These are often persistent organic pollutants (POPs), such as organochlorine insecticides (chlordane, DDT), which build up on the plastic and can be released back into organisms when plastic is ingested (e.g. mistakenly eaten as food). Due to this build up of pollutants and the material properties, plastic can be dangerous for many organisms. Scientists have shown that up to 80% of vertebrates (marine mammals, seabirds, sea turtles and fish) have plastic inside them, which often leads to death by impairing organ functions (Thiel et al,2018).
Plastic waste in the environment is divided into two categories according to its size: macroplastics (> 5 mm) and microplastics (< 5 mm). Microplastics can also be classified into primary and secondary microplastics according to their origin. Primary microplastics are industrially manufactured, such as pellets and beads for the cosmetics industry, and secondary microplastics are produced by the chemical and physical break down process of macroplastics.

Literature

Braun, D. (2012) Erkennen von von Kunststoffen- Qualitative Kunststoffanalyse mit einfachen Mitteln, Kap. 1. Kunststoffe und ihre Erscheinungsformen (S. 21-15), Carl Hanser Verlag München
Braun, D. (2013) Kleine Geschichte der Kunststoffe, Neuzeit-1900-1960 -Die Großen Drei S.215-238, Carl Hanser Verlag München
Crespy, D. (2008) 100 Jahre Bakelit: das Material für 1000 Anwendungen, Angewandte Chemie, 120/3368-3374
Detzel, A.; Kauertz, B. & Derreza-Greeven, C. (2012) Untersuchung der Umweltwirkungen von Verpackungen aus biologisch abbaubaren Kunststoffen, Umweltbundesamt
Gächter, Müller (1990) Kunststoffadditive. 3. Ausgabe. Hanser Verlag, München/Wien, 1990,
Hecking, C., Martin, A., & Voss, L. (2018). Der vermüllte Planet, Spiegel online; https://www.spiegel.de/wissenschaft/natur/plastikmuell-welche-wege-fuehren-aus-der-abfallkrise-a-1223743.html (25.06.2020)
Ißbrücker, C.; von Pogrell, H. (2013) Biobasiert, bioabbaubar oder beides, Nachrichten aus der Chemie, 61
Kaiser, J. (2010) The Dirt on Ocean Garbage Patches, Science 328(5985)/1506
Leberton, et al (2018): Evidence that the Great Pacific Garbage Patch is rapidly accumulating plastic. Scientific reports 8 (1), S. 4666.
Newman, S. et al., (2015) The Economics of Marine Litter, Marin Anthropogenic Litter Kap.14, S.378-380
PlasticEurop (2018) Plastics-the Facts 2018, An analysis of European plastics production, demand and wast data, Kap. Markt Data, 14-27
Primpke, S. et al (2017) Mikroplastik in der Umwelt, Chemie in unserer Zeit, 51/402-412
Rochman, C. M. (2015) The Complex Mixture, Fate and Toxicity of Chemicals Associated with Plastic Debris in the Marine Environment, Marine Anthropogenic Litter Kap.5, S.117-140, Springer
Schalg, G., & Wenz, B. (23. April 2019). SWR2 Wissen. Retrieved from SWR2: https:// www.swr.de/swr2/wissen/kampf-dem-plastik,broadcastcontrib-swr-11532.html Statista (2020) Weltweite und europäische Kunststoffproduktion in den Jahren von 1950 bis
2019. Abgerufen von https://de.statista.com/statistik/daten/studie/167099/umfrage/ weltproduktion-von-kunststoff-seit-1950
Thiel, M. et al (2018) Impacts of Marine Plastic Pollution from Continental to Subtropical Greys- Fisch, Seabirds and Other Vertebrates in the SE Pacific, Frontiers in Marine Science, Vol.5, 238 Thielern, M. (2013) Biokunststoffe, Pflanzen Rohstoffe Produkte (Bioplastics, Plants, Raw Materials, Products), bioplastics Magazine, Fachagentur Nachwachsende Rohstoffe e. V. (FNR)

MATERIALS FOR LEARNERS

1. PLASTIC IN EVERYDAY LIFE

Imagine that all plastic disappears overnight. You are rudely awakened because your mattress, duvet and pillow are gone, and the light switch is no longer there. You stand in the dark and think about what else is missing.

a) Write down all the plastic things you would miss today. Think about what you have already used and what you will use in the future.

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b) Plastic doesn't just disappear from our lives, instead we actually throw a lot of it away. Circle all the things that you have already thrown away today and that you will throw away during the coming month.

c) Add up all the items from a. and enter them under the total number. Now count the circled items from b) and enter them under the share of rubbish..

Total number of items ______________

Share of rubbish ______________

d) Compare your numbers with those of your classmates. Then calculate the average number of plastic items and rubbish in your class.

Info-Box
The average (Ø) can be calculted by adding up all the plastic items from all pupils (sum) and then dividing by the number of pupils..

Average =
Total number of plastic items
divided by number of pupis

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e) Calculate what percentage (%) of the plastic used is rubbish on average.

Info-Box

To calculate the percentage (%) of rubbish of the plastic items used, we use the formula for calculating the percentage. The percent number (rubbish) is divided by the basic value (plastic items) and then multiplied by 100.

Percentage (%) =
Percent number
divided by Basic value
x100%

2. PROPERTIES OF PLASTIC

We all use plastic in many different parts of everyday life. Plastic meets a variety of needs and can be used in different areas. This is possible because plastics consist of many small molecular building blocks called monomers (mono=one), which are linked to form long or large molecular chains. They are called polymers (poly=many) and consist of 100 to over 10,000 monomers. In addition to basic polymers, other substances called additives can be added to the plastics to change their properties..

How do the properties of different plastics differ? Test this in an experiment.

a) Formulate assumptions (hypotheses) about the breaking properties, burning behaviour and melting behaviour of plastics. Enter them on the experiment sheets.

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b) Independently test the different properties of plastics. Proceed like a scientist.

EXPERIMENT:

TASK

1. Develop one experiment for each behaviour to test your hypotheses. Use the materials provided.

2. Perform the experiments and record your results on the experiment sheets.

Use the extractor fan when attempting to burn plastic!

MATERIAL

• Plastic particles
o Polyethylene (PE)
o Polyvinyl chloride (PVC)
o Polystyrene (PS)
o Rubber band
o Unsaturated polyester resins (UP)
• Bunsen burner
• Crucible tongs
• Fire-resistant base
• Test tubes
• Safety glasses
• Beaker with water (extinguishing water)

Experiment sheet: Breaking properties of plastics

Assumptions/ hypotheses	
Chemicals/ materials/ equipments	
Procedure	
Observation	
Analysis and interpretation	

Experiment sheet: Burning behaviour of plastics

Assumptions/ hypotheses	
Chemicals/ materials/ equipments	
Procedure	
Observation	
Analysis and interpretation	

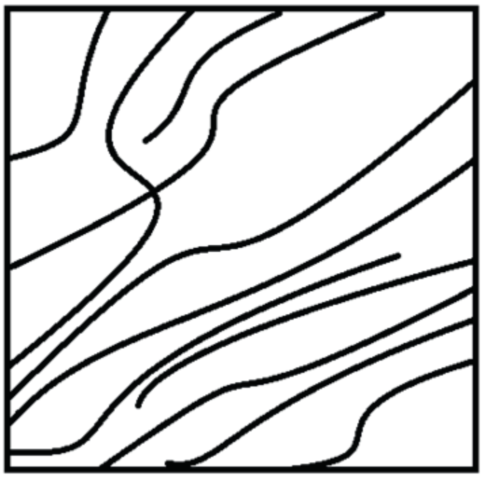
Experiment sheet: Melting behaviour of plastics

Assumptions/ hypotheses	
Chemicals/ materials/ equipments	
Procedure	
Observation	
Analysis and interpretation	

c) Summarise your results in the table.

Plastic	Polyethylene (PE)	Polyvinylchloride (PVC)	Polystyrene (PS)	Rubber band	Unsaturated polester resins (UP)
Experiment Breaking behaviour					
Experiment Burning behaviour					
Experiment Melting behaviour					
Polymerclass					

d) Read through the information and add the polymer class to the table.



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Examples: Packaging material, fishing lines, hoses

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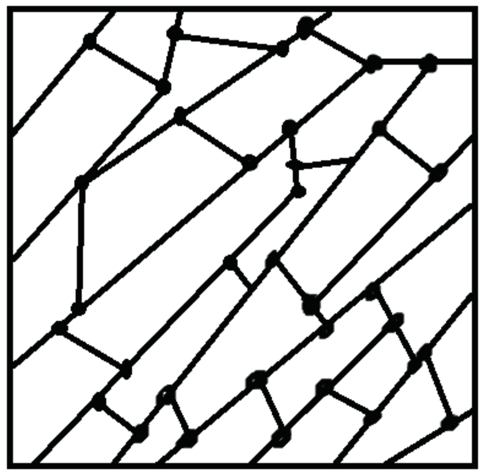

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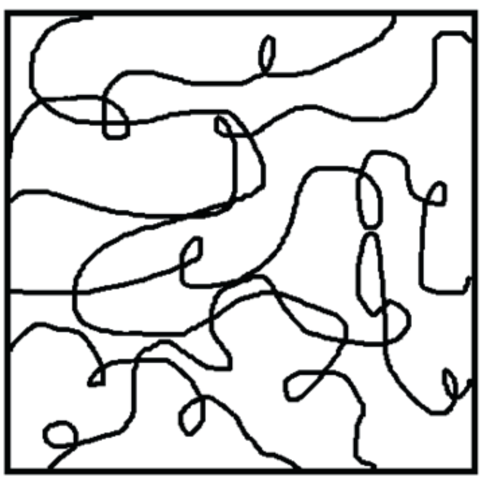

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Examples: Mattresses, shoe soles, table tennis bats, rubber bands.

e) Check your assumptions from 2a) and write a statement about them.

f) Think about which plastic from which polymer class is most commonly found in nature. Give reasons for your answer.

3. MICROPLASTICS AT HOME

In addition to the large amount of packaging waste, plastic waste also accumulates in tiny pieces every day called microplastic. This is hidden in cosmetics and hygiene products and also in our clothing. It gets into rivers, lakes and the ocean via wastewater.

In small groups, test how much microplastic is produced when clothes are washed.

Info-Box

Plastic is divided into macroplastic (≥5mm) and microplastic (<5mm) according to its size.
Microplastics are divided into primary microplastics, pellets or beads that are produced industrially, and secondary microplastics, which are produced when macroplastics break down.

a) Formulate hypotheses (assumptions) about the amount of microplastics in wastewater.

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b) Perform the experiment according to the test instructions.

EXPERIMENT:

TASK

1. Fill the bucket with 2-3 litres of water and put the fleece in. Wash it thoroughly for about 5 minutes. Wring the water out of the fleece into the bucket and hang it up to dry.
2. Now slowly pour the wash water through a paper filter placed inside a funnel.
3. Pour all the water over the filter and then rinse the bucket above the filter again with water (from the spray bottle).
4. Now look at the filter under the binocular microscope and collect all the fibres from the filter. Count the fibres you find, if there are too many, try to estimate the amount.
5. Compare some of the fibres under the microscope with natural fibres, e.g. from your clothes. Make a sketch of each.

MATERIAL

- Microfibre towel (new)
- Water
- Metal bucket
- Binocular microscope
- Microscope slides and cover slip
- Tweezers
- Spray bottle with water
- Filter paper
- Funnel
- Petri dishes
- Natural fibres (hair, wool, linen))

Experiment sheet: Microplastics

Assumptions/ hypotheses	
Chemicals/ materials/ equipment	
Procedure	
Observation	
Analysis and interpretation	

a) How many fibres did you find? ______________

b) List differences and similarities between natural and synthetic fibres..

c) Check your hypotheses. Were your assumptions correct? Give reasons for your answer.

d) Think about ideas for how to reduce the release of microplastics into wastewater in the future.

4. THE JOURNEY OF PLASTIC

There is a lot of plastic waste in the ocean and on beaches. Most of the rubbish does not enter the ocean directly from ships, instead the wind blows it there or it reaches the ocean from rivers. On its way from rivers to oceans, the rubbish is influenced by many factors.

a) List things that can affect plastic on its way from the river to the ocean.

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b) Formulate hypotheses (assumptions) for the behaviour of plastic on its way from the river to the ocean.

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c) In addition to the wind, temperature and salt content also have an effect on ocean currents. In small groups, develop an experiment on temperature and salt content. Investigate the distribution of plastic waste in our rivers and oceans using microplastics as an example.

EXPERIMENT:

TASK

1. Formulate hypotheses (assumptions) about the behaviour of plastic in the ocean.
2. Plan an experiment together. Try out various things and use the materials provided.
3. Perform the experiment and record your results on the worksheet.
4. Discuss the results in small groups. If necessary, revise your experiment set up and perform further experiments.
5. Discuss and note down the result. Talk about any possible errors.
6. Check your hypotheses.

MATERIAL

- Plastic particles
- Water container (50x20x3cm [w/h/d]) with dividing wall
- 2x 500ml beakers
- 2 spatulas or spoons
- Tap water (warm/cold)
- Ice cubes
- Table salt (NaCl)
- Food colouring

Experiment sheet: Temperature

Research question **Assumptions/ hypotheses**	
Chemicals/ materials/ equipment	
Procedure	
Observation	
Analysis	

Experiment sheet: Salt content

Research question **Assumptions/ hypotheses**	
Chemicals/ materials/ equipment	
Procedure	
Observation	
Analysis	

d) Describe how plastic behaves in rivers.

e) Describe how plastic behaves in the ocean.

f) Check your hypotheses. Were your assumptions correct? Give reasons for your answers.

g) Consider which physical property the observed behaviour of the plastic is connected to.

g) Discuss the impacts on nature when plastic enters rivers and oceans.

5. IDEAS FOR THE FUTURE

a) Many environmentalists want to do something about the amount of rubbish in the ocean and are developing ideas on how to get rubbish out of the ocean again. In small groups, think about how easy or difficult it is to remove rubbish from the ocean. Give reasons for your answers. Can you think of other ideas to help reduce the problem?

b) What can you do help reduce the plastic problem in oceans?