Alternative Plastics

At a glance

	Content summary	National Curriculum links	Activities
Lesson 1	Practical experiments preparing eco-friendly plastics from natural materials	Working scientifically; organic compounds; carbon compounds as feedstock for plastics	**Activity A:** How can we prepare eco-friendly plastics?
Lesson 2	Investigating food packaging, recycling and properties of plastics	Explaining applications of science in society; discussing consequences of our choices; recycling	**Activity C:** Investigating food packaging

Background and National Curriculum links

The activities are intended for one or two Year 10-11 lessons on plastics. Students make plastics that are not made from petroleum-based substances. They consider how food is packaged, recycling and if the plastics they made could be viable alternatives to plastics currently used. The two activities could take place in one lesson, or be spread across two lessons to fit additional curriculum topics.

National Curriculum

- The viability of recycling certain materials;
- Carbon compounds as feedstock for plastics;
- Structure of natural and synthetic organic compounds;
- Carrying out experiments appropriately, manipulating equipment, and considering health and safety.

Teacher subject knowledge

Teachers require:

- understanding of polymerisation;
- knowledge of the chemical structures of carbohydrates and proteins.

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Cross-curricular links

The first synthetic plastics were produced in the early 20th century. In 1907, Henry Bækeland reacted phenol (C_6H_5OH) with formaldehyde (methanal, CH_2O). The reaction produced a resin, which he named 'Bakelite' after himself. Realising Bakelite's potential, Bækeland perfected, then patented, the production process in 1909. Bakelite was used as an insulator in electrical items. Household items including telephones, radios and jewellery made from Bakelite are highly collectable.

From the 1920s onwards, plastics became cheap to produce, enabling a range of affordable products to be made. Poly-ethene (or polyethylene) was first made in 1933 by Eric Fawcett and Reginal Gibson at Imperial Chemical Industries in Northwich, Cheshire. We still use high-density and low-density polyethene today. Nylon was first made by Du Pont chemist Wallace Carothers in 1935. This was developed as a fibre, still used in fabrics. Polystyrene was sold on an industrial scale from 1954 by Koppers Company, in Pittsburgh, USA for packaging and insulation.

We assume that food and drink is readily available in neat, stackable, hygienic, conveniently-sized plastic packaging. Before plastics, leaves, hollowed-out wood, animal skins, gourds, amphorae, barrels, glass, mulberry bark, buckets, urns, glass bottles, vases, jugs, paper bags, tins, cartons and boxes were used to transport food and drink. Plastic containers became near universal from the 1970s onwards. Now we are moving towards reducing single use plastics significantly.

Student background knowledge

The lessons will contribute to students' understanding of organic chemistry and particularly polymerisation. Basic understanding of the bonding and structure in carbohydrates and proteins is required.

Resources and timing

One or two 50 – 60 minute lessons are required. The activities could be spread over two lessons. Activity B can be a homework task.

Technical requirements

This lesson involves preparation of plastics from potato starch, gelatin and milk casein. The experiments can be shared across a class, so students can work in pairs or small groups to prepare one or more plastics as time and resources permit.

Activity A: How can we make eco-friendly plastics?

To make all three plastics, each pair or group of students will need:

- Eye protection
- Bunsen burner
- Heatproof mat
- Tripod and gauze
- Glass rod
- Spatula
- 250 cm^3 beaker (note: potato starch preparation requires 2)
- Distilled water
- Petri dish / white tile or silicone mould

Optional equipment

This optional equipment is helpful but not essential:

- Small silicone moulds (e.g. non-stick ice cube trays) or a silicone baking sheet
- Food colouring
- Biscuit cutters in various shapes

Preparation of plastic film from potato starch

Students can use potatoes or commercial potato starch. If potatoes are used, a large pestle and mortar is needed to extract enough starch to make sufficient plastic to cover a Petri dish or white tile. If small pestle and mortars are available, top up the starch that students extract with bought potato starch. Extracting starch takes about 15-20 mins. If time is short, this should be done before the lesson.

Making plastic film takes about 20 mins. The main hazard is boiling the mixture dry. The plastic film can be dried in a drying cabinet for about 90 minutes at 100^0C, left at room temperature for 2 days, or in a warm place for about 24 hours.

An alternative resource sheet for this experiment is available at: Text 065-80 (rsc.org) .

Each pair or group of students will need:

- Grater (if potatoes are the starting material)
- Large pestle and mortar (if potatoes are the starting material)
- Large watch glass
- Petri dish or white tile
- About 100 g potatoes
- Tea strainer or similar
- 400 cm^3 beaker
- Universal Indicator paper
- Dropping pipettes

- 25 cm^3 measuring cylinder
- 10 cm^3 measuring cylinder
- About 10 cm^3 0.1 $moldm^{-3}$ sodium hydroxide (IRRITANT)
- About 10 cm^3 0.1 $moldm^{-3}$ hydrochloric acid (IRRITANT)
- About 500 cm^3 distilled water

- 2.5 g potato starch (not required if sufficient is extracted from potatoes)
- Access to balance
- Food colouring (optional)
- Propane-1, 2, 3-triol (glycerol), 2 cm^3

For preparing plastic from gelatin

- Access to equipment listed above
- 3 packets of gelatin (15 - 20 g)
- About 100 cm^3 distilled water

For preparing plastic from milk protein (casein)

- Access to equipment listed above
- About 200 cm^3 milk
- About 20 cm^3 white vinegar
- Paper towels
- Thermometer

Answers to questions

1. What is your plastic like? Describe its appearance and properties.
   See the information sheet.
2. What is the name of the chemical reaction that makes a plastic?
   The process is polymerisation. The monomers involved are listed on the information sheet.
3. Is the plastic a bioplastic? How do you know?
   All three plastics are bioplastics as they are made from plant material.
4. Is the plastic biodegradable? How can you test this?
   The plastics are biodegradable. This can be tested by mixing them with soil / pre-made compost and leaving them for several weeks.
5. Could the plastics that you made be used in packaging food?
   - Yes they can – potato starch is used in bags and formed into cartons. Casein is being tested as packaging for soups and sauces.
   - Gelatin has not been tested for packaging.

6. What other uses might these plastics have?
   - Casein can be shaped into jewellery such as beads and brooches, and used for buttons, brushes, mirrors and other small items.
7. What are the advantages and disadvantages of using bioplastics?
   These are listed on the information sheet.

Extensions

Experiment with alternative sources, for example, corn starch (cornflour), different types of milk and altering conditions to modify the strength and structure of the plastics.
What would be needed to scale up production?

Activity B: Investigating food packaging

Have available a range of plastics used in food packaging – students can contribute clean items from home. Items can include plastics and non-plastics. Plastic items may include:

- milk containers; meat / vegetable trays; tubs for ice cream / yoghurt / cheese; wrappers for vegetable/ fruit; tins; paper cartons; drinks bottles; cardboard boxes; glass jars / bottles; bags.

If items are not available, the task can be completed from the images on page 10.

Discuss how food is packaged. What materials are used to package food?

- Plastic, tin, paper, foil, card, glass …

Separate the packaging into 'sustainable' and 'unsustainable' piles depending on the type of material. Unsustainable packaging is plastic based on fossil fuels; paper, glass and card is regarded as sustainable.

Questions can be discussed depending on students' abilities. 1 – 3 are appropriate for everyone. 4 & 5 may be more suitable for higher ability students. Overall, the point is to show that using sustainable plastic packaging reduces reliance on plastics made from crude oil.

1. What do you notice about the type of packaging we use?
   - Unsustainable packaging is used for fresh and short-life span foods.
   - Sustainable packaging tends to be used for food that has a long shelf life.
   - Unsustainable packaging may be cheaper and more readily available than sustainable packaging.

2. Why do we need food packaging?
   - Transports food hygienically and conveniently.
   - Helps make food available everywhere.
   - Allows food to be stored and served at the appropriate temperature.
   - Can be thrown away.

3. How can we change to use less unsustainable plastics?
   - Buy milk in bottles.
   - Buy loose, unpackaged fruit and vegetables.
   - Buy re-usable wrapping (beeswax) sheets for sandwiches and storage.
   - Carry water in re-useable bottles.
   - Challenge supermarkets and food outlets to use less plastic packaging.
   - Develop alternatives such as the plastics made in the experiments.

4. How is recyclable food packaging actually recycled? In summary:
   - Tins are recycled through household waste collection. They are separated from the plastics, and magnets are used to separate aluminium from steel. Aluminium cans are melted down and remoulded into new items. Steel items are reheated to over 1500°C, melted and remoulded into new items.
   - Plastics need to be washed prior to recycling. Each type is recycled separately. See resource *Plastic Recycling Codes Explained, Types of Plastic and the Applications of Recycled Plastics* (azom.com). Identification codes enable plastics to be recycled as single substances.
   - Some plastic packaging is not recyclable and goes to landfill. Each bag or wrapper takes about 100 years to decompose.
   - Paper and card is recycled by first removing ink, then is mixed with water to break down fibres to make a slurry. New fibres are added to the slurry, which is used to make new paper/card.
   - Paper and card is made from cellulose. The fibres weaken over time. Cellulose can be recycled about eight times.

5. How do bonding and structure make a plastic useful?

   The structure of a plastic depends on the nature of the monomers and how the polymer chains interact with each other. In plastics, polymer chains are held together by covalent bonds. Bonding between polymer chains requires less energy to break. The overall strength of the bonds in the plastic within and between polymer chains dictates how the plastic is used.

Extensions

Challenge students to reduce plastic use over a four-week period. Record the plastics used (numbers and recycling codes can be found on the underside of plastic items). Which plastic(s) are used most often? Which can be used less often?

This website has useful information about single use plastics
[Fact Sheet: Single Use Plastics - Earth Day]

Visit a plastic recycling company. How are different plastics recycled?

Resources

A short, 94 second video on the history of packaging is available at: https://www.digimarc.com/resources/history-of-packaging.

The www.digimarc.com website has a number of short videos about packaging and branding.

The website Earth Easy has information, advice and resources that may be helpful, including an image of plastic recycling and identification codes. See: https://learn.eartheasy.com/articles/plastics-by-the-numbers/.

Plastic identification codes and plastic recycling are described in this article: Plastic Recycling Codes Explained, Types of Plastic and the Applications of Recycled Plastics (azom.com)

Recycling paper and cardboard is described in this article: Recycling Paper and Cardboard and What Happens to Paper and Cardboard When It Goes to be Recycled (azocleantech.com)

Activities

Activity A: How can we make eco-friendly plastics?

In this lesson you are going to make an eco-friendly plastic. This is a plastic that does not come from crude oil. Once you have made the plastic, you will think about what it can be used for. There are three plastics you can make:

- from potato starch;
- from gelatin;
- from milk protein (casein).

To prepare plastic from potato starch

First extract the starch from potato.

1. Grate about 100 g of potato. The potato should be clean but does not need peeling. Put the grated potato into the mortar.
2. Add about 100 cm^3 of distilled water to the mortar.
3. Grind the grated potato in the water carefully with the pestle.
4. Pour the grated potato/water mixture through the tea strainer into the beaker, leaving potato solids in the mortar.
5. Repeat steps 3 and 4 twice more. You should get more liquid containing starch in the beaker.
6. Let the liquid in the beaker settle for 5 mins. White starch should collect at the bottom.
7. Carefully pour off the water from the beaker, leaving the starch. You need the starch to make the plastic.
8. Add about 100 cm^3 distilled water to the starch and stir gently.
9. Leave to settle again. Pour off the water again.
10. Use the starch to make the plastic.

To make potato starch plastic

1. Put 22 cm^3 of water into a beaker.
2. Measure 4 g of potato starch slurry in to the beaker.
3. If you didn't use potatoes, mix 25 cm^3 water and 2.5 g of powdered potato starch.
4. Add 3 cm^3 of 0.1 moldm-3 hydrochloric acid.
5. Add 2 cm^3 of propane-1,2,3,-triol.
6. Cover the beaker with a watch glass. Place the beaker on a tripod and gauze.
7. Heat the mixture very gently using the Bunsen burner.
8. Bring the mixture to boiling point. Simmer gently for about 15 minutes. Do not boil dry! Stop heating if this looks likely.
9. When the mixture has boiled, test the pH. Dip the glass rod into the mixture. Dot the moist end of the rod onto Universal indicator paper. It should be acidic.

10. Add about 3 cm^3 0.1 $moldm^{-3}$ sodium hydroxide solution dropwise to neutralise the mixture. Test the pH after addition of every few drops using a glass rod as above. Stop when the pH is about 7.
11. (Optional) Add a drop of food colouring. Mix using the glass rod.
12. Pour the mixture into a Petri dish or on to a white tile.
13. Use the glass rod to push it around to cover the dish / tile evenly.
14. Leave the plastic to dry for 24 hours on a radiator or two days at room temperature.

To prepare plastic from gelatin

1. Measure 75 cm^3 distilled water into a beaker.
2. Add the contents of three gelatin packets to the water. Stir with a glass rod to mix.
3. (Optional) Add 2 – 3 drops food colouring.
4. Place the beaker on a tripod and gauze. Heat gently, stirring with a glass rod until the gelatin dissolves.
5. Stop heating when the mixture starts to steam and thicken.
6. Remove any foam with a spatula. The foam clouds the plastic.
7. Pour the mixture into a Petri dish or silicone mould.
8. Leave to set for about 45 minutes.

To prepare plastic from milk protein (casein)

1. Measure about 200 cm^3 milk into a beaker.
2. Place the beaker on a tripod on a gauze.
3. Heat the milk using a gentle blue flame until it is steaming hot. The temperature should be around 50°C.
4. Turn off the gas. Place the beaker on a heatproof mat.
5. Add 20 cm^3 white vinegar to the milk. Stir with a glass rod. White clumps should start to form. Allow to cool.
6. Prepare around 4 – 6 layers of paper towels next to the beaker on the mat.
7. Tilt the beaker, then, using a spatula, scoop as much solid as possible on to the paper towels.
8. Fold the edges of the paper towels over the milk solids.
9. Dry the solids by pressing so that liquid goes into the paper towels. Use extra paper towels if necessary.
10. Remove the solids from the paper towels.
11. (Optional) Add a few drops of food colouring.
12. Knead the solids into an even ball of 'plastic dough'. This is plastic made from milk protein, called casein.
13. Shape the plastic. Leave it to dry for about 48 hours at room temperature.

Questions

- What is your plastic like? Describe its appearance and properties.
- What is the name of the chemical reaction that makes plastic?
- Is the plastic a bioplastic? How do you know?
- Is the plastic biodegradable? How can you test this?
- What are the advantages and disadvantages of using bioplastics?
- Can the plastics be used in packaging food?
- What else can these plastics be used for?
- What are the advantages and disadvantages of these alternative plastics?

Activity B: Investigating food packaging

food-product-labelling.jpg (1000×350) (paraspack.com)

Look at the pictures and any food packaging items nearby to find out which materials are used to package food.

In the table, list food items that are packaged in SUSTAINABLE and UNSUSTAINABLE materials.

Sustainable packaging – is not made from fossil fuels, e.g. cardboard cornflakes box.

Unsustainable packaging – is made from fossil fuels, e.g. plastic oil bottle.

Food item	SUSTAINABLE	UNSUSTAINABLE
Cornflakes	Cardboard box	
Oil		Plastic bottle

Questions

1. What do you notice about the types of food packaging that we use?

2. Why do we need food packaging?

3. How can we change to use less unsustainable plastics?

4. How is recyclable food packaging actually recycled? Find out how recyclable food packaging is actually recycled. Choose one from:
   - Paper / cardboard
   - Tin cans
   - Plastics

   Share what you find out with your class.

5. How do bonding and structure make a plastic useful?

Alternative Plastics Information Sheet   Lesson 1 Activity A: How can we make eco-friendly plastics?

Plastic	Image	Description	Monomers	Products	Advantages and disadvantages
Potato starch		A thin transparent pale yellow brittle film. Colour depends on addition of food colouring	Glucose molecules in amylose and amylopectin. Amylopectin has branched chains that are denatured by addition of hydrochloric acid		Advantages – it can be made from waste potato; easy to make; biodegradable; can be moulded Disadvantages – extracting the starch requires energy; requires a lot of potatoes
Gelatin		A pliable colourless transparent film that hardens when dried. Colour depends on food colouring	Collagen molecules. Collagen is a protein	No image or products	Advantages – easy to make Disadvantages – involves animals as a source of gelatin; no identified uses as yet
Milk casein		A white malleable solid	Casein molecules. Casein is a protein		Advantages – milk is readily available from a variety of plant and animal sources; edible; biodegradable; can be moulded Disadvantages – a lot of milk is needed; not a wide range of uses at present

1. plastic from potato starch image - Bing images
2. gelatin plastic image creative commons - Bing images
3. Potato Plastic | James Dyson Award
4. milk casein plastic image - Bing images