Polymers in everyday things

Background information for teachers

Polymers are a part of everyday life and examples can be found almost anywhere. Many people think of polymers simply as plastics used for packaging, in household objects and for making fibres, but this is just the tip of the iceberg.

Areas in which polymers are important include:

1. Kitchen applications and food
2. Medical products for wound care, dentistry and in contact lenses
3. Sportswear and sporting materials
4. Protective equipment for work and leisure activities
5. Home and personal care products.

Further information on some of the uses of polymers in these areas is given below. Polymers are produced by addition reactions or condensation reactions.

1. Polymers and food

Polymers are used very widely in the production, distribution, packaging and preparation of food. some examples of such uses are listed below.

Farming:

- Sheeting to protect crops
- Encapsulation of seeds (gels and nutrients)
- Protective clothing for farm workers.

Distribution:

- Packaging in an inert atmosphere
- Vacuum packing
- Insulated packaging.

Retail:

- Carrier bags (now biodegradable)
- A variety of packaging types
- Display units.

In the kitchen:

- Storage (sealable containers, cling film, vacuum packing machines)
- Food preparation (plastic cutting boards, microwave-safe transparent containers, flexible utensils, cook-in-the-bag techniques).

In food

- Swelling of starch – perfect chips, roast potatoes, risotto.
- Denaturation of protein and connective tissue – cooking meat at low temperature.
- Thickening of soup using starch, gelatine (a heteropolymer of amino acids) or insulin (a non-digestible polysaccharide).

2. Polymers in medical products

Contact lenses

The material used in contact lenses was originally made by bulk free radical polymerisation, which was carried out very slowly to minimise stress. The polymer rods were then cut into buttons, which were shaped on a lathe to give the correct optical shape. Nowadays, cast moulding with UV initiation is the preferred technique. To extend the wearing time of contact lenses, researchers had to look at a long list of required properties:

- Mechanical properties
- Resistance to dehydration
- Fluid transport
- Recovery characteristics
- Transparency
- Wetability
- Resistance to lipid, protein and environmental debris
- Oxygen transmissibility (to let oxygen reach the cornea).

The polymers used in contact lenses are silicones and high water content materials.

Wound care
There are several types of polymer that give physical and biological protection (*ie* act as tissue sealants):

- Fibrin glue, which is naturally occurring and is formed by mixing fibrinogen and thrombin
- A cross-linked protein formed by mixing a natural protein (albumin) with a synthetic cross-linker, *eg* $PEG(SS)_2$ (PEG=polyethylene glycol)
- Cyanoacrylates – exact properties depend on the alkyl chain.

These materials are easily polymerised and form strong bonds to the tissue.
Transparent adhesive dressings consist of a polyurethane film plus a pressure-sensitive adhesive. The adhesive is normally an acrylate.

Dental polymers
The silver/mercury amalgam used for fillings in the past has been replaced by polymeric materials because of concerns about the poisonous nature of mercury vapour and because larger amounts of tooth have to be removed to provide a key for the amalgam.

Tooth enamel is hydroxyapatite. Dentine is 40% protein and 60% hydroxyapatite. Any material used to fill a tooth must be resistant to moisture, extremes of heat and cold, abrasion, mechanical stress, bacterial microflora and shrinkage stresses and must have an acceptable appearance. A resin composite that can be shaped and cured in situ is the most commonly used material.

The procedure involves first preparing the tooth by etching it with acid to remove debris. An adhesive is then applied and the solvent evaporated. Light is used to cure the adhesive then the filling paste is added and light cured. Finally, the filling is polished.

As well as the properties listed above, the mixture needs to be biocompatible, suitable for light curing but not too light sensitive, stable and easy to use. It must have a low heat of polymerisation and a long shelf life. The resins used are cross-linking methacrylate-based thermosets. However, they are not strong enough for use in fillings on their own so glass and other fillers are used to produce a composite.

An adhesive is used to bond the resin to the tooth, *eg* PENTA, which contains a phosphate group that chelates with the calcium ions in the tooth.

3. Polymers in sport

Sporting equipment often consists of many different types of polymer and can usefully be broken down into clothing and footwear, protective equipment, and games or event equipment.

Trainers (athletic footwear)

Almost all parts of a modern trainer rely on polymers, from the upper part of the shoe to the sole.
A trainer upper can contain polymers in the laces, foam padding and non-woven liner. Nylon™ is often used in the fabric and synthetic leather is also a polymer. The soles consist of an outer sole, a mid-sole, and a stability bar. The outer sole is rubber. Coloured soles are made of synthetic rubber, whilst black ones are the natural material. The mid-sole is designed to be energy absorbing. It consists of a foam made of open cell polyurethane with physical cross-linking that gives a porous flexible solid.

Protective equipment

Protective equipment for sports needs to contain both hard plates to spread the load of an impact (these are often polycarbonates or aramids, which are aromatic polyamides) and padding for fit and comfort (foams). Examples are helmets worn in cricket, baseball, American football and cycling.

Polymers in games or event equipment

Polymers have been used to improve performance in events such as the pole vault and in games like golf.

The pole vault

The rules for the pole vault state that the pole may be made of any material or combination of materials and may be any length or diameter. Over the years the material used has progressed from a rigid ash or hickory pole to bamboo to aluminium or steel to flexible fibreglass.

The pole is a substantial help to the vaulter as some simple physics shows. The kinetic energy of the vaulter if fully transferred to potential energy at the top of the vault can be expressed as 1/2 mv2 = mgh

So, if the vaulter is running at 10 m s–1, the maximum height she/he can reach is 5.1 m. However, Sergei Bubka's world record is 6.14 m! There has to be something in the technique (run-up, plant, swing, rock-back and clearing the bar) or in the pole that allows the extra height to be gained. In fact, when the pole is bent it stores elastic strain energy and this allows the extra height to be gained.

Golf balls

More than 1000 million golf balls are produced annually and the evolution of balls and clubs that have allowed improvements in performance. Originally golf balls were wooden or consisted of a feather ball in a leather case. In 1845 smooth balls made from 'gutta percha', a trans-1, 4-polyisoprene polymer, were introduced. In 1902 balls with a rubber thread core and a gutta percha cover were first made. Dimples were introduced to improve the aerodynamic qualities of the ball.
The development of Ziegler-Natta catalysts allowed a polymer of cis-1,4-polybutadiene to be produced and used in golf balls. The latest balls have polybutadiene cores and covers made of materials such as Surlyn®.

Carbon fibre in sport

Many natural materials are composites and have anisotropic properties. Such composites have enhanced properties that cannot be achieved with the individual component materials, such as an enhanced stiffness to weight or strength to weight ratio. Nowadays, carbon fibres can be bonded with epoxy resins to make synthetic composites that are used in fly-fishing rods, snowboards, high performance cycles (frame weight 1 kg), golf shafts, tennis racquets, windsurfing masts and safety cells for drivers of Formula 1 racing cars.

Carbon fibres are made by pyrolysing polymeric materials. Atactic polyacrylonitrite is dissolved in a solvent, extruded to give multifilaments and thermally stabilised at 200–300 °C to give a ladder polymer. This polymer is then heated to 1000 °C in an inert atmosphere, which removes the non-carbon elements and some nitrogen. In the polymer the intramolecular C≡N groups try to get as far apart as possible whilst the intermolecular cyanide groups interact.

The ladder polymer is a conjugated nitrile which, on heating eliminates N2, H2 and HCN as well as some aromatic fragments.

4. Polymers in protective equipment for work and leisure activities

Aramids

Many items of protective equipment are made from meta and para aramids. The meta compounds have the trade names Nomex® or Teijinconex® and the para compounds Kevlar® or Twaron®.
The aramids are stable because the bond dissociation energies of C-C and C-N bonds in aromatic systems are 20–30 % higher than those in aliphatic systems. The materials are polar, have high rigidity, crystalline and form large amounts of char when exposed to a flame.

Kevlar® consists of perfectly orientated chains in an extended configuration. It has a low density and high performance at low weight.

Useful properties of para-aramids	Useful properties of meta-aramids
Thermal stability	Thermal stability
Chemical stability	Chemical stability
Flame resistance	Flame resistance
Toughness	Dielectric properties
Damage tolerance	Intumescences (porous charring)
Dimensional stability	
Low creep	

Table 1 Comparison of aramid properties

Products could be formed as yarns, staple (a short fibre), floc (formed by the aggregation of a number of fine suspended particles), fabric, paper, pulp and composites.

The materials have a myriad of applications:

- Soft and hard ballistic protection
- Protective apparel
- Fibre optics, ropes and cables
- Composites
- Friction products, gaskets, hot gas filtration
- Electrical insulation, electronics
- Tyres.

For example, Kevlar® is used in:

- Bullet proof vests and helmets, although it would not stop a knife
- Store rooms for tornado protection – these are tested by firing pieces of wood at the Kevlar® surface.

Polymers in mountaineering

Mountaineering and hill walking would be much less pleasant and safe without modern polymers. Ropes are made from nylon and boots from high friction rubber.
Smooth solid rubber shoes are used for climbing. These work because as the shoe moves across the rock the sole is alternately compressed and allowed to expand so that it grips the surface.

Waterproof, breathable coats are made from nylon laminated with a polymer membrane. It is important that a coat keeps out the rain but it is much more comfortable if sweat can escape so an impermeable coat is not the best option.

Surface tension causes water to form beads. If the surface of the coat is rough and is comprised of peaks and troughs of a suitable size, these water droplets are too big to get into the troughs so they run off the coat. Many modern waterproof coats are covered in a layer of expanded PTFE membranes, which are very hydrophobic.

Behind this layer is a hydrophilic porous barrier layer made of polyurethane. The material formed by these layers is known as GORE-TEX®.

A new material called eVENT® is now also available. In this material, the polyurethane of GORE-TEX® is replaced by a perfluoroalkyl acrylic copolymer, which also coats the insides of the pores in PTFE membrane.

Polymers in everyday things

This set of activities illustrates some uses of polymers. Much of the material will be particularly useful for teachers of GCSE Applied Science specifications, in which the applications of materials feature prominently.

A large amount of chemistry background is given here for teachers' information only. It is not intended that students would need to know some of the details given.

The Polymers in everyday things activity set consists of three student worksheets:

- Polymers in everyday things – contact lenses

- Polymers in everyday things – dentistry
- Polymers in everyday things – mountaineering.

Each worksheet provides background information and a series of questions that guide students to relate the properties of materials to their uses in particular contexts. Students also compare the advantages and disadvantages of some synthetic materials with those of naturally occurring ones.

Notes on using the activities

The format of the activities is quite flexible and they can be used as a teaching aid when a teacher is present or as material for part of a cover lesson when a specialist teacher is not available. Students can use knowledge from previous lessons, reference books and internet searches (if web access is available) to help them answer the questions. To get the most out of **Polymers in everyday things – mountaineering**, internet access is advisable.

Each activity requires students to read the information provided on the worksheet and answer some associated questions. A number of suggested questions have been provided which teachers may use or adapt to suit the needs of their students. Once this written exercise has been completed, it is advisable to organise a follow-up class or group discussion about the information on the worksheet and students' answers to the questions. This will help ensure students have fully understood the material and will allow them to express their opinions about what they had read.

You may also wish to set students the task of further investigating some aspect of the topic using reference books and/or the internet. The information they gather could be used to produce a poster or presentation, for example.

If students are to use the internet at any stage of these activities, be aware of the following points:

- Contact lenses – entering 'polymers in contact lenses' into a search engine such as Google produces a selection of websites with relevant information;

http://www.contactlenscouncil.org/scon-history.htm shows a time line of the history of contact lenses; **http://www.contactlenses.org/whatare.htm** provides useful information about gas-permeable lenses (both sites accessed January 2006).

- Dentistry – a search for 'dental polymers' with the Google search engine gives websites that are a bit difficult for the target group; the search term 'teeth fillings' gives hits of general interest, whereas 'materials in tooth fillings' gives websites more specifically relevant to the topic discussed here. You may wish to check the search results given by whichever search engine you favour before asking students to use the internet.
- Mountaineering – internet searches should be used with caution: the top hits produced by a search for 'clothing', for example, are usually commercial sites with little science interest; the search term 'moderate protection' is likely to give some inappropriate sites on more exotic clothing. The worksheet directs students to two websites to help them answer particular questions. If access to the internet is difficult, you may wish to provide alternative sources of information or to print out selected material from the suggested websites before the lesson.

Answers to suggested questions

Polymers in everyday things – contact lenses

1. Cosmetic/cultural reasons (*eg* appearance) / convenience (*eg* sports people).
2. Preference (*eg* may not want to have to put contact lenses onto eye) / some contact lenses need to be kept moist/dry out and this could cause inconvenience.
3. Transparent / can refract light / rigid / can be made to the correct shape.
4. Glass could shatter/break.
5. Artificial polymers had not been discovered.
6. If something is transparent it allows light rays to pass through it so that objects behind it can be clearly seen.
7. So that it does not tend to fall off the eye / comfort.

7b. So that any chemicals on the surface of the eye do not react with the material in the lens (which may eventually degrade it).

7c. Cost reasons / so that it is affordable to those who need them.

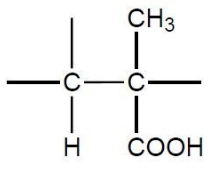
8. Methylmethacrylate
9. PMMA was not very comfortable for users of contact lenses made from PMMA. There were problems such as oxygen not passing through to the cornea and the need to use wetting solutions. These are not problems when it comes to using PMMA for aquariums where the durability of the material and its clarity are most useful properties.
10. Because polyacrylamide is hydrophilic / accept 'much of the lens is water'.
11. After cross-linking the polymer absorbs water.
12. Comfort / there is no need to use a wetting solution (as the water is already there in the lens).
13. Hard (lenses)
14. Fluorine
15. Silicon
16.

	Advantages	Disadvantages
Soft lenses	Soft and flexible Material is hydrophilic No need for wetting Cheaper than other types Can use some types for just one day and discard	Fragile clarity of vision may be affected
Hard lenses (PMMA)	Good clarity of vision Very durable	Not very comfortable Need to use a wetting solution on eyes Takes some time to get used to them Do not allow oxygen to get to the surface of the eye.
Rigid gas-permeable lenses	More comfortable Oxygen can pass through to eye surface (cornea) Quickly get used to wearing them Good rigidity/clearer vision Good for astigmatism or bifocal needs	High cost Some inflexibility

17. Almost any answers are possible here. If the answers are to focus on polymers then any of the suggestions made in this teachers' sheet are applicable. The main idea is to emphasise that scientists continue to try to find materials to improve the quality of people's lives.

Polymers in everyday things – dentistry

1. Calcium, phosphorus, oxygen, hydrogen.
2. 22
3. Calcium
4. Carbon
5. pH 8 is only very slightly alkaline but pH 0.5 is very acidic.
6. It is still possible to chew but the gum does not now put sugar around your teeth which would cause plaque.
7. Eat less of the foods that causes plaque to form, brush teeth regularly.
8. Mercury, silver, copper and zinc.
9. Cosmetic reasons (to avoid seeing the grey filling on the back teeth) / back teeth do more chewing and the mercury amalgam filling is strong and wear resistant.
10. The best answers will refer to environmental problems associated with disposal.
11. Objectivity/the need to have other scientists (who are not connected with the original work) check the results / to avoid anyone just putting out there own thoughts without thorough scrutiny.
12. If dentists remove fillings then there is mercury vapour about, although this is at an acceptable level for the patient (who just breathes it as it is removed), the dentist may have to do this several times a day.
13. Some method of extracting vapour / good ventilation in room.
14. Mark as a level of response answer. Science discovered the use for mercury amalgam in fillings for teeth. It has helped millions of people. As possible issues about its safety arise, scientists can carry out research to pin down whether there is a substantial danger or not. They can decide levels of acceptable safety. This can only be done by detailed research where results can be duplicated and supported by others. Meanwhile scientists carry out more research to find materials with better properties still and which carry even less risk.
15. Cosmetic reasons
16. Composite materials exploit the advantages of each material from which it is composed without suffering the weaknesses of these materials.
17. It is a harmful substance, avoid swallowing, breathing in or skin contact.
18. $C_4H_6O_2$
19.



20. The resin would set with background light before the composite is added.
21. Resin has shrunk and allowed a small gap to form, this has been exploited by bacteria allowing dental decay (caries) to form, when the caries reaches the dentin the person will feel pain and know there is a problem.
22. Best advice is to use a white composite filling. Explain that it is less durable than mercury amalgam but that it will not suffer too much mechanical stress. Its appearance will be much better in such a prominent place in the mouth. Also it is only a small filling and so it is OK to use composite. Its colour can be matched to the tooth it is in. It does not contain mercury. However it may cost more than mercury

amalgam and could wear out faster. [These are some of the key ideas; there could be others.]

23. The best advice is to probably have a mercury amalgam filling. The teeth at the back of the mouth suffer very large mechanical stresses as they chew food. Mercury amalgam is very durable unlike composite fillings. The silvery colour of the amalgam should not be a cosmetic problem as they teeth are at the back of the mouth. It is a large filling and composite material is not so suitable. Although they contain mercury, safety guidelines show that the level of risk is acceptable. [These are some of the key ideas; there could be others.]

24. Phosphate

25. Attractive in appearance

26. Release of fluoride ions will help other teeth in child's mouth / although filling won't last a long time, neither will the child's milk teeth / it gives a good seal to rest of tooth.

27. The glass ionomer filling gives a good seal to the existing tooth, the composite can the give a good colour match to the filling at the surface.

28.

Advantages of glass ionomer fillings compared to composite fillings	Disadvantages of glass ionomer fillings compared to composite fillings
Interacts with the enamel and dentin of existing tooth forming an excellent (chemical and biological) seal with the tooth	Poorer colour match to existing tooth
The fluoride ions that are part of the filling are slowly released and since these are next to the teeth they react with the tooth enamel further strengthening the teeth	They are weaker under normal chewing forces.

Polymers in everyday things – mountaineering

animal skins	fibres from plants	wool	silk
10 000	8000	6000	3000

number of years ago

1.

Examples of plants used to make clothing	Examples of animals used to make clothing
Hemp	Sheep (for wool)
Nettles	Cows (for hide)
Flax	Pigs (for hide)
Cotton	Silk worms

2.

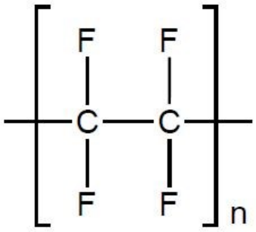
3. a. Colder climates in far north or far south of the hemispheres.
   b. Hotter climates (tropical or equatorial).
   c. It hadn't been discovered.

4.

	Polyester	Nylon
Year when first used	1942	1935
What it is used for now	Clothing and handles	Used to make bearings, blow mouldings, and clothing fabric.
Useful properties	It has excellent dimensional stability, high dielectric strength, and good toughness. It has moderate chemical resistance, low resistance to strong acids and bases, is notch sensitive, and is not recommended for outdoor use or in hot water. Copyright © 2006 eFunda	It has high lubricity and moderate strength. It is tough, inexpensive, and has poor dimensional stability due to water absorption (hygroscopic nature). Copyright © 2006 eFunda

This excellent site would allow teachers to ask many more questions of this nature. Time lines would also be possible.

5. Thermosetting: a plastic that can be moulded into shape during manufacture but which sets permanently rigid on further heating (due to cross links forming which cannot be reversed). Thermoplastic: a plastic that can be repeatedly softened on heating and then will harden on cooling (no cross links form).
6. More continuous movement created more sweat (which then condensed).
7. Water vapour particles are much smaller.
8. Monomer
9. Alkenes

10.


11. It must be stretched.
12. It could crack if repeatedly bent in the same place / fires could cause it to melt.
13. PTFE has holes in it that are big enough to allow water vapour to pass through, but small enough to prevent liquid water passing through / the PTFE itself is quite fragile and so it is joined to layers of other stronger, more durable fabrics.
14. It helps the Gore-Tex® resist contamination by body oils. If this were not done, the oils could prevent the Gore-Tex® fabric from breathing properly.
15. From the home page click on ‘what is it’. In the article that follows click on ‘dry venting’ TM and ‘dry system’ TM.

Polymers in everyday things – contact lenses

(Background information)

Polymers are a part of everyday life and examples can be found almost anywhere. Many people think of polymers simply as plastics used for packaging, in household objects and for making fibres, but this is just the tip of the iceberg.
Polymers are used in all sorts of applications you might not have thought much about before, for example in modern contact lenses.

What is a contact lens?

A contact lens is a prescription medical device manufactured from high-grade plastic polymers.
The contact lens rests on the front surface of the eye (the cornea) and works just like eyeglasses – it bends light rays so that images are properly focused on the retina (at the back of the eye).
Contact lenses can be worn by people with eye disorders as an alternative to glasses.

The history of contact lenses

The first contact lenses were made from glass shells filled with jelly. Early contact lenses were uncomfortable and often very unhealthy for the eye. Until 1930 there was no alternative to using glass for making contact lenses – no other suitable material was available.
In the 1930s suitable polymers were discovered and by 1950 the first polymer contact lenses were being made.
Research into new types of polymers has now provided three types of material that can be used to make different kinds of contact lenses. These are called hard (created in the early 1960s), soft (created in the early 1970s) and gas-permeable (created in the late 1970s) lenses.

What properties are desirable in polymers for contact lenses?

Polymers are the most suitable materials available now for contact lenses to be made from.

The properties of an ideal polymer for contact lenses include:

- Transparent
- Some flexibility
- Low density
- Tough
- Unreactive to chemicals on the eye surface
- Easy to manufacture
- Made from a raw material that is available in abundance
- Easy to mould
- Refractive index suitable for bending light rays
- Hydrophilic (‘water-loving’)
- Lets oxygen gas pass through to the eye surface
- Produces lenses that are easy to insert, remove, clean and store.
- Scientists first developed materials that had some of these properties. Continual research work produced polymers that were more and more suited to the application.

What polymers are used to make contact lenses?

The first polymer contact lenses became commonly available in the early 1960s and were made from a polymer called poly(methylmethacrylate) (PMMA). Lenses made of PMMA are called hard lenses.

PMMA is still used in Plexiglas® and Lucite®, as well as for things like aquariums and ice hockey rink barriers.

PMMA lenses are hard, rigid and not very comfortable; it sometimes takes users many weeks to get used to them. The lenses do not allow oxygen to pass directly to the cornea, which can be damaging to the eye. Users have to put a wetting solution in their eyes before putting the lenses in. Hard lenses are not very popular anymore, even though they give good clarity of vision and are very durable – they can last for years.

The first soft contact lenses were introduced in 1971. These were made from a polymer called polyacrylamide. This polymer is different from PMMA because it contains nitrogen atoms in its structure (PMMA does not contain nitrogen). Polyacrylamide is similar to the polymers used to make acrylic fibres for fabrics. When the polyacrylamide chains are cross-linked, the material absorbs water. Substances such as this are called hydrophilic ('water-loving').

This property makes polyacrylamide a useful material for producing contact lenses. Between 38% and 79% of a soft contact lens is water. This water keeps the lens soft and flexible. However, the high water content also makes the lens more fragile and reduces clarity of vision. Soft lenses are cheaper than hard lenses and this has added to their popularity. In fact, some soft lenses can be used for one day and then discarded.

In 1979, the first rigid gas-permeable lenses (also known as RGPs) became available. These lenses are made from a combination of PMMA, silicones and fluoropolymers. This combination allows oxygen to pass directly through the lens to the eye, which makes the lens more comfortable for the wearer. It may only take three hours to get used to wearing this kind of lens. The rigidity of RGPs can also make vision clearer than with soft lenses. RGPs are better suited to correcting astigmatism and for bifocal needs than the other kinds of lenses. The disadvantages of RGPS include their high cost and some inflexibility in the lens.

The future of contact lenses

People are now starting to buy contact lenses for fun, choosing coloured or designer contact lenses. As contact lenses become more popular, the companies that make them will be able to spend more money on research into the different types of materials that could be used to make better or cheaper lenses in the future.

Polymers in everyday things – contact lenses

1. Suggest why people may wish to wear contact lenses instead of glasses.
2. Suggest why some people who wear glasses do not wish to wear contact lenses.
3. Write down two properties of glass that made it suitable for use in the contact lenses made before 1950.
4. Suggest why research scientists looked for alternative materials to glass for use in contact lenses.
5. Why could polymers not be used in contact lenses before 1930?
6. Explain the meaning of the word ‘transparent.’
7. Suggest why the ideal material for a contact lens should:
    a. Have a low density
    b. Be unreactive
    c. Be easy to manufacture.
8. What is the name of the monomer that polymerises to form poly(methylmethacrylate)?
9. PMMA is still used for aquariums but not in contact lenses. Explain these facts.
10. Users of PMMA contact lenses had to apply a wetting solution to their eyes before putting the lenses in. Why is this not necessary with polyacrylamide lenses?
11. How does cross-linking affect the properties of polyacrylamide?
12. Why is the absorption of water by the material used to make contact lenses an advantage for the users of the lenses?
13. What type of contact lens is made from PMMA only?
14. What halogen element is found in fluoropolymers?
15. Which element of Group 4 of the Periodic Table is found in silicones?
16. Each of the three types of polymer used in contact lenses has advantages and disadvantages.
    Copy and complete the table below to summarise these strengths and weaknesses. Give as many points as you can for each kind of lens.

	Advantages	**Disadvantages**
Soft lenses (polyacrylamide)		
Hard lenses (PMMA)		
Rigid gas-permeable lenses		

17. Continued research into materials by chemists and materials scientists is important. Name two other areas, in addition to contact lenses, where this is important.

Polymers in everyday things – dentistry

(Background information)

Polymers are a part of everyday life and examples can be found almost anywhere. Many people think of polymers simply as plastics used for packaging, in household objects and for making fibres, but this is just the tip of the iceberg.
Polymers are used in all sorts of applications you might not have thought much about before. Polymers and composites (materials made by combining two or more materials) are vital to modern dentistry, for example.

Teeth

Bones and teeth, the hard tissues in the human body, are made partly of organic and partly of inorganic material. The inorganic component mainly consists of a substance called hydroxyapatite.
The simplest formula of hydroxyapatite is $Ca_5(PO_4)_3(OH)$.
The outer layer of your teeth is the hardest material in your body and is called enamel.

Enamel

consists of approximately 92% hydroxyapatite. Enamel is a ceramic material.
Beneath the enamel, the bulk of a tooth is made of dentin. This is a composite material and contains a mixture of hydroxyapatite, collagen, water, and salts. Collagen is an organic substance.
Teeth function in one of the most inhospitable environments in the human body. They are subject to larger temperature variations than most other body parts and can cope with exposure to ice at 0 °C and to hot tea and coffee. Teeth also encounter pH changes in the range 0.5 to 8, as well as large mechanical stresses during chewing.

Tooth decay, called caries, occurs when teeth are frequently exposed to foods containing carbohydrates (starches and sugars). These foods include milk, some soft drinks, ice cream, cakes and even some fruits, vegetables and juices. Bacteria that live in the mouth form plaque. Plaque is a film on the teeth where bacteria reproduce. The plaque interacts with deposits left on your teeth from sugary and starchy foods to produce acids. Over time, these acids damage tooth enamel because they dissolve the hydroxyapatite present in your teeth. The acids formed by plaque can be partly counteracted by saliva in your mouth.

The acids in plaque can eventually dissolve the enamel surface of the tooth and create holes (cavities) in the tooth. Cavities are usually painless until they grow very large and destroy the nerve and blood vessels inside the tooth. It is important that any holes that form in our teeth are filled as soon as possible.

Fillings

Amalgam fillings

When we visit the dentist for a filling, he or she may use a material that looks like a silvery metal to fill up the tooth cavity. This filling material is often called ‘amalgam’. Dental amalgam is an alloy of mercury (50%), silver (30%), tin, copper and zinc. It is made by dissolving the solid metals in the liquid mercury. Amalgam has been used to fill teeth for about 160 years.
The table shows some of the advantages and disadvantages of amalgam fillings.

Advantages	Disadvantages
Reasonably priced and cost effective	Silver colour is no longer considered aesthetically acceptable (it is thought to look unpleasant)
Strong, resistant to wear and durable	Does not stick to the tooth, which means the dentist has to make a large undercut cavity to keep the filling in place
Dependable	Conducts heat too well, which results in some people with amalgam fillings experiencing pain when they eat hot or cold foods
Least time consuming kind of filling for a dentist to perform	Contains mercury (mercury compounds are poisonous)
Average lifetime of amalgam fillings is about 15 years	Getting rid of millions of potentially environmentally hazardous old fillings is a substantial disposal problem
Used for more than a century with good results	

Dental amalgam and the 'mercury issue'

In 1995 a news programme ran a story about dental amalgam. A researcher claimed that amalgam is poisonous because of its mercury content and is responsible for most of the diseases that have not yet been cured by medical science. Many people who watched this programme were appalled and contacted their dentists immediately to have their amalgam fillings removed, or even to have their teeth extracted!

When other scientists looked at the evidence they discovered that the research was poorly done.
The results were misinterpreted and often contradictory.
Scientists have evidence that the mercury metal used in amalgam fillings is very inactive.

The American Food and Drug Administration has concluded that amalgam causes no demonstrated clinical harm to patients if it is properly placed and that removing existing amalgam fillings will not prevent ill health or reverse the effects of existing diseases. The use of amalgam is still strongly supported by the American Dental Association.

It is certainly not disputed that mercury is a poison if it enters the body in large quantities. Although the mercury in amalgam fillings is bound to the other metals in the amalgam, it can be freed during chewing or when the teeth are brushed. When this happens, the mercury is released from the filling as a vapour. Mercury vapour is also present when amalgam fillings are placed into and removed from teeth. To remove a filling, the dentist has to drill into it. The friction between the drill and the amalgam can vaporise some of the mercury in the filling. It is thought that the amount of mercury vapour that enters the body by inhalation during this process is small enough to be safe.

New research is being carried out to investigate the relationship between amalgam fillings and some diseases, such as multiple sclerosis and Alzheimer's disease. No link has yet

been proven. The UK Department of Health and the US and Canadian authorities generally favour the continued use of amalgam fillings on the basis of current scientific advice.
The Department of Health advises that pregnant women avoid having amalgam fillings put in or removed as a precautionary measure. This is because mercury has been shown to cross the placenta from mother to unborn baby.

White fillings

White fillings are routinely used on front teeth and are increasingly being used on back teeth. There are two main types of white filling materials currently used by dentists: composite fillings and glass ionomer cements.

Composite fillings

Composites used for filling teeth are generally made of silica or glass particles bound with a polymer resin. The polymers that are used as the resin in composites for fillings are based on a monomer called methacrylic acid.
The polymer resin is usually filled with between 35 to 85% glass filler.
The procedure used to place a composite filling in a tooth involves several steps. First, the tooth must be prepared. It is etched with acid to remove debris and an adhesive is applied. The solvent in the adhesive is then evaporated.
Next, the cavity is filled with a layer of composite. This layer is hardened by shining a light on it – a process called photocuring. The light causes the monomer molecules to react with one another and link together to form a solid resin.
The resin shrinks a little during polymerisation so several successive composite layers are added and photocured. Photocuring is useful because it allows the dentist time to work with the material, building and shaping it correctly before it is exposed to light. When the dentist is ready, the filling can be hardened immediately by shining light on it. Finally, the filling is polished.
Composite fillings have advantages and disadvantages. The table below summarises these.

Advantages	Disadvantages
Colour and texture can be matched to the patient's teeth by the addition of different fillers	Less durable than amalgam and not strong enough to withstand the chewing forces in the back of the mouth
May be used to change tooth colour, shape and size to improve the smile.	Subject to shrinkage and loosening when the material sets, which leads to formation of a small gap between the tooth and filling
Does not contain mercury	Cannot be used for large fillings
Very useful for front teeth and small holes in the back teeth where the biting load is not too great and appearance is crucial	Wears out faster than amalgam
Less tooth has to be removed to provide a key for the filling than is necessary with amalgam fillings	If the coating is too thick, the polymer may separate from the tooth surface during the setting process, which weakens the bond between the filling and the tooth
	The acid-etching technique removes minerals from the dentin in the tooth and can weaken it
	Dental caries and composite fillings have poor X-ray contrast with their surroundings, which makes it hard for the dentist to identify new areas of decay
	Filling a tooth using composites is a more precise procedure and takes longer to perform than inserting an amalgam filling; composite fillings may therefore cost more

Glass ionomer fillings

Glass ionomer fillings are similar to composite fillings because they also use a polymer resin. However, the filling material contains strontium, phosphate and fluoride ions. The big advantage of this filling material is that it interacts with the enamel and dentin in the tooth and forms an excellent seal between the filling and the tooth. A true biological and chemical link is formed with the tooth and this reduces the sensitivity of the filled tooth.

Another advantage of glass ionomers is that the fluoride ions from the filling material are continually released by reaction with saliva. These fluoride ions are next to the teeth and can react with the enamel. This helps strengthen the teeth and prevent further decay. The disadvantages of glass ionomer materials are that they are not as aesthetic as composites, and they are weak under normal chewing forces.

Polymers in everyday things – dentistry

1. Write down the names of the elements in hydroxyapatite.

2. How many atoms in total make up the simplest formula of hydroxyapatite?

3. Write down the name of the metal element in hydroxyapatite.

4. What element must be present in collagen if it is ‘organic’?

5. How does the information above show that teeth are more likely to encounter strong acids than strong alkalis?

6. Dentists often recommend chewing sugarless gum. Suggest why.

7. Suggest two other ways to help prevent caries.

8. Which of the metals in amalgam are called ‘transition metals’?

9. Nowadays amalgam is only used on teeth at the back the mouth. Suggest why.

10. The European Economic Union has passed legislation to phase out the use of amalgam for fillings. Suggest why.

11. It is important that all scientific research is checked carefully by scientists outside the group who did the research before any results are published. Explain why

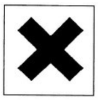
12. Suggest why dentists may be more prone to the effects of mercury than their patients.

13. It is suggested dentists wear gloves to avoid skin contact with mercury. Suggest one other precaution they could take.

14. Explain why scientific research is important. Use the 'mercury issue' as an example.
15. The use of white fillings for front teeth is very popular. Why?

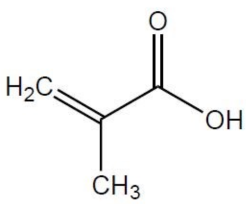
16. What is the advantage of using a composite material rather than any one of the substances from which it is made?

17. This symbol appears on bottles of methacrylic acid:



What precautions should be taken when using this substance?

18. The structure of methacrylic acid is shown below.

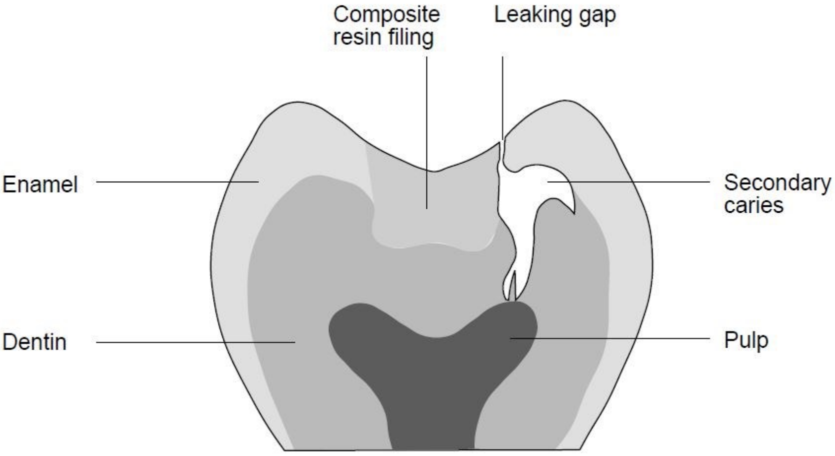


Write down the simplest formula for methacrylic acid.

19. Draw the repeat unit of PMAA poly(methacrylic acid).

20. It is important that the resin is not too sensitive to light. Suggest why.

21. Look at the diagram below. Explain what has happened to the tooth.



22. You have to advise someone about the best type of filling for a small cavity on a canine tooth. This is the third tooth along from the centre of the teeth. What advice would you give? Explain your choice.

23. You have to advise someone about the best type of filling for a large cavity on a molar tooth. This is a large tooth at the back of the mouth. What advice would you give? Explain your choice.

24. Find the formula for tooth enamel. Which of the ions in glass ionomers is also in tooth enamel? (The presence of this ion is what helps the glass ionomer bond so well to the tooth.)

25. What is meant by the term ‘aesthetic’?

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26. Dentists often use glass ionomer fillings in the ‘milk teeth’ of young children. Suggest two reasons why.

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27. Some dentists put a layer of glass ionomer in fillings and then place composite material on top of it. Suggest why.

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28. Complete the table below to summarise the advantages and disadvantages of glass ionomer fillings compared to composite fillings.

Advantages of glass ionomer fillings compared to composite fillings	**Disadvantages of glass ionomer fillings compared to composite fillings**

Polymers in everyday things –mountaineering

(Background information)

Mountaineering and hill walking would be a much less pleasant and safe experience without modern polymers. Waterproof and breathable coats are made from nylon laminated with a polymer membrane. The polymers in this membrane are called polytetrafluoroethene (PTFE) and polyurethane. Climbing ropes are made from nylon and boots from high friction rubber – both of these materials are polymers.

Clothing for the cold and wet

The development of new materials for use as coverings has played a major role in the history of all clothing. Until about 10 000 years ago, people used only animal skins. The next development was about 8000 years ago, when humans learned to obtain fibres from wild plants such as wild flax, hemp and nettles. These fibres could be spun into thread and made into cloth textiles. The development of agriculture led to the domestication of fibre plants like cotton, hemp and flax.

Wool was probably the first animal fibre to be made into cloth. People began to raise sheep for wool about 6000 years ago. Different kinds of wool, as well as mixtures of wool with other fibres, were used to create tightly woven fabrics with smooth surfaces or more loosely woven fabrics with rougher surfaces.

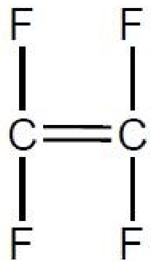
By about 3000 BC people in China had begun to use silk thread. They had domesticated silkworms, which they fed on mulberry leaves. The fresh cocoons of these worms could be unwound to produce long strands of silk fibre. This fibre was spun into thread, and the thread was woven into cloth. The first widespread use of cotton from cotton plants was in ancient India around 3000 BC. This material was light and could be dyed and printed by hand using wood blocks with patterns cut into them.

Synthetic materials, produced from substances made by scientists rather than from plant fibres or animal hair, provided substitutes for natural fabrics in the 20th Century. Synthetic materials are often superior to natural fibres in their strength and durability. They also have the advantage of being lightweight. Rayon and nylon were developed as synthetic substitutes for silk. Polyester was introduced into clothing in the early 1950s and could be blended with rayon or cotton for use in so-called ‘wash-and-wear’ fabrics that need little or no ironing.

Synthetic fibres fell out of favour in the late 1960s and 1970s because clothing made of these materials was found to be less comfortable than clothes made of natural fibres. However, new kinds of polyester have been developed that are more durable and have a softer, more natural feel. These synthetic materials became increasingly popular in the late 20th century. Nylon is called a ‘thermosetting polycondensate’ polymer. Nylon was used in outdoor clothing in the past because it is tough, lightweight and keeps water out. It also keeps out UV light. However, it does not let any water pass through and this means that water vapour from sweat condenses on the inside of the material, which makes it wet even if no water gets in from the outside.

In recent years Gore-Tex® linings have totally changed the comfort properties of outdoor clothing. Gore-Tex® is a thin, porous membrane that is bonded to fabrics like nylon and polyester to make them both waterproof and breathable. This has dramatically improved the ability of outdoor garments for active people to cope with perspiration wetness and the discomfort it causes. The Gore-Tex® lining is full of very small holes called pores: there are 1.4 billion pores per square cm of material. These pores are too small for water droplets to pass through, so rain and snow stay on the outside of the garment. However, the pores are large enough for molecules of water vapour to pass through, which means the fabric is 'breathable' because water vapour from sweat can escape.

Gore-Tex® liners are made from the polymer PTFE, which is also known as TEFLON® and was discovered by Roy Plunkett in 1938. (Refer to RSC publication, Chemists in a Social and Historical context.) PTFE is made by polymerising tetrafluoroethene.



In 1969 Bob Gore discovered that PTFE could be stretched to form a strong, porous material called expanded PTFE (ePTFE). It is this stretching that puts the tiny holes into the material. ePTFE is now used in various forms for several different applications, including outdoor clothing. The first waterproof, breathable ePTFE fabric was introduced in 1976 under the name Gore-Tex®.

One problem with the ePTFE Gore-Tex® layer is that it is too fragile to be used by itself. Instead, it must be combined with other stronger, more durable fabrics to make it useful to active people outdoors. Modern Gore-Tex® outdoor wear is usually made of two or more separate layers bonded or sewn together. The best option for people who use Gore-Tex® a lot is a high quality Gore-Tex® fabric with a 'three-ply' construction.

This three-ply fabric is usually made by bonding the Gore-Tex® (ePTFE) layer to a nylon layer one side and to another material on the other side. The ePTFE is then sandwiched in the middle of a three layer laminate (three-ply) construction. The third layer is usually a light, open weave material chosen to keep weight down and maximise vapour transmission.
The Gore-Tex® film is also impregnated with an oil-repelling (oleophobic) compound that helps it resist contamination by body oils. If this were not done, the oils could prevent the Gore-Tex® fabric from breathing properly.

One problem that has to be overcome in making Gore-Tex® clothing is that the holes made by stitching are bigger than the micropores in the Gore-Tex® layer. These stitching holes need to be sealed. The ePTFE film layer can crack if it is repeatedly flexed in the same spot, or wear through as a result of rubbing (abrasion) in areas of high wear. Seam sealer applied to noticeable abraded areas will slow or stop leaks.

Campfire sparks would quickly melt large holes all the way through a PTFE laminate.

Polymers in everyday things – mountaineering

1. Construct a time line to show the development of clothing material.

2. Complete the table shown below

Examples of plants used to make clothing	Examples of animals used to make clothing

3. Different materials are used for clothing in different countries around the world. Some textiles are better suited to a particular climate than others.
   a. Suggest where wool is most useful.
   b. Suggest where thin woven cotton is most useful.
   c. Nylon was not used in 3000 BC. Why?

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4. Look at the website at http://www.efunda.com/materials/polymers/history/history.cfm?list_order=time (accessed January 2006). Find the polymers polyester and nylon on the website and

use the information provided to help you complete your own copy of the table.

	Polyester	Nylon
Year when first used		
What it is used for now		
Useful properties		

5. Find out the difference between thermosetting and thermoplastic type polymers. You could use the internet or look in books. If you use the internet, type ‘thermosetting and thermoplastic polymers’ into your search engine.

Thermosetting	Thermoplastic

6. The formation of condensation inside nylon clothing was more of a problem for a mountaineer than for a fisherman sitting on a riverbank. Suggest why

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7. What does the formation of condensation suggest about the size of a particle of water vapour and the size of a droplet of water from rain?

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8. What word describes the small molecules, such as tetrafluoroethene, that combine to make polymers?

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9. What name is given to the group of compounds that contain carbon to carbon double bonds?

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10. Write down the formula of the polytetrafluoroethene molecule made when n molecules of tetrafluoroethene combine.

11. What must be done to PTFE to change it into a material with very small holes?

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12. Write down two ways that a Gore-Tex® outdoor jacket could be damaged in use.

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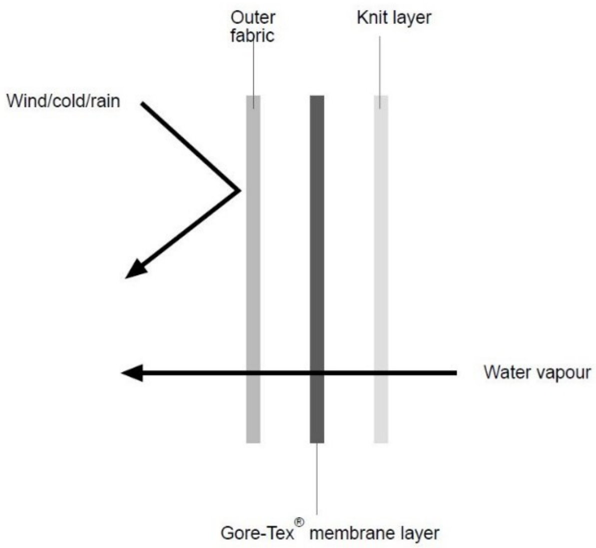
13. Explain how Gore-Tex® linings work. Use the diagram below to help you with your answer. Include an explanation of why there are three layers in the fabric.



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