

Polymers

Teacher Notes



Polymers is funded as part of the Reach and Teach educational programme supported by the Wolfson Foundation



THE
WOLFSON
FOUNDATION

Polymers

Why focus on G&T and higher achievers?

Within the education system every child has the right to develop their learning so as to maximise their potential.

These exercises are designed to give students enthuse and enrich activities that although related to the curriculum are in fact taking the learning experience to the next level whilst also showing chemistry in a familiar context. This has been found to be a successful model for not only improving learning but also for raising levels of motivation. Higher achieving students can find the restraints of the standard curriculum to be demotivating leading to underachievement.

The different activities are designed to improve a number of skills including practical work/dexterity, thinking/analysis skills, literacy, research activities, use of models and teamwork. Students should also gain confidence through the activities and improve the ability to express themselves.

Some of the activities would appear to be complex for KS3, however at this stage in their learning high achieving students are open to new concepts and are ready to explore issues without pre-conceptions. They are keen to link ideas and develop concepts and understanding. It can prove to be an uplifting experience.

Introduction

Understanding the formation and properties of polymers gives an insight into how they are used in everyday life. The chemistry involved is varied and links together many aspects of the subject including an introduction to organic chemistry, ions, structure and bonding. The activities that include both practicals and questions help to develop student's basic understanding of chemical reactions.

This programme is also designed to develop students thinking and investigative skills.

Topic	Type of activity	Summary	Timing - Practical (mins)	KS3	KS4	KS5	Page
Developing a glue	Practical	A simple practical introducing polymers. It investigates the constituents of different milks and how they affect the efficiency of the glue produced.	15-45	√	√		12
Latex	Practical	Latex is cross linked in this experiment to form rubber and foam rubber.	20	√	√		16
Alginate worms	Practical Questions	This activity further develops the ideas of cross linking and how charged molecules affect the link.	20	√	√		17
Making polylactic acid	Practical Questions	Polylactic acid is a versatile polymer with many familiar	30	√	√		20

		applications. As well as forming the polymer the activity explores its properties and uses.					
Making a plastic from potato starch	Practical Questions	Again using a familiar material, starch from potatoes, the formation of a polymer is explored.	45	√	√		24
Experiments with smart materials - hydrogels	Practical Questions	Developing the idea of how a polymer can be a smart material by investigating the properties of hydrogels and how these can be used in specific applications.	30-60	√	√	√	30
Making nylon	Practical	This forms a good example of a condensation polymer and how it is manufactured.	15	√	√	√	37

The first activity is an introduction to the varying chemistry and properties of polymers by investigating the property and effectiveness of glues formed from different samples of milk. This is an acid-base reaction. The importance of active ingredients is clearly apparent.

The latex activity illustrates another acid-base reaction that is used to cross link the polymer chains to form rubber. The reaction can be extended to form foam rubber by the addition of a hydrogen carbonate to the mix, therefore generating carbon dioxide that becomes trapped in the matrix. It can act as a revision exercise on equation writing and testing for gases. A further investigation can be to compare the bounce of balls made by both methods, or the strength of elastic bands made by single or multiple dipping.

Alginates also cross link to form firm polymers. This activity illustrates what sort of materials are effective at cross linking by comparing molecules with single charges to those with a double charge and how they affect the properties.

Poly(lactic acid) is a very versatile polymer that is used to make everyday items as wide ranging as packaging materials to food additives. The activity explores its manufacture on a simple scale and how it has been developed in order to be so useful. This is achieved through both the practical and the follow up questions. Another example of this is in activity 5 where another simple molecule, starch, is used to make polymers with different properties. These are again explored in a series of questions.

Investigating hydrogels provides a good example of a smart material, a material that 'changes' according to its changing environment. The practical aspects investigate the water retention properties of hydrogels, cross linking, and the effects of pH upon the carboxylic acid based polymer. This then investigates how these properties can be used to provide targeted drug delivery systems and even fire extinguishers. This is achieved through both practical work and answering questions. It is also possible to develop the practical into an investigation of cost effectiveness of nappies, water retention versus cost.

Nylon is probably the only condensation polymer that it is possible for students to practically prepare. This version clearly illustrates the fact that two monomers are involved and a small molecule is emitted, in this

case hydrogen chloride gas, a condensation product. It also reinforces that a condensation product does not have to be merely water – a common misconception.

Aims and objectives

The aims and objectives of these activities are:

- Developing questioning skills through problem solving.
- Exploring the use of models to expand understanding
- Develop practical skills and dexterity.
- Promote independent learning and research skills.
- Relate properties to applications.
- Understand what is meant by a *SMART* material.

Chemistry topics:

- Word/Symbol equations
- Addition polymerisation
- Condensation polymerisation
- Properties of polymers
- Cross linking
- Acids and bases

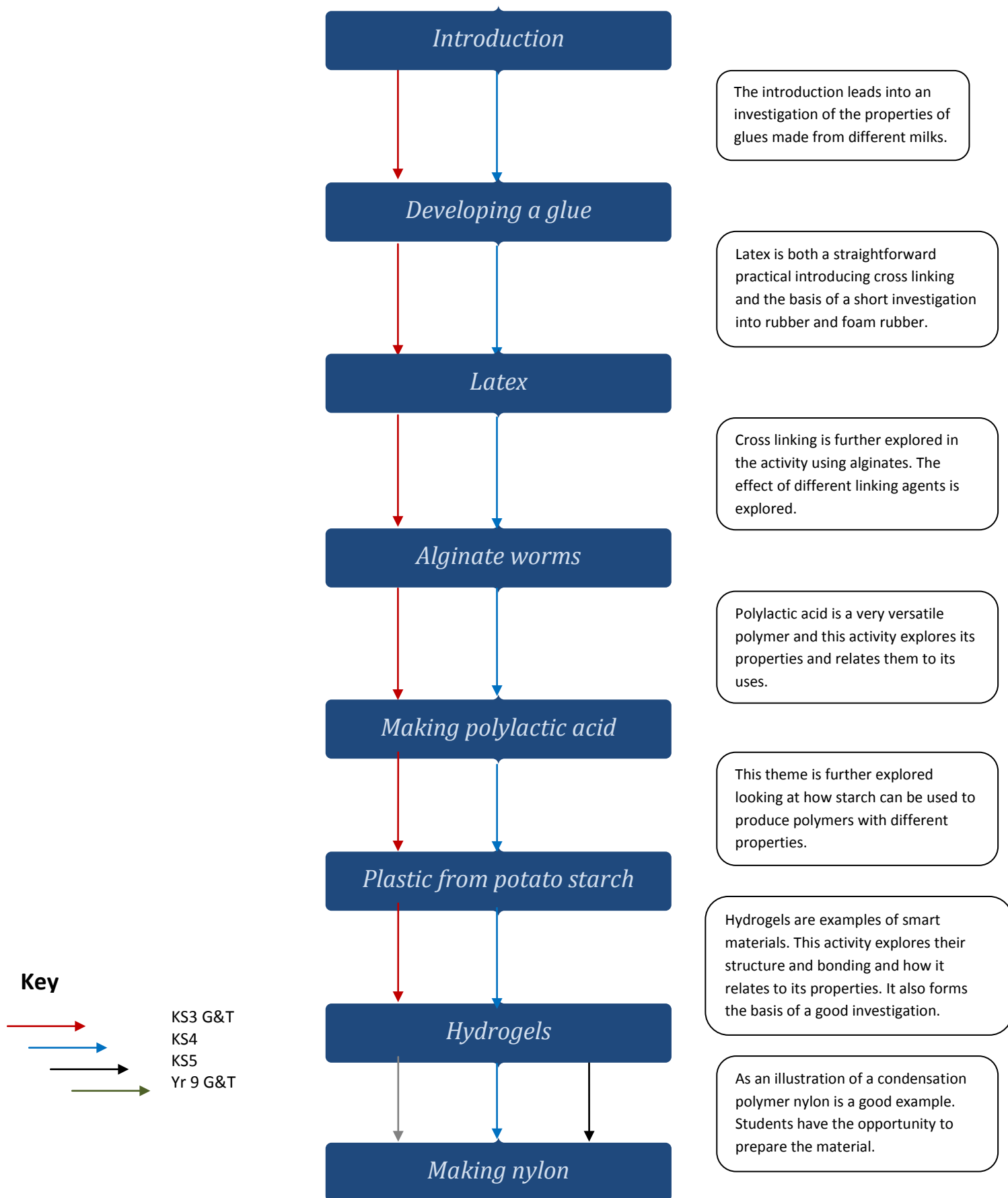
These exercises can be used with key stages 3, 4 and 5, as indicated on the *Possible Routes*. They can also be generally used as revision exercises for key stage 5.

These activities have proved very successful with key stages 3 and 4 and have stimulated students into further independent learning. They have enhanced understanding of metals, their properties, extraction and uses.

These exercises provide a reinforcement and revision tool for a number of topics from the A level syllabus.

At all levels there is promotion of questioning skills, independent learning and research skills.

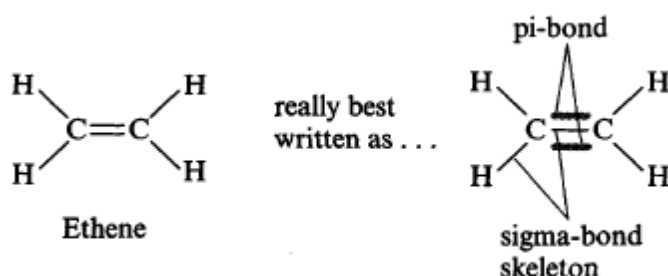
Possible routes



An introduction to alkenes and polymers

The homologous series of the alkenes has a general formula C_nH_{2n} . The importance for society of the series of alkenes is that they are the major starting point for polymers and plastics. Look around where you are now, and notice the importance of plastics and polymers to you - pens, clothing, carpets, packaging, coatings for wires, shoes, furniture, curtains and fabrics.

This homologous series is based on the characteristic carbon-carbon double bond. The simplest alkene is ethene, C_2H_4 . In conventional diagrams, the two bonds between the carbon atoms are shown by a double line joining them together, although in practice these bonds are a single sigma (σ) bond and a pi (π) bond. Note that a π bond involves electron density *above and below* the σ bond. For simplicity the bond is shown as a double bond, $C=C$. (It is worth revising covalent bonding at this point).



Carbon-carbon double bonds consist of one σ and one π bond

The names of alkenes are obtained by simply changing the '-ane' of the alkane with the same number of carbon atoms to '-ene'. So, all the compounds of this hydrocarbon series have names ending in -ene.

The first five members of the homologous series are shown below.

Name	Molecular Formula C_nH_{2n}
$n = 1$	No compound
$n = 2$ Ethene	C_2H_4
$n = 3$ Propene	C_3H_6
$n = 4$ Butenes	C_4H_8
$n = 5$ Pentenes	C_5H_{10}

The first three names (up to $n = 4$) are non-systematic, and then names become more systematic. The alkene where $n = 5$ is named pentene, and $n = 6$ is hexene, *etc.*

Consider the following worked examples.

Example 1 :

What will be the general names and molecular formulae of the next four members, with $n = 7, 8, 9, 10$?

Answer: The number of carbon atoms in a chain is named after the Latin number, so when $n = 7$ the compound is hept - ene, or heptene. The general formula is C_nH_{2n} , so the molecular formula of heptene is C_7H_{14} .

When $n = 8$, the compound is oct - ene, or octene, C_8H_{16} .

When $n = 9$, the compound is non - ene, or nonene, C_9H_{18} .

When $n = 10$, the compound is dec - ene, or decene, $C_{10}H_{20}$.

The names of the compounds beyond propene will have to be refined further to show where the C=C double bond is actually located in the carbon chain.

Example 2:

Make the model for the structural formula of propene, using the simplified C=C for the double bond, but remembering that double bonds are planar a-bonds at 120 degrees to each other with bonds above and below the C-C sigma bonds.

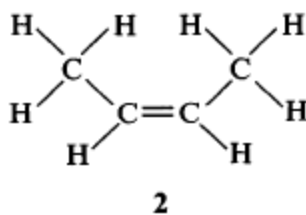
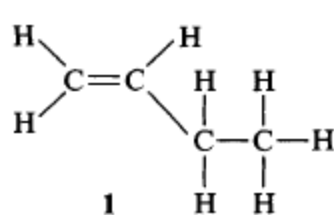
There is only one possible way of putting together these atoms to make up propene. Isomers, or alternative structures, are possible in the later members of this series.

Example 3:

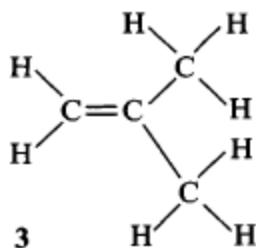
What will the structure of butene look like? It is best to use a molecular model kit if possible. Name the compounds you make.

You will notice that in butene there is more than one possibility for putting the carbon chain together to form different arrangements. Show these arrangements and name the compounds.

Answers:



(This can have either the *cis* or *trans* configuration – see later section on isomerism)



- 1 But-1-ene.
- 2 But-2-ene (this can also have *cis* and *trans* configurations).
- 3 2-Methylprop-1-ene or simplified to 2-methylpropene.

Isomers of C_4H_8

Note that the position of the double bond in the chain is numbered by the lowest numbered carbon atom (counting from the nearer end of the molecule - numbers can run from either direction) to which it is attached. We try to keep the location of the double bond in the name as close to the -ene as possible.

In structure 3, the name is based on the longest carbon chain containing the -ene. Here there are three carbon atoms, so the chain is propene. The methyl group is attached to the middle carbon, which is the second carbon atom from either direction.

Try drawing and naming some higher members of the alkene series, say $n = 6$!!!!

Compare your names and structures with those produced by a colleague. When you make models of these compounds it is good to view them from different angles and to twist the chains around. Often you can construct molecules that are the same but you do not realise it until you see the models from a different angle.

WHAT IS MEANT BY SATURATED AND UNSATURATED CARBON COMPOUNDS?

Alkenes are called 'unsaturated' because they contain a C = C double bond and therefore less hydrogen than the corresponding alkanes. They can undergo addition reactions in order to become 'saturated'. The alkanes have no double bonds and all their bonds are sigma bonds between (C-C and C-H). They cannot undergo addition reactions because they are saturated already. An even more unsaturated series of hydrocarbons is the alkynes, C_nH_{2n-2} , which contain a carbon-carbon triple bond, (C≡C), made up of a sigma and two pi bonds. The best known member of this series is C_2H_2 , ethyne (also known as acetylene).

THE CRACKING OF ALKANES AND THE POLYMERISATION OF ALKENES

The natural crude oils from which we make fuel oils *etc.* are made up of an immense number of saturated hydrocarbons with chains of different lengths, sometimes up to 100 carbon atoms in length. Crude oils are very dark in colour, often quite sticky, and very smelly. To make them into useful, smaller molecules, the long chains are broken up or 'cracked'. This is done by vapourising suitable fractions from the distillation of crude oil, and then passing them over hot catalysts that help to break up the chains into manageable lengths. The process is called

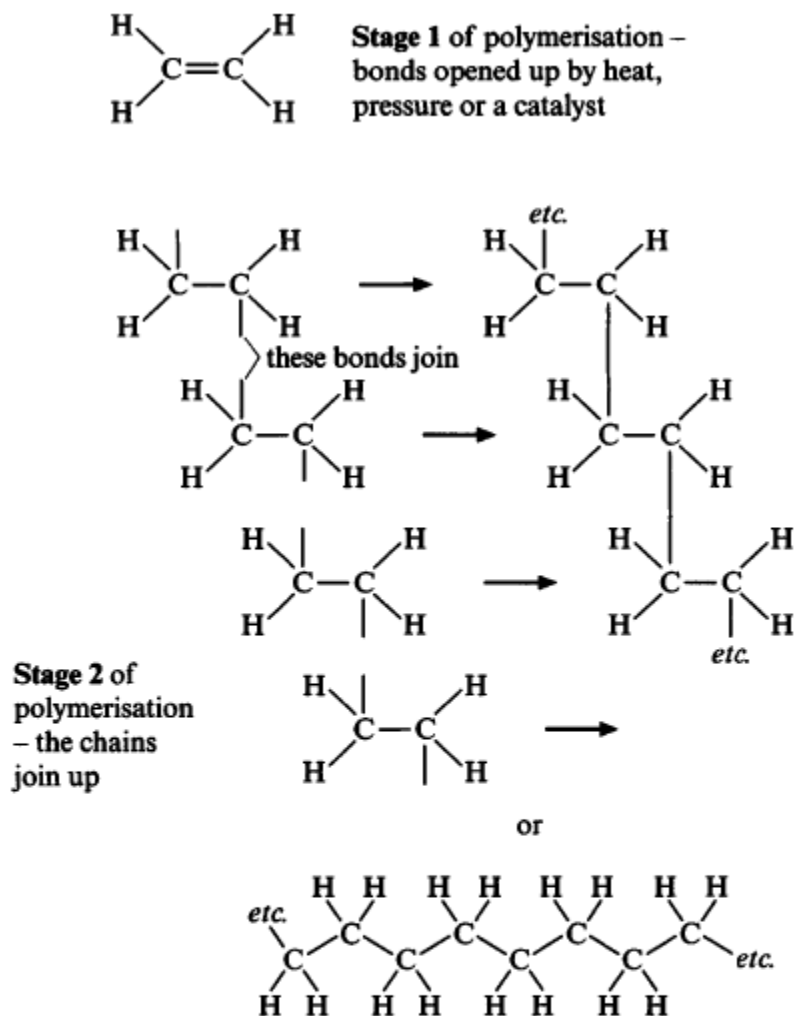
'Cat-Cracking', or catalytic cracking, or cracking by catalyst. The products from this process can then be separated by distillation into the separate and more useful products used for making plastics, fuels, pharmaceuticals, dyes, detergents, *etc.*

The chains can be broken up into CH_4 , C_2H_6 and other alkanes, C_2H_4 , C_3H_6 , C_4H_8 and other alkenes, and also H_2 . The mixture of unsaturated molecules is very useful for making designer-sized polymers, as shown for ethene.

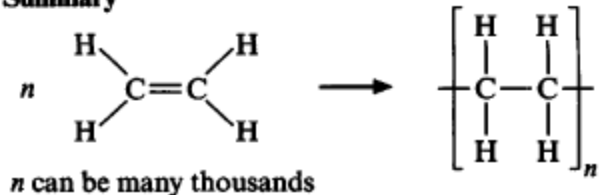
If ethene is compressed to about 1000 atm pressure with a trace of oxygen present as a catalyst, it polymerises to poly(ethene), or Polythene (the trade name). This discovery was made by accident just

before the Second World War. Polythene was for some years a secret, as it was the only material capable of insulating the very high voltage cables used in the early radar systems which helped to win the Battle of Britain. The conditions and the catalyst can now be regulated to produce the correct chain length and degree of chain branching, and so produce the polymer length best suited for the job. For example, low density, bendy materials are used for making detergent bottles, and high density tough, rigid materials for making buckets.

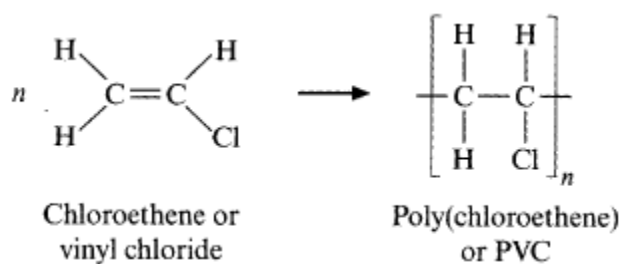
When one molecule adds on to another repeatedly with no other substance being formed, the process is called addition polymerisation. As you will see from below the double bonds in ethene molecules open up as they form new single bonds with each other.



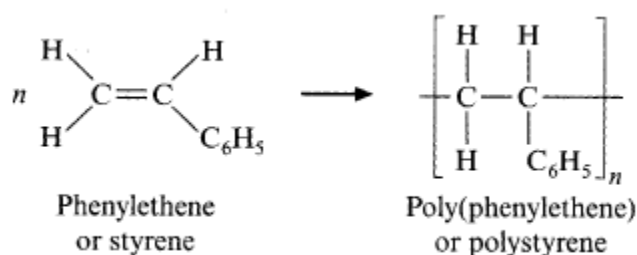
Summary



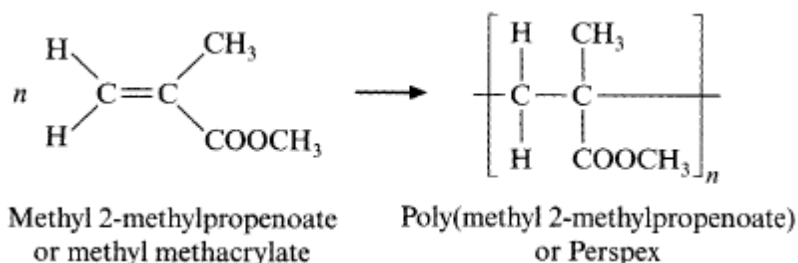
By modifying the starting material, a wide range of polymers can be made; *e.g* if the starting material is monochloroethene (vinyl chloride, then poly(chloroethene) 'polyvinylchloride', PVC) can be made. PVC is one of the most versatile polymers of all, with uses ranging from upholstery to drainpipes.



Starting with styrene (phenylethene), poly(styrene) can be made.



Perspex [or poly(methyl methacrylate)] is also made by polymerisation of a similar starting material, methyl 2-methylpropenoate (methyl methacrylate).

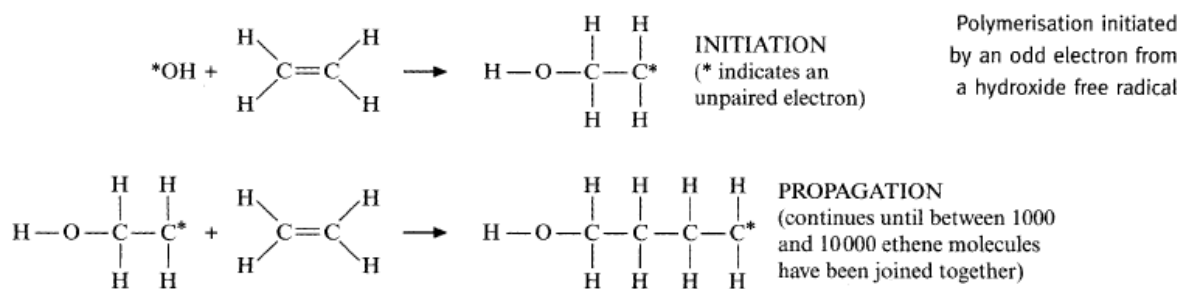


These polymers are all made by addition polymerisation. In all addition polymerisation there are usually three stages:

Stage 1 is the creation of the 'active' molecules ready for polymerisation, often initiated by sunlight or a 'free radical' catalyst. It is as though the double bonds have been opened up. This is called **initiation**.

Stage 2 is when the 'opened up' molecules join together to form longer and longer chains. This is called chain **propagation**.

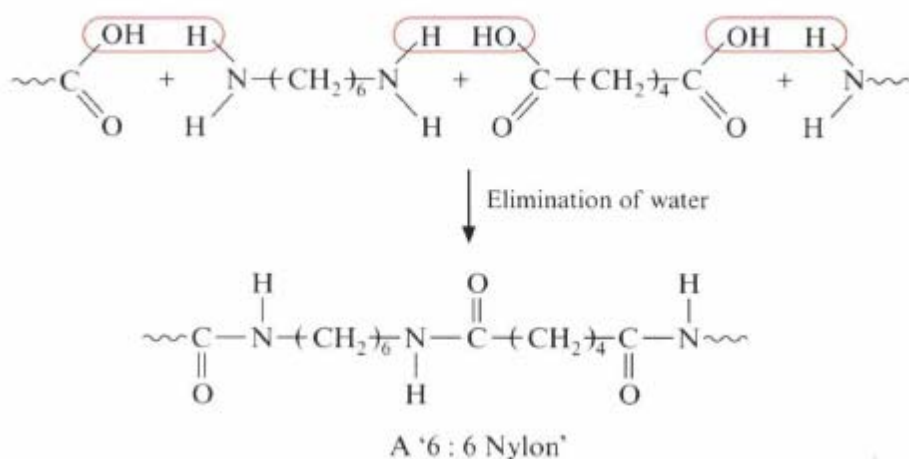
Stage 3 is the **termination** of the reaction, either if the materials have all reacted or if the reaction is terminated by adding another material to stop the chains getting too long. The reaction can also be terminated by two odd-electron molecules joining together, but this event is comparatively rare.



TERMINATION occurs when two free radicals react together or a free radical 'scavenger' is added

These are examples of 'addition polymerisation', which can only occur where compounds have double bonds in them. For further reading about polymerisation you might like to find out what is meant by *isotactic*, *syndio tactic* and *a tactic* polymers.

There is, however, another type of polymerisation that can occur with compounds that are already saturated. This type is called **condensation polymerisation**. It occurs between molecules that have structures and groups present in them that, when reacted together, can eliminate a small molecule, *e.g.* water or HCl. This is the type of reaction which occurs when Nylon is formed from a dicarboxylic acid with a diamine.



Biodegradable Plastics

UK plastic facts:

- We produce three million tonnes of plastic each year
- Households are the biggest producers of plastic waste
- 60 % of household waste comes from packaging
- More than 80 % of this plastic is used once and then goes to landfill sites
- Only 7 % of plastic is recycled.

In addition to household waste, there is also the issue of plastic litter (mainly packaging) which is discarded in the environment. On land it is ugly but in the sea it can be deadly – it can cause injury and death to birds, fish and other sea creatures. Given all this, it is not surprising that people are concerned about plastic waste and are increasingly looking to scientists to produce a degradable plastic to help solve the problem. However, there is much debate among scientists and environmentalists as to whether degradable or non-degradable plastic is better for the environment. The conclusions drawn by researchers studying this topic are not always what you might expect. To understand fully the effect a product has on the environment it is necessary to carry out a 'life cycle analysis,' which means looking at the impacts of production, use and disposal of the product.

There are two kinds of degradable plastic: photodegradable and biodegradable.

Photodegradable plastic is usually made of oil-based polymers, just like ordinary plastic. It either has bonds in its structure that can be weakened and broken by sunlight, or it contains a chemical additive which absorbs light and then attacks the polymer and breaks some of the bonds. Once a photodegradable plastic is exposed to light it begins to break down – whether you want it to or not. This can be disastrous if it is mixed in with other plastics during recycling. Photodegradable plastics tend to break down into small particles of plastic rather than decomposing completely. The idea is that these small pieces will then biodegrade. Unfortunately, they are often not biodegradable and so remain in the environment. The effect that a build-up of small pieces of plastic in the soil might have on the environment has not been investigated. At present, most plastic waste ends up in a landfill site where it is buried in a dark hole in the ground. Under these conditions, photodegradation cannot take place.

Biodegradable plastics can be made from oil or from plant-based products. They are attacked by bacteria, fungi or other micro-organisms which use them as food. The most commonly used plastics have been tested to find out whether they are biodegradable. Polythene is biodegradable as long as its chains have a molecular weight of less than 500; most other polymers are not. Polyesters are susceptible to biodegradation but they are used very little in packaging materials. As the majority of plastic waste is from packaging, using polyesters will not really help solve either the problem of the large quantity of waste produced or that of litter in the environment.

There is a lot of interest in the idea of making a plastic that can biodegrade in a landfill site. Unfortunately, once a landfill is covered with soil, there is limited oxygen and water available (the conditions are said to be 'anaerobic') and the rate of degradation of all materials (even those that biodegrade rapidly on the surface) becomes extremely slow. Discarded food has been found in landfill sites several years after it was thrown away. With this in mind, the British Plastics Federation (a trade association of plastics manufacturers) opposes degradable plastics on the grounds that plastic waste is best recycled. The environmental pressure group 'Friends of the Earth' agrees, arguing that degradable plastic does nothing to promote lasting solutions to plastic waste and that we should be aiming to reduce the amount of plastic we use in the first place and reuse or recycle what we do use.

For further information you could try looking at:

<http://www.degradable.net/> – this company sells degradable bags and chemicals that can be added to plastic bags to make them degradable.

<http://www.guardian.co.uk/supermarkets/story/0,12784,1274047,00.html> – a newspaper story on degradable bags.

Developing a glue using milk forms a good introduction to polymers, especially as the investigation focuses on a natural product.

Activity 1: Developing a glue

Teacher notes

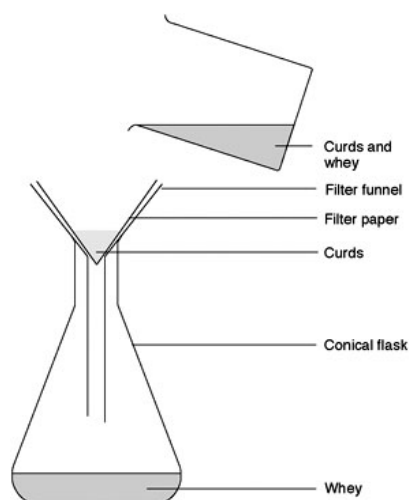
A glue can be made from milk by souring it using vinegar (an acid) which separates it into curds and whey. The curds can be neutralised by various bases to produce a variety of different glues. The glue can be tested for strength by sticking together two lolly sticks and attaching weights to them. This activity lends itself to group, investigative and competitive work.

Lesson organisation

In general it is a good idea to give students the basic glue-making recipe described in the procedure notes and then allow them to vary it. Depending on what you are trying to achieve in the activity, you may or may not want them to make detailed notes about exactly what goes into each mixture. Students can make up one 'batch' with one type of milk and then divide the curds and water mixture into portions and add a different base to each portion. A large number of different glues can then be made without too much effort.

The glues can be tested by first using them to stick together lolly sticks, and then attaching weights to the sticks until the glue gives way. If paper is used instead, the paper almost always breaks first as the glues are surprisingly strong. Students should wear eye protection, because the sticks can splinter if they break. In addition, a sand tray or box of crunched up newspaper should be placed under the weights to avoid harming students' feet.

Making one glue takes about 15 mins. More glues can be made quickly as the students already have the equipment set up. This can be fitted into one long lesson, although there may be difficulties with getting the glues dried and tested. It is probably better suited to two lessons; one to make the glues and the other to test them.



Procedure

HEALTH & SAFETY: Wear eye protection

Making the glue

a Measure 100 cm³ of milk and 20 cm³ of vinegar into a beaker. Place the beaker on a tripod and gauze and heat over the Bunsen burner. Stir constantly until small lumps start to form. Stop heating, but keep stirring until no more lumps form.

b Let the lumps settle, then decant the liquid from the top. Filter the rest of the mixture and keep the solid part (which is called the curds.) Wash the beaker.

c Gently squeeze off any excess liquid from the curds and then put them into the beaker. Add 15 cm³ of water and stir until the mixture is smooth.

d Add about half a spatula of the base and check that the mixture is neutral using indicator paper. If it isn't, add more base until it is. This is the glue.

e Use the glue to stick together two lolly sticks. Only have 2 cm of the sticks overlapping and stuck together. Label the lolly sticks with the milk and base used.

f Make other glues by using different bases and milks and use them to stick together more lolly sticks.

Testing the glue

a Arrange two tables or chairs about 10 cm apart. Lay your glued lolly sticks so that they form a bridge between the two.

b Hang a weights hook onto the lower of the two lolly sticks as close to the glued join as you can. Add weights about 10 N at a time and record the force required to break the glue.

Teaching notes

This activity can be used to encourage a group of students to work together, as an investigation ('which is the strongest glue?') or as a competition ('who can make the strongest glue?')

Variations to the glue making can include: using ordinary, semi-skimmed and skimmed milk with a variety of bases – eg sodium hydrogen carbonate, magnesium carbonate, calcium carbonate. Carbonates are good as they bubble when you add them so it is easy to tell when the glue is neutralised without needing to use indicators; the pH of the glue (ie add not enough through to excess base); the acid used to curdle the milk.

Skimmed milk tends to give the best glues. The glue consists of particles of the protein casein that are precipitated from the milk by the adding the acid. It is the polymerisation of these protein molecules that forms the glue. The fat in the milk can get in the way of these polymer chains – lubricating them like oil does in a bicycle chain – and preventing them from sticking together as effectively.

Casein is the predominant protein found in fresh milk and cheese. In milk it exists in the form of a soluble calcium salt.

In its acidic form, casein is precipitated by acids such as ethanoic acid (the predominant acid in vinegar). In this experiment, calcium ethanoate is a by-product of the initial souring process, and it is one of the components of the whey solution. The insoluble casein which forms the curds has relatively little secondary or tertiary structure. This means it cannot denature (change structure). It is relatively hydrophobic, and this is why it is fairly insoluble in water.

If appropriate, students may like to be reminded of Little Miss Muffet 'who sat on a tuffet, eating her curds and whey' Students should realise that they have probably eaten curds and whey, because these are the lumps and the liquid in cottage cheese. However, in cheese manufacture vinegar isn't the agent used to precipitate out the casein; the enzyme 'rennin' is used instead.

In addition to being consumed in milk, casein is used to manufacture adhesives, binders, protective coatings, plastics (such as for knife handles and knitting needles), fabrics, food additives, and many other products. It is commonly used by bodybuilders as a slow-digesting source of amino acids.

Student questions

Here are some possible questions for students. (Answers in italics.)

1 What do you think is the purpose of the vinegar in this experiment?

To convert the casein into an insoluble form - the curds.

2 Why is sodium hydrogen carbonate added?

To remove any excess acid.

3 What is the gas given off when the sodium hydrogen carbonate is being added?

Carbon dioxide - acids react with carbonates to form this gas.

4 Use a search engine to find information about casein, which is present in milk. What type of substance is casein?

Casein is a protein, or, more precisely, a phosphoprotein.

Web-links

Inspirational chemistry has information about how a new glue was developed for the superconductors in the international ATLAS project.

<http://www.rsc.org/Education/Teachers/Resources/Inspirational/>

Developing a glue

Technician notes

Apparatus and chemicals

Eye protection

Each working group requires:

Making the glue

Milk – semi-skimmed, full fat, and skimmed – at least 100 cm³

Vinegar (**Low hazard**) (see note 1)

Bases – e.g sodium hydrogen carbonate (**Low hazard**), magnesium carbonate (**Low hazard**), calcium carbonate (**Low hazard**), milk of magnesia (**Low hazard**)

Spatulas

Stirring rods

Measuring cylinders (100 cm³ and 25 cm³)

Beakers (100 cm³ and 250 cm³)

Bunsen burner

Heat resistant mat

Tripod

Gauze

Filter funnel and paper

Lolly sticks (see note 1)

Indicator paper

Testing the glue

Weights (the ones on a hook are ideal) to be added about 100 g at a time

Sand tray or box of scrunched up newspaper

Technical notes

Vinegar (**Low hazard**) Refer to CLEAPSS Hazcard 38A

Sodium hydrogen carbonate (**Low hazard**) Refer to CLEAPSS Hazcard 95C

Magnesium carbonate (**Low hazard**) Refer to CLEAPSS Hazcard 59A

Calcium carbonate (**Low hazard**) Refer to CLEAPSS Hazcard 19B

Milk of magnesium (**Low hazard**) Refer to CLEAPSS Hazcard 59B

1 Distilled vinegar is best because it is colourless. Other forms of vinegar can be used. A dilute solution of ethanoic acid could also be used.

2 Lolly sticks are available in most craft shops.

Producing rubber from latex introduces the principle of cross linking. This material is something familiar to them and should therefore raise the students' interest. The extension is adding sodium hydrogen carbonate; an activity that promotes a revision of gas identification and a link to the manufacture of foam.

Activity 2: Latex

Teacher notes

Making rubber from latex. To make a rubber ball, place 10cm³ of latex solution in a small beaker. Add about 5 cm³ of vinegar and stir (citric acid solution works just as well). This causes cross-links to form and a rubber ball forms quickly. Wearing nitrile protective gloves and eye protection, pick out the rubber ball, place it in a bowl of water and squeeze well to remove excess latex. Dry the ball with a cotton cloth. The ball can be tested for its elastic properties in a bounce height experiment.

Try making foam rubber by adding one spatula of sodium hydrogen carbonate before you add the vinegar. Bubbles of carbon dioxide permeate the rubber as it forms. Compare this to normal rubber in a bounce test.

To make an elastic band, place a pencil or test tube end in the latex solution so that the end is well covered and then dip the end in a beaker of vinegar, followed by a beaker of water. The rubber can be rolled off the end as a ring. It has been suggested that you can test the strength of the rubber band in a simple stretch test, but it has never been strong enough to try in my experience!

Latex

Technician notes

Making rubber from latex.

Each group will need:

Requirements	
Materials	Chemicals
Eye protection	Latex solution (200 cm ³) –from SEP (Low hazard , faint smell of ammonia, a few people may be allergic to latex)
100 cm ³ beakers (4)	Dilute ethanoic acid solution (low hazard see CLEAPSS Hazcard 38A (0.1M is fine, or citric acid instead)
stirring rods(4)	Sodium hydrogen carbonate (10g) (low
Bowl of water, cotton cloth for drying.	
Nitrile protective gloves	

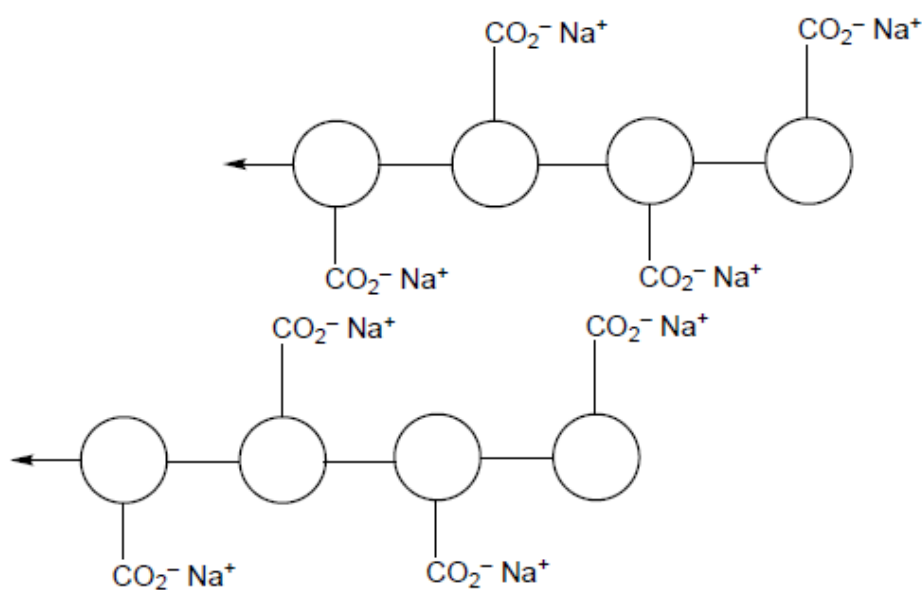
Test tubes (4), Spatula (1)	hazard) See Hazcard 95C
Pencils(4)	

Cross linking is further investigated with this experiment using alginate. The effect of using ions with either a single or double charge in the linking process is investigated. This helps students understand the process of linking polymer chains.

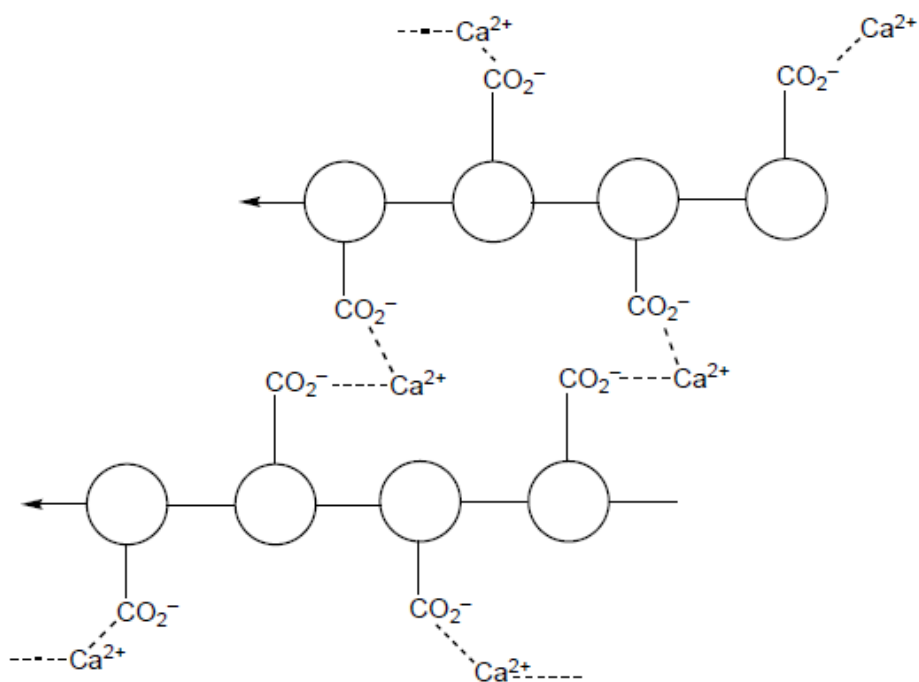
Activity 3: Cross-linking polymers – alginate worms

Sodium alginate is a polymer which can be extracted from brown seaweed and kelps. It is one of the structural polymers that help to build the cell walls of these plants. It has some unusual properties and a wide variety of uses.

The polymer can be represented like this:



When sodium alginate is put into a solution of calcium ions, the calcium ions replace the sodium ions in the polymer. Each calcium ion can attach to two of the polymer strands. This is called cross-linking and can be represented like this:



- Collect approximately 5 cm³ sodium alginate suspension or Gaviscon[®] solution.

1. Describe the sodium alginate suspension or Gaviscon[®].

.....

2. What is the formula of

a. a sodium ion?

.....

b. a calcium ion?

.....

3. Why can the calcium ion attach to two strands of the polymer, but the sodium ion to only one?

.....

.....

4. Predict how you think the properties of the polymer will change when it is poured into a solution of calcium ions.

.....

.....

Equipment required

- Approx 5 cm³ sodium alginate suspension (**low hazard**) See CLEAPSS Hazcard 95C or Gaviscon® (**low hazard**)
- Dropping pipette
- 2 x 150 cm³ beakers
- Approx 100 cm³ saturated sodium chloride solution (**low hazard**) See CLEAPSS Hazcard 47B
- Approx 100 cm³ 1% w/v calcium chloride solution (**low hazard**) See CLEAPSS Hazcard 19A
- Labels for the beakers
- Eye protection.

Health and safety

Wear eye protection.

What to do

- Put the calcium chloride solution into one of the beakers and the sodium chloride solution into the other. Label the beakers clearly.
- Using the pipette, squirt the sodium alginate or Gaviscon® into the calcium chloride solution. You are aiming to make 'worms,' although you can make beads if you prefer.
- Remove a few of your worms straight away and put them into the beaker of sodium chloride solution.
- Swirl both beakers gently and observe what happens to the worms in each one. You can remove and squeeze the worms as well as observing their appearance. You will need to wait a few minutes for all the reactions to be complete.

Questions

5. Describe how the polymer changed when it was poured into the calcium ion solution. Did this agree with what you predicted?

.....
.....

6. Describe what happens when the 'worms' are placed in sodium chloride solution.

.....
.....

7. Explain what happens in this experiment in terms of the ions and the polymer molecules. Use the term 'cross-linking' in your answer.

.....
.....
.....

Many uses

Alginate is used in many applications and new ones are being found all the time. The uses range from applications in the food industry to wound dressings, medicines and dental impression materials.

Calcium alginate (the cross-linked polymer) is used in wound dressings. These dressings are particularly useful for slow healing wounds like leg ulcers, which can continue to bleed and weep for a long time. Part of the blood clotting mechanism involves calcium ions and on contact with blood the calcium alginate releases calcium ions in exchange for sodium ions – just as you observed in the experiment above. These extra calcium ions can help the blood to clot and encourage healing. It is easy to remove any excess calcium alginate when the dressing has to be changed.

8. What could the wound be rinsed with to remove the excess calcium alginate?

.....

Alginate is a common food additive, E400. It is used as a thickener, stabiliser and gelling agent. It is often found in ice cream, where it is used to thicken the product so that even if it melts, it does not drip too much.

9. Find five other foods that contain alginate. Try to think of a reason why it might be included in at least two of the products you have found.

.....

.....

Activity 4: Making polylactic acid

Polylactic is another very versatile polymer that students will meet in their everyday life. It is even used as a packaging material as well as being a food additive!

Lactic acid can be made from glucose or other sugars by bacteria or it can be obtained directly from milk. It is added to food and drink products, but it can also be used as the starting point for making a plastic called polylactic acid. Polylactic acid can also be made from petrochemicals (chemicals from oil).

Polylactic acid is used for making items as diverse as packaging materials and surgical thread.

In this activity you will make some polylactic acid and discover why it has an ever-increasing number of uses.

Making the plastic

This activity allows you to join about 10–30 lactic acid molecules together to begin to make a polymer. In industry several hundred molecules are joined together and so the properties of the polymer product are different from those of the polymer you will make.

You will need

- Test-tube
- Test-tube holders
- Bunsen burner and heat proof mat
- Anti-bumping granules
- Lactic acid (**Irritant**) See CLEAPSS Hazcard 38C
- Hydrochloric acid 2 mol dm⁻³ (**Irritant**) See CLEAPSS Hazcard 47A
- Petri dish or white tile
- Eye protection.

Health and safety

Wear eye protection.

The boiling point of lactic acid is 122 °C. It will get very hot during the experiment. Be careful not to get it on your skin. If you do, put your skin under the cold tap immediately and then tell your teacher.

What to do

- Fill a test-tube 1/5 full with lactic acid.
- Add 5 drops of hydrochloric acid and two anti-bumping granules.
- Put the test-tube holders around the top of the test-tube and begin to heat the tube. Be careful not to point the open end of the test-tube at anyone in the room – try to point it towards a wall.
- Keep the mixture gently boiling and stir or gently shake the tube occasionally to mix the contents.
- After about 10 or 15 minutes the mixture will begin to go a yellowish colour. Leave it for another minute or two and then quickly pour the contents of the tube out onto either a petri dish or a white tile.
- Leave the mixture to cool.

Questions

1. If you have successfully polymerised the lactic acid, what will have happened to the size of the molecules?

.....

2. Look at the lactic acid you started with and your product. Describe the differences in properties between them (be careful – your product will be very sticky).

.....

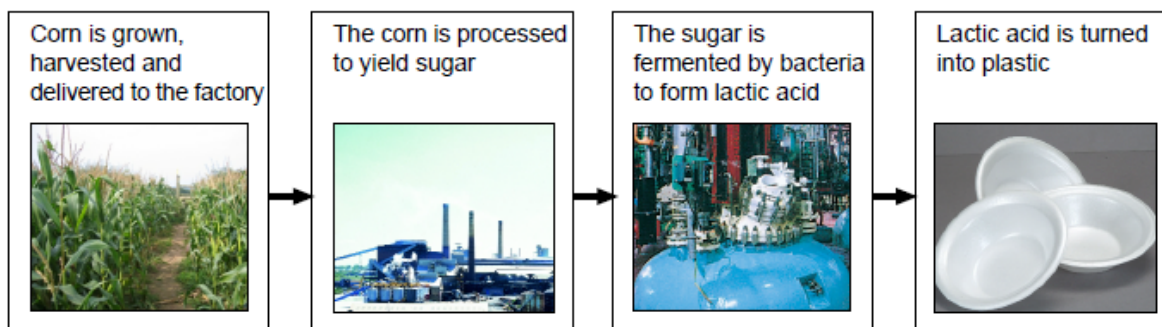
.....

.....
3. Try to explain the change in properties in terms of the size of the molecules in the materials.

.....
.....
.....

Using polylactic acid

Polylactic acid is commercially manufactured in the USA and in Japan. It can be made into consumer items as diverse as disposable plates and cups, packaging and clothing. The lactic acid used to make it is derived from corn. The process used to make it involves both biotechnology and chemistry.



1. What are most plastics are made from? (What is the raw material?)

.....

2. What is the raw material for making polylactic acid?

.....

When the plastic polyethene is made, energy is used to make the ethene and to turn the ethane into polyethene. As ethene is a gas, it is usually piped from place to place. When polylactic acid is made, the corn has to be transported from the field to the factory and the distances involved can be vast. The PLA (polylactic acid) plant in Nebraska is in the middle of a huge corn field to minimise transportation costs.

3. Look at the stages of the process for making polylactic acid shown above. Which of the stages uses energy? Where is this energy likely to come from?

.....
.....

To make a kilogram of polyethene, 81 MJ worth of fossil fuels is required. This includes 29 MJ worth of raw materials and 52 MJ of fuels that are burnt to release the energy needed for the manufacturing process. To make a kilogram of polylactic acid, 56 MJ of fossil fuels is required.

All of this is burnt to release energy. When fossil fuels are burnt, carbon dioxide is released into the environment. When a fossil fuel is turned into plastic, the carbon dioxide is not released but is locked in the plastic and only released into the environment if that plastic is burnt or decomposes.

4. When polylactic acid and polyethene are made, which results in the most carbon dioxide being released to the environment?

.....

5. Why is this less of a problem than it might seem at first? (Hint: think about what the polylactic acid is made from).

.....

6. Polylactic acid is about five times as expensive as polyethene. Why do you think this is?

.....

.....

The chemical industry is trying to make itself 'greener.' There are three main ways it is likely to do this:

- Use less oil
- Develop cleaner chemical processes
- Avoid damaging ecosystems.

It is also important to reduce any risk to employees working in the chemical industry and to the users of its products.

7. Which of the two products (polyethene and polylactic acid) uses less oil?

.....

Although the oil saving is not much at the moment, it is hoped that in time the process for making polylactic acid will become more efficient and use less oil. This could be achieved by burning leftover parts of the corn to produce energy or by scientists spending a lot of time doing research to find a better way to make the product. Improvements have already been made that have significantly reduced the cost of polylactic acid.

However, businesses have to make money and there is no advantage for a manufacturer who develops an environmentally friendly product that is very expensive to produce. A manufacturer could spend a lot of money on research and not manage to find a way of using less energy. Consumers are not normally willing to pay more for an item just because it is 'environmentally friendly.'

8. Do you think the government should do something to help companies who make 'greener' packaging? Packaging that is not degradable could be taxed, for example, or the government could pay for some of the

research needed. Remember – this means that you will end up paying for it eventually! Things wrapped in plastic may become more expensive or taxes may go up, which could lead to your parents having less money to spend on you. Explain your answer.

.....
.....
.....

One of the main benefits of polylactic acid is that it is biodegradable. Polyethene is too, but it will probably take hundreds of years to biodegrade. Polylactic acid can be put into a compost heap and will degrade within a few months.

9. Where does most rubbish in Britain end up? What happens to it there?

.....

10. Which products would it be best to make out of polylactic acid. How would you market those products?

Continuing the theme of familiar addition polymers, the following activity investigates the use of starch from potatoes as a source material. As with polylactic acid the polymer formed is very versatile and has many uses.

Activity 5: Making a plastic from potato starch – extracting starch

In this activity you are going to extract starch from potatoes. This starch can be used to make a plastic.

A similar process is used in industry to extract starch, which is then used in a number of products, including food and packaging.

You will need:

- Approx 100 g clean (not muddy) potatoes
- Grater
- Tea strainer
- Distilled water
- Pestle and mortar
- 100 cm³ measuring cylinder.

What to do

- Grate about 100 g potato. The potato does not need to be peeled, but it should be clean.
- Put the potato into the mortar and add about 100 cm³ distilled water. Grind the potato carefully.

- Pour the liquid off through the tea strainer into the beaker, leaving the potato behind in the mortar. Add 100 cm³ water, grind and strain twice more.
- Leave the mixture to settle in the beaker for 5 minutes.
- Decant the water from the beaker, leaving behind the white starch which should have settled in the bottom. Add about 100 g distilled water to the starch and stir gently. Leave to settle again and then decant the water, leaving the starch behind. You can now use the starch to make a plastic film.

Making a plastic from potato starch – making the plastic

In this activity you will make a plastic film from potato starch and test its properties.

Potato starch is a polymer made of long chains of glucose units joined together. It actually contains two polymers:

- Amylose, which is a straight chain of glucose units
- Amylopectin, which is a branched polymer, also made of glucose units.

The amylopectin prevents the starch from becoming plastic-like. You will use hydrochloric acid to break down the amylopectin and change the structure and properties of the polymer.

You will make two different batches of the potato plastic. In one you will add some propan-1,2,3-triol (also known as glycerol), which will act as a plasticiser. In the other batch, you will leave the propan-1,2,3-triol out.

Making the potato plastic

You will need:

- Eye protection
- 250 cm³ beaker
- Large watch glass
- Bunsen burner and heat proof mat
- Tripod and gauze
- Stirring rod
- Potato starch
- Propan-1, 2, 3-triol (**Low Hazard**) See CLEAPSS Hazcard 37
- Hydrochloric acid 0.1 mol/dm³ (**Low hazard**) See CLEAPSS Hazcard 47A
- Sodium hydroxide 0.1 mol/dm³ (**Irritant**) See CLEAPSS Hazcard 091
- Food colouring
- Petri dish or white tile
- Universal Indicator paper
- Eye protection
- Access to a balance
- 25 cm³ measuring cylinder
- 10 cm³ measuring cylinder.

Health and safety

Wear eye protection.

What to do

- Put 25 cm³ water into the beaker and add 2.5 g potato starch, 3 cm³ hydrochloric acid and 2 cm³ propan-1,2,3-triol.
- Put the watch glass on the beaker and heat the mixture using the Bunsen burner. Bring it carefully to the boil and then boil it gently for 15 minutes. Make sure it does not boil dry – if it looks like it might, then stop heating.
- Dip the glass rod into the mixture and dot it onto the indicator paper to measure the pH. Add enough sodium hydroxide solution to neutralise the mixture, testing after each addition with indicator paper. You will probably need to add about the same amount of sodium hydroxide as you did acid at the beginning (3 cm³).
- If you wish you can add a drop of food colouring and mix thoroughly. Be careful not to spill the food colouring – it stains.
- Pour the mixture onto a labelled petri dish or white tile and push it around with the glass rod so that you have an even covering.
- Label your mixture and leave it to dry out. This will take about 1 day on a radiator or sunny windowsill or two days at room temperature.

Repeat the steps described above, but leave out the propan-1,2,3-triol. Make sure you label your mixtures so that you know which one contains propan-1,2,3-triol and which does not.

Making a plastic from potato starch – examining your plastic

Look carefully at your two petri dishes containing potato plastic.

1. Describe carefully the properties of each of the substances you have made.

.....
.....
.....

2. What difference has adding the propan-1,2,3-triol made?

.....

The propan-1, 2, 3-triol is acting as a plasticiser. Plasticisers are used in commercial products to change the properties of the polymer, just as you have used the propan-1,2,3-triol to change the properties of the potato plastic. The propan-1,2,3-triol gets in between the polymer chains and prevents them from lining up

in rows to form a crystalline structure. When the polymer becomes crystalline, it also becomes brittle and inflexible. You can think of the plasticiser as a small molecule that gets between the polymer chains and helps them to slide easily over each other so that the polymer behaves like a plastic.

3. Draw a diagram of the polymer chains with and without the propan-1,2,3-triol and use it to help you explain why the potato plastic has very different properties when propan-1,2,3-triol is present. Label which one is which.

Use a simple line like this to represent a polymer chain:



and like this to represent propan-1,2,3-triol.



Using plastics from potato starch

1. Do you think the plastic you made from potato starch will be biodegradable? Explain your answer.

.....
.....

2. How could you test your plastic to find out?

.....
.....

Extracting starch from potatoes takes a lot of energy. You had to grate the potatoes, grind them and rinse them several times. Similar processes are used in industry to extract starch, although sweetcorn (maize) is used more often than potatoes. The leftover bits are often used in animal feed so that none of the material is wasted.

3. In industry, where would the energy needed to extract the starch come from?

.....

4. What are most plastics made from? (What is the raw material used to make them?)

.....

Plastics made from plants or other living things are known as bioplastics. 'Bioplastic' does not mean the same thing as 'biodegradable plastic'. Some biodegradable plastics are made from oil and some bioplastics are not biodegradable.

5. Explain the meaning of the terms bioplastic and biodegradable.

.....
.....

6. Write a list of the advantages of making plastics for which the raw material comes from plants.

.....
.....
.....
.....

7. What are the disadvantages? (Hint: think about growing the plants.)

.....
.....

Your starch plastic will dissolve in water if you leave it overnight.

8. What effect will this solubility have on the number of things that this plastic can be used for? Write down three things for which it could not be used and some things for which it could.

.....
.....
.....

To try to make starch more useful, researchers have tried blending it with other plastics like polythene. They hoped that this would make the overall product more biodegradable than polythene on its own. Unfortunately, this was not the case. The plastic tended to fall to bits but the pieces were less biodegradable than ordinary starch.

More recently, a scientist called Catia Bastioli from Italy has taken starch treated in the same way that you have treated it (with acid and propan-1,2,3-triol) and mixed it with the polymer PVA (used in white glue).

The polymer that results is biodegradable but also water soluble. This means that its use is limited to things like packing dry goods, or replacing polystyrene foam, which is not biodegradable and is made from oil.

The method used to turn the starch into small pieces of foam packaging material is similar to the technique used to make foods such as Rice Krispies and Coco Pops.

Name of product	Price in £ per kg
Starch/PVA blend	3.40–4.40
polythene	0.50–0.60
polystyrene	0.60

9. The letter below was sent to a magazine. The editor does not know much about science and so has asked you to write a reply to be published in the next edition. Make sure that your reply:

- Uses accurate scientific information
- Is clear and concise
- Answers the question.

You may find the following website helpful when researching your answer. If you use information from a website, do not forget to think about whose website it is and if it is likely to be biased. If so, what effect this bias might have on the information on the site.

<http://www.greenlightproducts.co.uk>

Dear Editor

I try to be as environmentally-friendly as I can and I like to encourage others to do the same. I found out recently that it is possible to make plastics out of starch from plants, but most plastics are still made out of oil. I am horrified and wondered if you know why this is?

Yours sincerely

Anne Other

Hydrogels are a good example of a smart material – a material that responds to the environment in which it is used. The activity explores many of the properties of hydrogels used in different products. The individual experiments can be extended to include a review of cost effectiveness of products, such as nappies. The knowledge gained links through to more specialist applications such as drug delivery mechanisms.

Activity 6: Experiments with a smart material – hydrogels

A smart material is one that changes shape in response to changes in its environment. Hydrogels are smart materials and their properties are exploited in a number of products that are currently available on the market. Chemists are working to develop other applications for this unusual type of material.

You are going to investigate three readily available products that contain a hydrogel: disposable nappies, plant water storage crystals ('water crystals') and hair gel. Record detailed observations as you carry out each experiment.

Plant water storage crystals – part 1

You will need

- 1 teaspoon of water crystals
- Large beaker (at least 1 dm³) or plastic tub
- 500 cm³ concentrated tea.

What to do

- Estimate the volume of your water crystals.
- Put about 500 cm³ of the tea into the beaker or tub. Add 1 tsp of water crystals, stir gently and leave for at least half an hour (or overnight).

Plant water storage crystals – part 2

You will need

- Your water crystal and tea mixture from part 1
- Sieve (or a large funnel lined with a paper towel or large piece of filter paper)
- 2 x 250 cm³ beakers
- Salt solution
- Distilled water
- Dessert spoon
- Piece of white paper
- 2 x stirring rods
- Tea strainer (if you have not got a sieve)
- 2 petri dishes.

What to do

- Sieve your water crystal mixture. It is best to do this over a large tub rather than over the sink in case you drop the sieve. Carefully wash the gel crystals once or twice in water to remove any excess tea. Estimate the new volume of your crystals.
- Place the two 250 cm³ beakers on a piece of white paper.
- Put two dessert spoons of your gel crystals into each beaker, estimate their volume and then add about 200 cm³ salt solution to one beaker and about 200 cm³ distilled water to the other. Label the beakers. Keep the remaining gel crystals.
- Stir the mixtures gently – use a separate stirring rod for each one so that the solutions are not contaminated. Leave for 10–15 minutes, stirring occasionally.
- Place the two petri dishes on the white paper. Pour a little of your solutions into the petri dishes. Use a tea strainer to prevent any crystals getting into the petri dishes.
- Note the colour of each liquid.
- Sieve each of the remaining mixtures separately, discarding the excess liquid and returning the crystals to the beakers. Estimate the new volume of crystals in each beaker.

Hair gel

You will need

- Hair gel
- Salt
- Petri dish
- Teaspoon or spatula.

What to do

- Put a large teaspoonful of hair gel onto the petri dish lid.
- Gently sprinkle salt from a spatula over the hair gel.

Disposable nappy

You will need

- A disposable nappy
- Scissors
- A large ice cream tub or similar container
- Distilled water
- Salt
- Dessert spoon or similar measure
- A stirring rod or spoon
- A large beaker (at least 600 cm³)
- Eye protection
- Gloves if you have sensitive skin.

What to do

- Cut the middle section out of the nappy. You want the thicker piece which is designed to absorb urine. Discard the other piece.
- Make sure your ice cream container is completely dry – wipe it with a paper towel if necessary. If there is any moisture in the tub the experiment will not work properly.
- Wear eye protection for the next step. Put the centre piece of the nappy into the ice cream container and gently take it apart. You should start to see small white grains coming away from the nappy and this is what you are trying to collect. Keep gently pulling the nappy apart until you have collected as many of the grains as you can. Do not do this roughly or you will lose your product and put a lot of dust and fluff into the air. Avoid breathing in any dust you do create.
- Remove and dispose of all the fluff and other parts of the nappy, keeping the white grains in the bottom of the tub. The grains are heavier than the other materials and fall to the bottom of the heap, which makes it easier to separate them out.
- Estimate the volume of the grains.
- Pour the grains into the large beaker and add about 100 cm³ distilled water (you can just use the markings on the beaker to measure the volume). Stir the mixture and keep adding distilled water until no more can be absorbed. Stir between each addition of water. Estimate the final volume of the hydrogel.
- Add a dessert spoonful of salt and stir.

Summary

Write a summary of what happened in each of your experiments.

What have you learnt about hydrogels?

Can you explain any of their unusual properties?

Hydrogels

Technician notes

Each experiment will require:

Part 1

Tea

1 teaspoon of water crystals (phostrogen Swellgel)

1 dm³ beaker

500 cm³ strong tea (1 bag)

Part 2

Tea

Plastic sieve

2 x 250 cm³ beakers

200 cm³ sat NaCl soln

Distilled water

Plastic spoon

2 x petri dishes

Hair gel

1 teaspoon of cheapest hair gel

Salt

Petri dish

Teaspoon

Disposable Nappies

Ultra-absorbant nappy

Scissors

Ice cream tub (or similar)

Distilled water

Salt

Dessert spoon

Large beaker (at least 600 cm³)

Disposable nitrile gloves

Hydrogel & sugar

Plant storage crystals as before

Sugar

Distilled water

2 x 250 cm³ beakers

Sieve

Hydrogels and how they work

1. How much did the volume of the hydrogel in your experiments increase when it was put into water?

.....

2. What happened to the volume of the hydrogel when salt was added?

.....

3. Why is the hydrogel a 'smart material'?

.....

.....

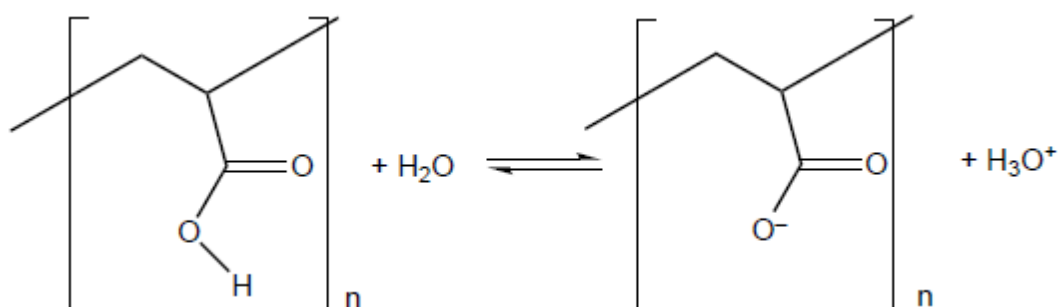
Understanding the structure and bonding of hydrogels helps to explain their properties. This in turn helps chemists to develop new hydrogels and find further uses for them.

Hydrogel structure

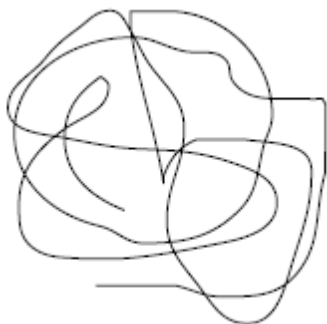
The hydrogel you have used is a polymer of a type of substance called a carboxylic acid. The acid groups stick off the main chain of the polymer, as shown in the diagram below.

When the hydrogel is put into water these acid groups react, the hydrogen atom comes off and the polymer chain is left with several negative charges along its length.

(Note: H₃O⁺ is another way of writing H⁺ in solution and shows that an acid is present.)



A polymer chain in solution tends to coil up so it looks like this:



However, the hydrogel polymer chain now has several negative charges along its length.

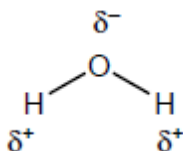
4. What will the negative charges do to each other?

.....

5. What effect will this have on the polymer chain?

.....

This diagram shows a water molecule.



6. What will happen to the water molecules when they get near the polymer?

.....

.....

Both of these effects mean that the molecules of the polymer get larger as they get wet. This makes the solution more viscous because the polymer resists the flow of the solvent molecules around it.

Quite why the polymer absorbs so much water is still not fully understood.

Drug delivery and smart materials

Research is currently being undertaken to find out whether it is possible to use hydrogels and similar materials as a drug delivery system – a way to get drugs and medicines to where they are required in the body.

1. What methods are currently used to get drugs and medicines into the body?

.....

.....
.....
.....

2. If a pill is swallowed, where does it go in the body?

.....
.....

These methods can cause a number of problems. While all drugs are rigorously tested to make sure they are safe for the vast majority of people, many drugs cause bad reactions in a few people. The negative effects range from an upset stomach to serious allergic reactions. Chemists are now trying to develop a delivery system that will target a drug at the particular site where it is required. For example, if you have a bad cut on your leg and take antibiotic pills, the drug travels all round your body and not just to your cut leg. This increases the risk that the drug will cause problems. If the drug is only released at the cut then the likelihood of an adverse reaction is reduced. When the drugs are extremely strong, such as those used in chemotherapy to treat cancer, the possible side effects are wide ranging and include hair loss, severe stomach upset and lethargy. Targeting the drugs so that only the cancer cells are affected is a major goal in current research. Since drugs can be toxic to the body, the aim is to place them in a non-toxic carrier so they can pass through the body without causing any damage. The carrier needs to be smart so that it will release the drug at the required site and nowhere else. Chemists are investigating a wide range of potential carriers, including hydrogels.

The experiment you did with tea and hydrogel is a model of this type of drug delivery system. The drug is first loaded onto the carrier and then it is released at the right location.

3. In this model, which is the drug and which is the carrier?

.....
.....

4. What happens to the hydrogel when it is soaked in tea solution? Give as much detail as you can.

.....
.....

5. What happens to the tea in the hydrated crystals when they are soaked in salt solution? What happens to it if the crystals are soaked in distilled water? Explain your observations in as much detail as you can.

.....

.....

In this model, the presence of the salt changes the behaviour of the 'carrier,' causing it to release the 'drug.' As more is understood about exactly how drugs work, research is focusing on how to deliver them in a way that ensures they make their active ingredients available at the time and place required by the body.

One type of substance being studied for use in carriers is microgels. These are similar to hydrogels but the particles are far smaller, often only up to 100 nm in diameter. This is an example of nanotechnology.

6. If the particles are very small, what effect will this have on the overall surface area of the carrier and on the rate at which the drug is released when the conditions are right?

.....

.....

Hydrogels and microgels can also change shape and release a drug in response to a change in pH or temperature. Conditions such as temperature, saltiness or ionic concentration and pH can all be different in an infected or diseased area of the body than under normal conditions. If chemists can understand both how the disease operates in the body and how the microgels and hydrogels behave in different conditions it should be possible for them to target drugs accurately at the sites where they are required.

The previous activities have focussed upon addition polymers and their properties. Activity 7 demonstrates the manufacture of a condensation polymer, in this case nylon. The experiment clearly illustrates the idea of two different monomers bonding alternatively and eliminating a small molecule, a condensation product. It is important to remind students that although it is called a condensation product, it is not necessarily a water molecule, it can be hydrogen chloride as in this example.

Activity 7: Making nylon – the 'nylon rope trick'

Topic

Polymerisation.

Timing

About 15 min.

Level

Pre-16 or post-16, depending on the sophistication of theoretical treatment.

Description

A solution of decanedioyl dichloride in cyclohexane is floated on an aqueous solution of 1,6-diaminohexane. Nylon forms at the interface and can be pulled out as fast as it is produced forming a long thread – the ‘nylon rope’.

Apparatus

- Eye protection
- Disposable gloves
- One 25 cm³ beaker.
- A pair of tweezers.
- Retort stand with boss and clamp.

Chemicals

The quantities given are for one demonstration.

- 2.2 g of **1,6-diaminohexane** (hexamethylene diamine, hexane-1,6-diamine, H₂N(CH₂)₆NH₂). (**liquid – corrosive; solution** (at concentration below) – **low hazard**) See CLEAPSS Hazcard 3B
- 1.5 g of **decanedioyl dichloride** (sebacoyl chloride, ClOC(CH₂)₈COCl). (**corrosive**) See CLEAPSS Hazcard 41
- 50 cm³ of **cyclohexane**. (**highly flammable, harmful**) See CLEAPSS Hazcard 45B
- 50 cm³ of deionised water.

Method

Before the demonstration

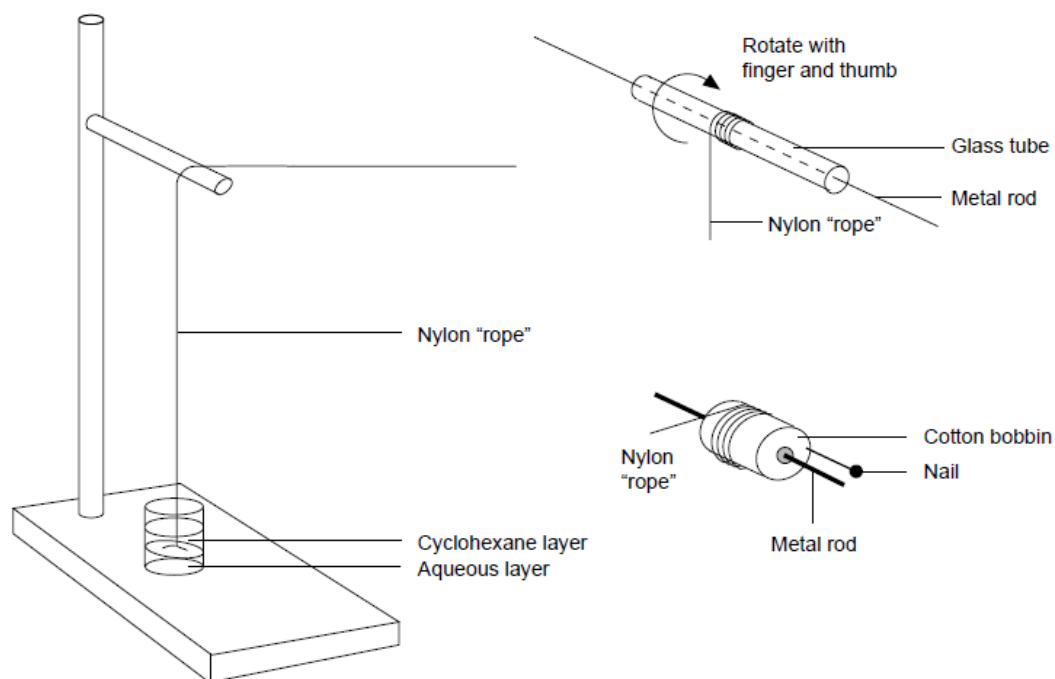
Make up a solution of 2.2 g of 1,6-diaminohexane in 50 cm³ of deionised water. This solution is approximately 0.4 mol dm⁻³.

Make up a solution of 1.5 g of decanedioyl dichloride in 50 cm³ of cyclohexane. This solution is approximately 0.15 mol dm⁻³ and is both **highly flammable** and **harmful** (See CLEAPSS Recipe Book sheet 62).

The demonstration

Pour 5 cm³ of the aqueous diamine solution into a 25 cm³ beaker. Carefully pour 5 cm³ of the cyclohexane solution of the acid chloride on top of the first solution so that mixing is minimised. Do this by pouring the second solution down the wall of the beaker or pour it down a glass rod. The cyclohexane will float on top of the water without mixing. Place the beaker below a stand and clamp as shown (see figure).

A greyish film of nylon will form at the interface. Pick up a little of this with a pair of tweezers and lift it slowly and gently from the beaker. It should draw up behind it a thread of nylon. Pull this over the rod of the clamp so that this acts as a pulley. Continue pulling the nylon thread at a rate of about half a metre per second. It should be possible to pull out several metres. Take care, the thread will be coated with unreacted monomer and may in fact be a narrow, hollow tube filled with monomer solution. Wearing disposable gloves is a wise precaution.



The nylon rope trick

Visual tips

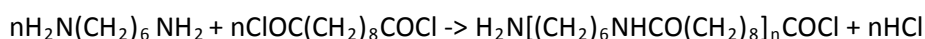
The beaker is rather small so allow the audience as close as possible consistent with comfort and safety.

Teaching tips

Point out that this demonstration is different from the industrial method of making nylon which takes place at a higher temperature. Molten nylon is then forced through multi-holed 'spinnerets' to form the fibres.

Theory

The reaction is a condensation polymerisation



The nylon formed is nylon 6–10 so called because of the lengths of the carbon chains of the monomers.

Nylon 6–6 can be made using hexanedioyl dichloride (adipoyl chloride).

The diamine is present in excess to react with the hydrogen chloride that is eliminated. An alternative procedure is to use the stoichiometric quantity of diamine dissolved in excess sodium hydroxide solution.

Extensions

There are many ways of conveniently winding the nylon thread – for example using a windlass improvised from a cotton bobbin or a short length of glass tube slid over the rod of a clamp.

Further details

This demonstration has been described in many sources using chlorinated solvents for the acid chloride. These are no longer considered safe and will soon become unavailable.

Cyclohexane is less dense than water whereas chlorinated solvents are denser. The layers are therefore inverted compared with the old method.

Cyclohexane is preferred to hexane as it is less hazardous.

Hexanedioyl dichloride (adipoyl chloride) can be used as an alternative to decanedioyl dichloride, but it does not keep as well.

Decanedioyl dichloride reacts with moisture in the air to produce decanedioic acid which forms nylon much less readily than the acid chloride. Ensure that the bottle is re-stoppered carefully after opening and consider storing it in a desiccator. The dichloride is also available in 5 cm³ sealed ampoules.

The cyclohexane solution will still make nylon for a couple of days after being made up even if left unstoppered. A solution kept in a stoppered bottle is still usable after two weeks. The solution can be stored over anhydrous sodium sulphate (**Low hazard** - see CLEAPSS Hazcard 98B) or calcium chloride (solid – **Irritant** - see CLEAPSS Hazcard 19A) to keep it dry.

Solid 1,6-diaminohexane can be difficult to get out of the bottle. The easiest way to manipulate it is to heat the bottle gently in warm water until it melts at 42 °C and dispense the liquid using a dropping pipette.

Safety

Wear eye protection.

Dispose of the mixture as follows:

First shake the reaction to mix the two layers. A lump of nylon will be produced which can be removed with tweezers, rinsed well with water, and disposed as solid waste. Failure to do this may result in the polymerisation taking place in the sink, leading to a blockage. The remaining liquids can be mixed with detergent and washed down the sink.

Glossary

Below are some of the terms used within this document:

Term	Definition
addition	The reaction between monomers of the same type containing a double bond. Only one product is formed.
condensation	The reaction between two different monomers that results in a chain of alternating monomers. Each reaction results in a secondary product consisting of a small molecule.
monomer	A small reactive molecule.
plasticiser	A chemical substance that alters the properties of a polymer.
polymerisation	The joining together of many monomers.

Royal Society of Chemistry
Education Department

Registered Charity Number: 207890

Burlington House
Piccadilly, London
W1J 0BA, UK
Tel: +44 (0)20 7437 8656
Fax: +44 (0)20 7734 1227

Thomas Graham House
Science Park, Milton Road
Cambridge, CB4 0WF, UK
Tel: +44 (0)1223 420066
Fax: +44 (0)1223 423623

Email: education@rsc.org
www.rsc.org/education

© Royal Society of Chemistry 2011