PRI

Some important polymers: introductory data

This activity is part of the introduction to the unit. It will help your data-analysis and information-retrieval skills. After carrying out the activity you should be familiar with the names of some important polymers. You will find out how much of each is produced and what the major uses are.

Polymers are a major product of the chemical industry. About 60% of all the chemicals it produces are used to make polymer products. It is now difficult to imagine life without them.

Polymers are used to make a range of different types of products (Figure 1). Some polymers are more suited to one particular application than to others. You will learn later in the unit how the structure of a polymer affects its properties and its use. The processing of a polymer is very important, too. It can determine the way chains pack together, which affects the properties of the polymer.

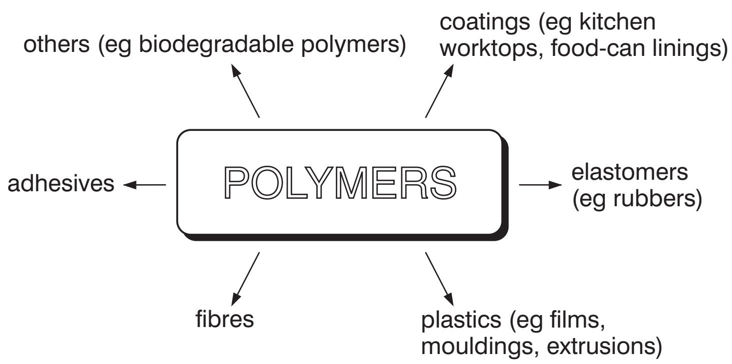


Figure 1 Some uses of polymers

You will meet examples of 'performance' polymers for use in special situations – polymers that shine in the dark, heat-resistant polymers, biodegradable polymers. These form an exciting new generation of polymers that are being developed in the 21st century.

By far the largest percentage of polymer production is concerned with making plastics for packaging, containers, tubes and piping.

Moulding of polymers

The polymer is often in the form of pellets. When heated these become soft and can be pushed through nozzles to form **pipes** (for example, for drainage) and **tubes** (for wires and cables). They can also be pushed through nozzles into moulds, where they cool to form the desired shape (buckets, bowls, boxes). This is known as **injection moulding**. In **blow moulding**, air is blown into the mould to form bottles. The molten polymer can also be extruded as film (shrink wrap, bags, bin liners).

This activity is concerned with the uses of some of the more common addition polymers. You will be asked to note the formula of each polymer and the formula of the monomer it is made from. But later in the unit you will learn more about how polymers are made and how their properties and uses are related to their structures.

Figures 2–6 give the annual UK production and uses of the polymers, together with the world production. (You may wish to colour the sectors of the pie charts.)

Poly(ethene)

There are three main forms of poly(ethene). One is called high density poly(ethene), hdpe, and another is low density poly(ethene), ldpe. These are discussed in this unit. The third form, linear low density poly(ethene), lldpe, is discussed in a later unit, **Designer Polymers**.

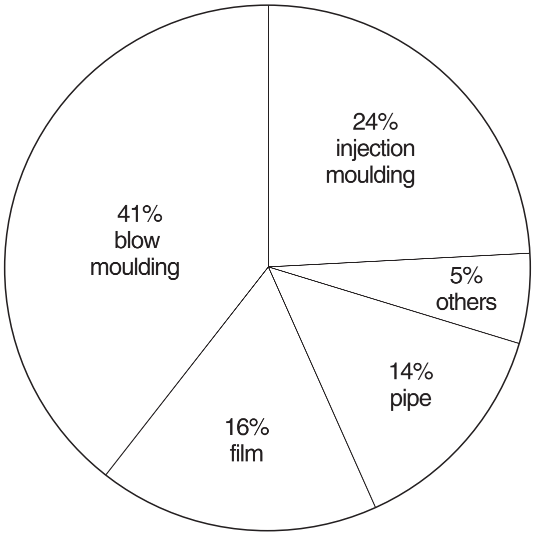


Figure 2 Uses of hdpe (high density poly(ethene))

Annual production of poly(ethene)		
UK	hdpe	280 000 tonnes
	lldpe	160 000 tonnes
	ldpe	200 000 tonnes
World	hdpe	22.5 million tonnes
	lldpe	14 million tonnes
	ldpe	15.6 million tonnes

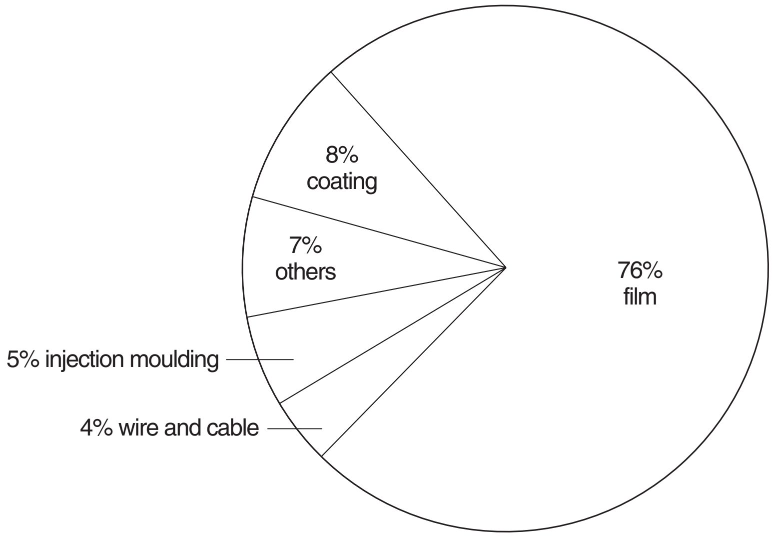


Figure 3 Uses of ldpe / lldpe (low density and linear low density poly(ethene))

Poly(propene)

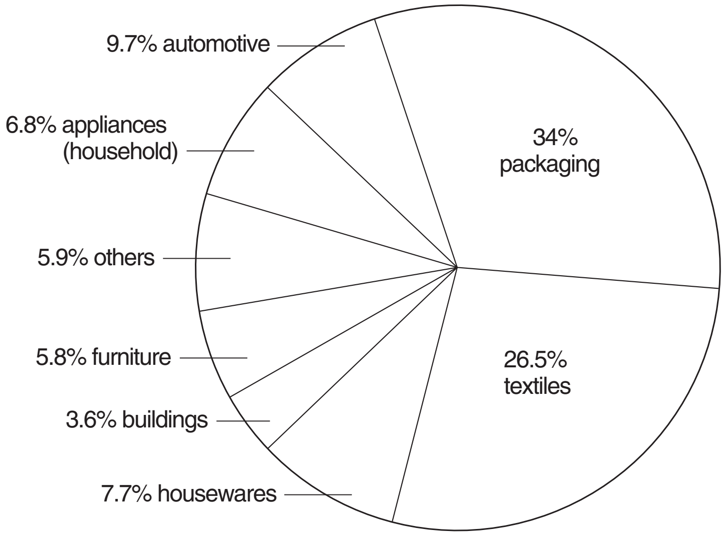


Figure 4 Uses of poly(propene)

Annual production of poly(propene)	
UK	300 000 tonnes
World	23.5 million tonnes

Poly(chloroethene) (polyvinyl chloride, PVC)

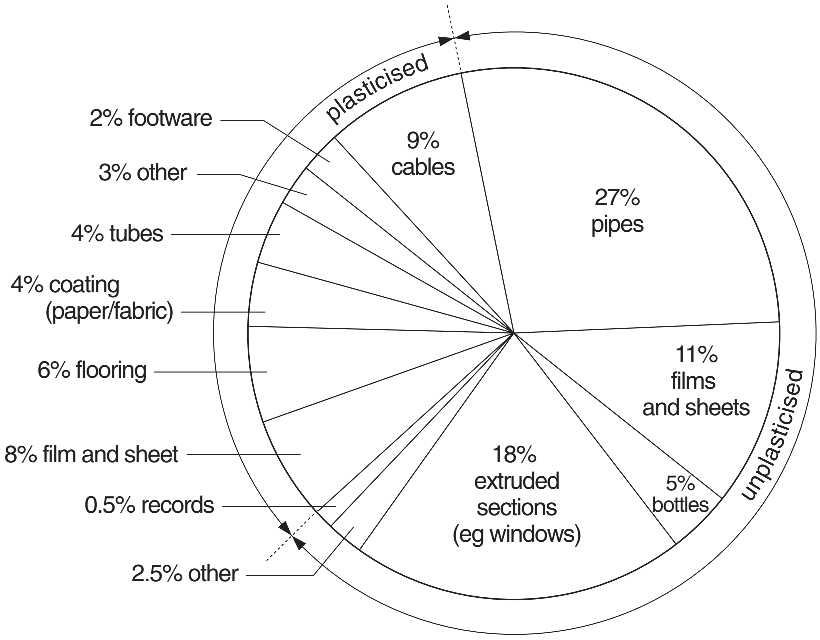


Figure 5 Uses of PVC

Annual production of PVC	
UK	470 000 tonnes
World	27 million tonnes

Poly(phenylethene) (polystyrene)

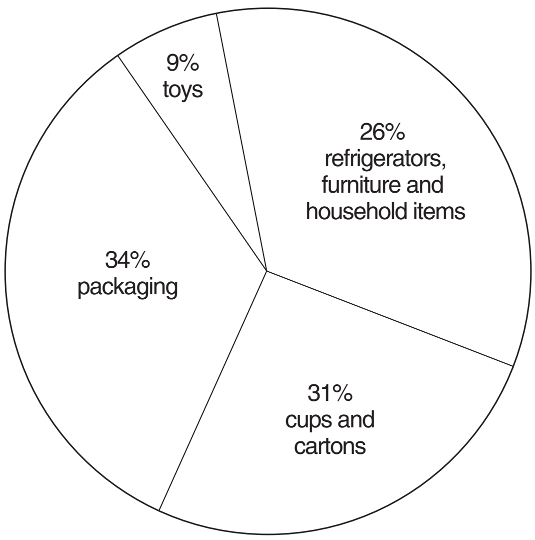


Figure 6 Uses of polystyrene

Annual production of polystyrene	
UK	270 000 tonnes
World	8.5 million tonnes

QUESTIONS

a Draw a table, like the one below, for the above polymers and complete as much of it as possible. You may not be able to give the formulae of the polymers at this stage but you will be able to later in the unit.

Name of polymer	Formula of monomer	Formula of polymer	Main uses

b Use a computer to produce a bar chart comparing the UK production and world production of these polymers. Use the data above and any further information that you can find on the Internet (start your search at the Salters Advanced Chemistry web site).

i In what ways can you relate the differences in production to the different products made from the five polymers?

ii What are the major differences between the uses of the high density and low density forms of poly(ethene)?

iii Poly(propene) is often said to be similar in use to hdpe. In what respects is this true? What is the major difference in the uses of the two polymers?

PR2

Making poly(phenylethene) (Optional extension)

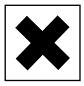
In this activity you will use a peroxide to initiate the addition polymerisation of an alkene. Phenylethene is a convenient alkene to use because it is a liquid with a boiling point of 145 °C. Di(dodecanoyl) peroxide (or lauroyl peroxide) is the initiator.

Requirements

- phenylethene (styrene) (10 cm^3)
- 10 cm^3 measuring cylinder
- di(dodecanoyl) peroxide (0.2 g)
- boiling tube and 2 test-tubes
- 250 cm^3 beaker
- cottonwool
- source of hot water
- methylbenzene (5 cm^3)
- bromine water (2 cm^3)
- spatula
- access to balance
- access to fume cupboard

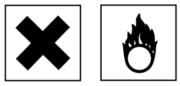
CARE You should carry out this experiment in a fume cupboard.

bromine water



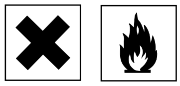
HARMFUL

di(dodecanoyl) peroxide



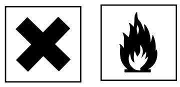
IRRITANT OXIDISING

methylbenzene



HARMFUL HIGHLY FLAMMABLE

phenylethene (styrene)



HARMFUL FLAMMABLE

CARE Eye protection must be worn.

WEAR EYE PROTECTION

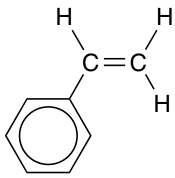
What you do

1. Place 10 cm^3 of phenylethene in a boiling tube. (**CARE** Phenylethene is flammable and harmful. Avoid breathing the vapour.)
2. Add about 0.2 g of di(dodecanoyl) peroxide (**CARE** Irritant) and shake the tube until the solid has dissolved.
3. Plug the tube with cottonwool and then heat it in a beaker of boiling water *in a fume cupboard* for about 20 minutes.
4. Compare the contents of the tube with the original phenylethene. Is there evidence that polymerisation is taking place?
5. Leave the tube in an oven or water bath at about 50 °C until the contents have set. (After step **3** you can pour the contents into a mould and use that instead of the boiling tube if you prefer.)
6. Dissolve a small quantity of the solid formed in methylbenzene. Add a few drops of the solution to 1 cm^3 bromine water in a test-tube. Stopper the tube and shake.
7. Now add a few drops of the monomer, phenylethene, to 1 cm^3 bromine water in a separate test-tube. Stopper the tube and shake.
8. Make a record of your observations.

QUESTIONS

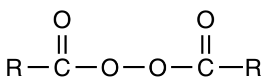
a What do your observations in steps **6** and **7** tell you about the structures of the monomer and the resulting polymer?

b The structure of phenylethene is:



Draw out part of the structure of poly(phenylethene).

c Di(dodecanoyl) peroxide is:



where R is a $CH_3(CH_2)_{10}$ group. Explain how this compound acts as an initiator for the polymerisation.

PR3

Using spaghetti to model polymer structure

In this activity, you will use strands of spaghetti to model how the molecules of some polymers are aligned in a solid

Requirements

- spaghetti (about 250 g)
- 2 dm^3 beaker (or saucepan)
- Bunsen burner, tripod and gauze (or kitchen hob)
- transparent container with a flat base and straight sides (such as a plastic ice cream or sandwich box)
- strainer

CARE Do not eat any spaghetti cooked in the laboratory.

What you do

1 Cook some spaghetti, in a saucepan or large beaker, using the manufacturer's instructions for the amount of water and length of time.
2 When cooked, strain the spaghetti so that it is free of water and pour it into the container.
3 Allow it to cool.
4 Turn out the solid cake. Sketch the arrangement of spaghetti strands on the base of the solid cake.

The spaghetti acts as a model for the chains in a polymer and the way they pack together in solid materials.

5 Label on your diagram:
i areas where the arrangement resembles a crystalline structure
ii areas where the arrangement resembles an amorphous structure.

QUESTION

Does the spaghetti model resemble a syntactic or an atactic polymer? Explain your answer.

PR5.1

Deflecting jets

This experiment illustrates the section in* Chemical Ideas 5.3 *which is about bond polarity and dipole moments. You are going to test streams of different liquids to see whether they are affected by an electrically-charged rod. If the molecules in the liquid are polar they should be attracted towards the rod.

Requirements

- burettes (5)
- water (50 cm^3)
- propanone (50 cm^3)
- ethanol (50 cm^3)
- cyclohexane (50 cm^3)
- methylbenzene (50 cm^3)
- 250 cm^3 beakers (5)
- plastic rulers (5)
- protective gloves

CARE Most of the liquids used are flammable. There must be no naked flames in the laboratory while doing this experiment.

WARNING Some of the liquids may dissolve plastic, so do not let them come into contact with the ruler.

WARNING At the end of the activity the liquids must be disposed of properly, as directed by your teacher. Do not throw any liquid other than water down the sink.

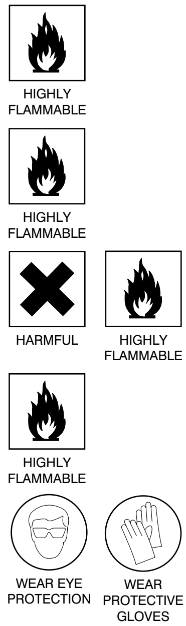
cyclohexane

ethanol

methylbenzene

propanone

CARE Eye protection and disposable gloves must be worn.



What you do

1. Set up a burette and fill it with one of the liquids provided. (**CARE** Some of these liquids are flammable and some have harmful vapours. Take notice of the hazard warnings associated with each liquid.) To save time, each group should start with a different liquid and the groups should move from burette to burette during the experiment.
2. Place an empty 250 cm^3 beaker under the burette to catch the jet of liquid. You can refill the burette from the beaker at the end of your turn.
3. Charge the ruler by rubbing it vigorously with a piece of dry cloth. A woollen sweater is good for this. Then turn on the burette tap so that a jet of liquid flows into the beaker.
4. Bring the ruler towards the jet *but do not let them touch* (see Figure 1). Observe what happens. Record how much, if at all, the jet of liquid is deflected, and what this tells you about the structure of the molecule. (Note that the charged rod can set up *induced* dipoles in the molecules of the liquid and lead to small deflections with molecules which possess no *permanent* dipole. So even molecules with no permanent dipole can give small deflections.)
5. Repeat the experiment with the other liquids provided.
6. Make out a table like the one that follows, and record your results.

Liquid	Structure	Effect of charged rod on jet of liquid	Does the molecule possess a permanent dipole?
ethanol	C_2H_5OH		

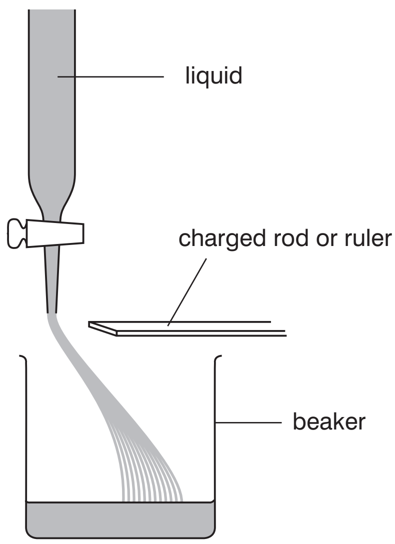


Figure 1 Deflecting jets of liquids

QUESTIONS

a Which liquids contain molecules that possess dipoles?

b Which groups of atoms in these molecules are responsible for the polarity?

PR5.2

Viscosity in alcohols

This activity requires you to interpret experimental observations in terms of the ideas on intermolecular forces you have been reading about.

Requirements

- test-tubes (3)
- stoppers (3)
- propan-1-ol ($10\,cm^3$)
- propane-1,2-diol ($10\,cm^3$)
- propane-1,2,3-triol ($10\,cm^3$)
- stopclock

CARE Propan-1-ol and propane-1,2-diol are flammable. Keep well away from naked flames.

propan-1-ol

HIGHLY FLAMMABLE

propane-1,2-diol

HIGHLY FLAMMABLE

CARE Eye protection must be worn.

WEAR EYE PROTECTION

What you do

1 Pour some propan-1-ol into a test-tube so that when it is stoppered there will be a small air gap left at the top of the liquid.

2 Invert the tube and record the time the bubble takes to rise through the liquid.

3 Repeat for the other two alcohols, using the other two test-tubes.

QUESTIONS

Viscosity (how thick or syrupy a liquid is) is a measure of how strongly the molecules attract each other. In this activity, the molecules must be forced apart to allow the bubble to rise.

a Draw structural formulae for the three alcohols you have used.

b Explain your results in terms of the groups contained in the alcohol molecules and the interactions between them.

PR5.3

Now you see it …

Poly(ethenol) is used to make plastic laundry bags for use in hospitals. The bags dissolve during the washing, which means that hospital workers do not need to handle the dirty linen and run the risk of infection. This activity introduces you to poly(ethenol), and gives you an opportunity to plan and carry out an investigation.

Requirements

- poly(ethenol) film (hot-water soluble variety – several small pieces)
- 250 cm^3 beaker
- washing powder
- glass rod
- Bunsen burner, tripod and gauze
- thermometer

CARE Eye protection must be worn.

What you do

Plan and carry out an investigation to find out how fast poly(ethenol) film dissolves in water under different conditions such as might be present in a washing machine.

What recommendations would you make to hospitals about the length of the wash cycle and the temperature of the wash?

PR5.4

Making 'slime'

In this activity you will have the opportunity to prepare a novel material and examine its properties. You can then relate these properties to its structure.

Requirements

- polystyrene drinking cup
- sodium borate solution, 4% (10 cm^3)
- poly(ethenol) solution, 4% (50 cm^3)
- protective gloves
- wooden sticks for stirring (flat-sided ones work best)
- 50 cm^3 measuring cylinder
- 10 cm^3 measuring cylinder
- green food colouring or fluorescent dye (optional)

CARE Eye protection and gloves must be worn.

WARNING 'Slime' spoils carpets and can remove paint.

What you do

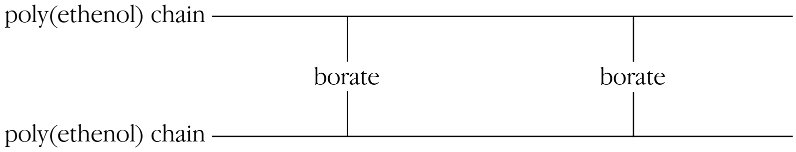
1 Put about 50 cm^3 of poly(ethenol) solution into the polystyrene cup. Stir the solution and note its appearance. (A few drops of food colouring or fluorescent dye may be added at this stage.)

2 Add 10 cm^3 of sodium borate solution and stir the mixture vigorously. Keep on stirring while the mixture is setting. When the mixture has set to a gel, remove it from the cup and continue to shape it with your hands (wear gloves).

3 Investigate the properties of the 'slime' you have produced and compare it with the poly(ethenol) solution you started with. 'Slime' is not dangerous, but as a precaution you should wear gloves and wash your hands at the end of the experiment.

Explanation

Borate ions in the sodium borate form cross-links between the poly(ethenol) chains:



The forces produced by these cross-links are of a different kind to the intermolecular forces between poly(ethenol) chains. They are also stronger, which allows you to see more clearly the effects of introducing forces between polymer molecules.

Summary

Write a brief account of the properties of 'slime' and describe how they differ from those of poly(ethenol). Explain your observations in terms of the intermolecular forces which are present.

PR6

Poly(pyrrole) – a conducting polymer

In this experiment you are going to 'grow' some poly(pyrrole) on a nickel electrode and then peel off the film of polymer so that you can test its conducting properties. You will only be able to peel the polymer off if the nickel electrode is very clean and smooth.

Requirements

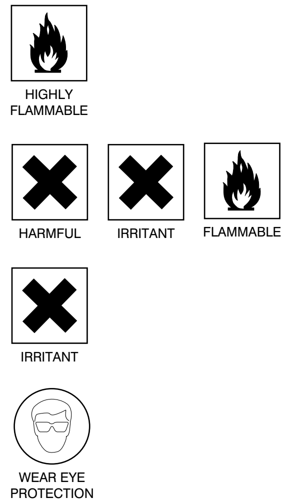
- pyrrole (0.68 g)
- copper foil (1 cm wide strip)
- nickel spatula
- wire wool or emery cloth
- 'Brasso' metal polish
- small pieces of cloth
- paper towels
- sodium 4-methylbenzenesulphonate solution (p-toluenesulphonic acid sodium salt solution), 0.1 mol dm^{-3} (200 cm^3)
- 250 cm^3 beaker
- 250 cm^3 conical flask
- 0–4.7 kΩ variable resistor
- 12 V d.c. supply (in 2 V steps)
- ammeter to read 30 mA
- razor blades or equivalent
- teat pipette
- propanone (20 cm^3)
- crocodile clips
- wires
- microscope slides
- multimeter
- 1.5 V light bulb and holder
- access to fume cupboard

propanone

pyrrole

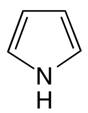
sodium 4-methylbenzenesulphonate solution

CARE Eye protection must be worn.



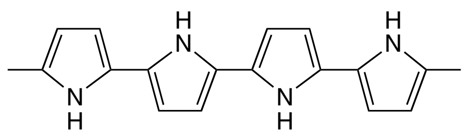
What is poly(pyrrole)?

The structure of pyrrole is:



It contains an unsaturated five-membered ring consisting of four carbon atoms and one nitrogen atom.

Poly(pyrrole) has this structure:



Part 1: Making poly(pyrrole)

1 The copper strip should be long enough to reach to the bottom of a 250 cm^3 beaker and also loop over the rim of the beaker at the top. This piece of copper will be one of your electrodes. Clean it with wire wool or emery cloth, and then rinse it with distilled water.

2 Use the flat end of a nickel spatula for the other electrode. Clean it with 'Brasso' (*not wire wool or emery cloth*). Rinse off the 'Brasso' with distilled water, then rinse the end of the spatula in propanone and dry it in the air.

3 Use a teat pipette to drip 0.34 g of pyrrole into a 250 cm^3 conical flask. (**CARE** Pyrrole is an irritant and has an unpleasant smell. Work in a fume cupboard and, if you spill any pyrrole on your hands, wash it off with lots of water.)

4 Add 100 cm^3 of 0.1 mol dm^{-3} sodium 4-methylbenzenesulphonate solution to the pyrrole. Carefully swirl the flask until the pyrrole has dissolved.

5 Pour the pyrrole solution into the 250 cm^3 beaker and set up the circuit illustrated in Figure 1.

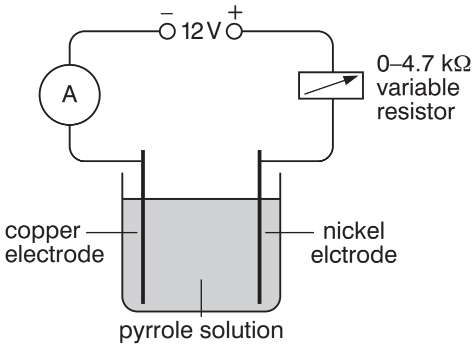


Figure 1 Making poly(pyrrole)

6 Start with the variable resistor at its maximum setting. Slowly increase the current by reducing the resistance until the ammeter reads 30 mA.

7 The nickel electrode should turn black within about 30 seconds. Bubbles of hydrogen will form at the copper electrode. Leave the experiment running for about 45 minutes in all.

8 Switch off the current and remove the nickel electrode. Wash it with water, then carefully peel off the poly(pyrrole) film. If you slide a razor blade between the film and the nickel you should be able to lift the intact film away from the electrode.

Keep the apparatus to use again in Part 3.

Part 2: Testing the conductivity of poly(pyrrole)

9 Support the polymer film on a microscope slide. It is best to fold the film in half and half again (four thicknesses). This reduces the chance of it burning out when a current is passed through it.

10 Use crocodile clips and wires to connect the polymer film into the circuit shown in Figure 2.

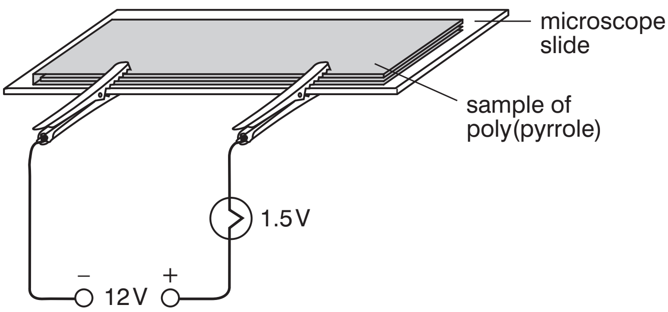


Figure 2 Testing the conductivity of poly(pyrrole)

11 First use the resistance setting on a multimeter to test whether the polymer has a measurable resistance. Then try to see whether you can make a 1.5 V bulb light with the poly(pyrrole) in the circuit. Do not put too high a voltage across the poly(pyrrole) or it may get hot and decompose. You should find that when the crocodile clips are about 1 cm apart the bulb will light at about 12 volts.

Part 3: Making a sample of poly(pyrrole) change colour

12 Using a clean nickel electrode, set up a fresh experiment to make poly(pyrrole). Start the experiment and watch it carefully. Switch it off as soon as the nickel electrode looks black. Take the electrode out of the electrolyte and examine its colour.

13 Put the coated nickel electrode back into the circuit. Reduce the voltage setting to 2 V and reverse the connections on the power supply so that the nickel strip becomes the negative electrode. Turn the power back on.

QUESTIONS

The poly(pyrrole) will gradually change colour. Take the electrode out of solution and examine its colour over a two-minute period.

a Is poly(pyrrole) as good a conductor as copper wire? How does the conductivity of poly(pyrrole) compare with polymers such as poly(ethene)?

b What colour is the poly(pyrrole) you made in the first experiment?

c Is it the same colour as the polymer film you made in step **12**?

d What colour was the poly(pyrrole) when it first came out of solution in step **13**?

e The poly(pyrrole) gains electrons at the negative electrode in step **13**. Has it been reduced or oxidised?

f Suggest why the poly(pyrrole) changes back to its original colour when it is exposed to air.

PR7

Check your notes on *The Polymer Revolution*

This activity helps you get your notes in order at the end of this unit.

Use this list as the basis of a summary of the unit by collecting together the related points and arranging them in groups. Check that your notes cover the points and are organised in appropriate ways. Remember that you will be coming back to many of the ideas in later units. In particular you will use many of the ideas about properties and structure in the **Designer Polymers** unit.

Most of the points are covered in **Chemical Ideas**, with supporting information in the **Storyline** or **Activities**. However, if the *main* source of information is the Storyline or an Activity, this is indicated.

- The historical development of addition polymers: discovery of poly(ethene) (**Storyline PR2**), different kinds of poly(ethene), Ziegler-Natta catalysts (**Storyline PR3**), conducting and light-emitting polymers (**Storyline PR6**) and dissolving polymers (**Storyline PR5**).
- Some examples of polymers discovered by accident (**Storyline** in general).
- Use of the terms: *polymer*, *repeating unit* and *monomer*.
- The meaning of the term: *addition polymerisation*.
- Predicting the structural formula of the addition polymer formed from given monomer(s), and vice versa.
- The use of systematic nomenclature to name alkenes.
- *Cis-trans* (geometric) isomers.
- The addition reactions of alkenes with the following: bromine, hydrogen bromide, hydrogen in the presence of a catalyst, and water in the presence of a catalyst.
- The meaning of the terms: *addition* and *electrophile*.
- The mechanism of the electrophilic addition reaction between bromine and alkenes.
- Whether a molecule is polar or non-polar is determined by its shape and the polarity of its bonds.
- Description and examples of the following types of intermolecular forces: instantaneous dipole–induced dipole attractions, permanent dipole–permanent dipole attractions and hydrogen bonding.
- The principal features of the molecular structure of water: bonding and shape of the water molecule and hydrogen bonding in water and ice.
- Explanation of the properties of addition polymers and other substances in terms of intermolecular attractions.
- The meaning of the terms: *thermoplastic*, *thermoset* and *co-polymer*.
- Crystallinity in polymers.
- The relationship between the properties of addition polymers and aspects of their molecular structure: chain length, side-groups, chain branching, chain flexibility, cross-linking and stereoregularity.
- The relationship of the properties of a dissolving polymer to its molecular structure (**Storyline PR5**).