INVESTIGATING THE EFFECT OF CONCENTRATION ON THE RATE OF A CHEMICAL REACTION

Introduction

The rates of chemical reactions depend on a number of factors, including the concentrations of reactants used. It is not easy to design experiments to measure the effect of concentration on the rate of a polymerisation reaction, such as the production of poly(ethene); therefore the reaction studied in this investigation is that of the decomposition of hydrogen peroxide in solution to produce water and oxygen.

$$2H_2O_2 \rightarrow 2H_2O + O_2$$

Because oxygen is a gas, the rate at which it is given off can be used as a measure of the reaction rate.

The decomposition of hydrogen peroxide is much quicker when a suitable catalyst is used. A number of substances will behave as catalysts. In this activity the compound manganese(IV) oxide is used.

What you need

'10 volume' hydrogen peroxide solution (100 cm^3)
potassium manganate(VII) solution (approximately 2 g in 100 cm^3 of water)
250 cm^3 beaker
25 cm^3 measuring cylinder
10 cm^3 measuring cylinder
250 cm^3 conical flask fitted with rubber bung and right angled delivery tube
100 cm^3 gas syringe with rubber tubing connection to delivery tube
filter paper disks, 7 cm diameter
paper towels
glass rod
tweezers or forceps
stopclock
retort stand and clamp
access to balance
eye protection

CAUTION Eye protection must be worn.

Potassium manganate(VII) solid is oxidising; do not spill any of the crystals if you use the solid.

Potassium manganate(VII) solution strongly stains skin and clothing.

Hydrogen peroxide solution can be hazardous; handle with care.

Manganese(IV) oxide, which is made during this investigation, is harmful; do not handle it with your fingers.

Note The concentration of a solution of hydrogen peroxide is usually measured in terms of its 'volume' rating. Hydrogen peroxide decomposes to produce oxygen, and the 'volume' rating shows how many times greater the volume of oxygen is than the volume of hydrogen peroxide solution which produced it. Therefore, for example, 10 cm^3 of '20 volume' hydrogen peroxide solution produces 200 cm^3 of oxygen. In this activity the solutions are chosen so that they will all eventually produce the same volume of oxygen.

What you do

Read through all the steps in these instructions and make sure you understand them before beginning the investigation.

1. The first step is to prepare some samples of manganese(IV) oxide catalyst. In this activity it is used in the form of fine powder impregnated into disks of filter paper. Manganese(IV) oxide is made by soaking into the filter paper a solution of another manganese compound, potassium manganate(VII), and allowing it to decompose in air into manganese(IV) oxide.

   Place about 10 cm^3 of potassium manganate(VII) solution into a 250 cm^3 beaker.

   CAUTION. Potassium manganate(VII) solution strongly stains skin and clothing.

   Using forceps or tweezers, dip a 7 cm diameter disk of filter paper into the potassium manganate(VII) solution so that the purple coloured liquid soaks into the paper. Remove the filter paper disk, using tweezers, and place it on a pad of paper towels to soak up any spare solution.

2. Repeat step 1 until about 8 disks of filter paper, soaked with potassium manganate(VII) solution, have been prepared. Leave the disks until they are dry and have changed colour from the purple of potassium manganate(VII) to the brown colour of manganese(IV) oxide. This will take several hours.

3. Set up the apparatus for the investigation as shown in Figure 1, but without the filter paper disk or hydrogen peroxide solution at this stage.

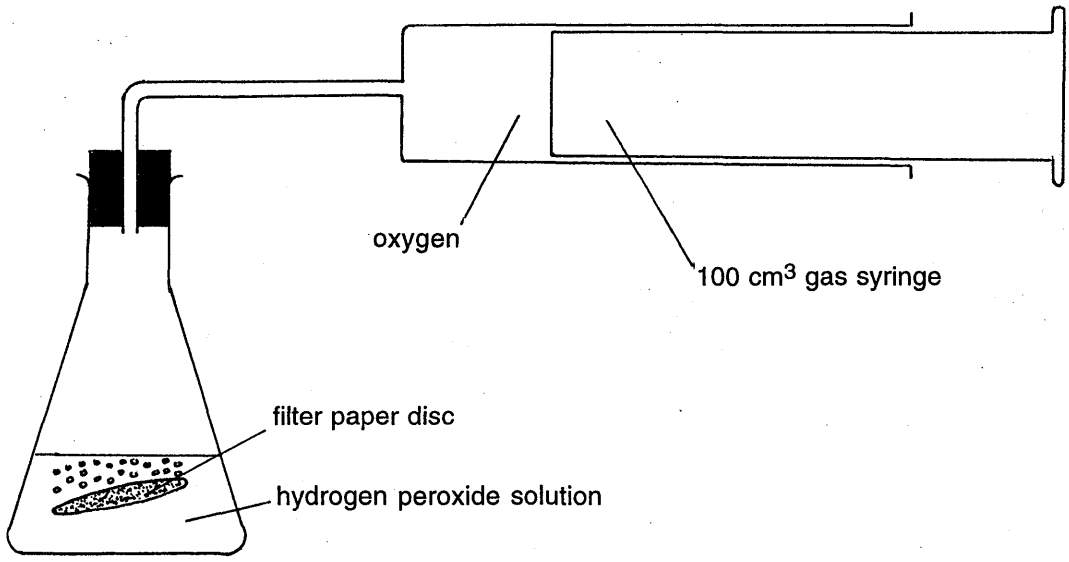


Figure 1. Apparatus for measuring the rate of decomposition of hydrogen peroxide solution

4. Disconnect the conical flask from the apparatus. Pour 20 cm^3 of '10 volume' hydrogen peroxide solution into the flask.

   CARE Hydrogen peroxide solution can be hazardous; handle it with care.

5. With the conical flask set vertically, push a filter paper disk impregnated with catalyst into the neck of the flask so that the disk of paper bends into a 'U' shape.

   CARE Manganese(IV) oxide is harmful; always use tweezers, not fingers, to hold the paper disks containing catalyst.

   Then carefully push the disk of paper as far into the flask as possible without the paper coming into contact with the hydrogen peroxide solution.

6. Make sure the gas syringe is set to zero, then connect the flask to the syringe.

7. Give the flask a short shake from side to side so that the filter paper disk falls into the hydrogen peroxide solution and reaction starts. The disk should float flat with all its surface in contact with the solution.

8. Start timing using the stopclock as soon as the disk falls into the solution.

   You might prefer to practise steps 5 to 8 using untreated filter paper disks and a flask containing water instead of hydrogen peroxide solution before you try the 'real thing'.

9. Record the time at 10 cm^3 intervals as oxygen build up in the gas syringe. To prevent the plunger sticking in the syringe body, and to keep the volume of gas increasing smoothly, you might need to tap the outside of the syringe gently with a pencil every few seconds. Stop the experiment when the volume of gas reaches 80 cm^3.

10. Make up three other solutions of hydrogen peroxide as shown in Table 1.

Volume of '10 volume' hydrogen peroxide solution / cm^3	Volume of water / cm^3	Concentration of hydrogen peroxide solution / 'volume'
20	10	6.7
20	20	5.0
20	40	3.3

Table 1. Instructions for making up hydrogen peroxide solutions of different concentrations

11. Repeat steps 2 to 9 using each of the solutions from step 10.

12. Record the results from the four experiments in a suitable form.

What it means

a. What factors, other than concentration, can affect the rate of a chemical reaction?

b. How does the design of this investigation ensure that factors other than concentration do not affect the reaction rate?

c. What is the advantage of using the manganese(IV) oxide catalyst absorbed into filter paper rather than adding it as loose powder, say from a spatula?

d. What total volume of oxygen would be produced from each of the hydrogen peroxide solutions used in these experiments?

e. Plot the results from the four experiments onto a graph. Plot volume of oxygen (in cm^3) on the vertical axis and time (in seconds) on the horizontal axis. Draw a smooth curve through the points for each experiment and label each curve clearly with the concentration of solution used.

f. Using your graph, estimate the time taken to produce 50 cm^3 of oxygen in each experiment. What fraction of the total reaction does this represent?

g. Explain how your estimates of the times taken to produce 50 cm^3 of oxygen show that the reaction rate is slower at lower concentrations of hydrogen peroxide.

INVESTIGATING THE EFFECT OF TEMPERATURE ON THE RATE OF A POLYMERISATION REACTION

Introduction

It is difficult to design experiments to investigate factors which affect the rate of polymerisation of ethene to produce poly(ethene). Partly this is because ethene is a gas. It is more convenient to do laboratory experiments with liquids rather than gases; therefore it is easier to investigate the polymerisation of a liquid alkene such as phenylethene (commonly called styrene).

The formation of poly(phenylethene), otherwise known as polystyrene, is the basis of many commercially available resin fillers used to repair the bodywork of cars and boats. These fillers come in two parts: a 'resin' containing the phenylethene monomer, and a 'hardener' containing a compound which is an initiator for polymerisation - in many fillers a peroxo compound, such as dibenzoyl peroxide, is used. This activity investigates how temperature affects the rate of polymerisation of one such resin filler.

What you need

commercially available styrene-based liquid resin and hardener
(David's Fastglas resin and hardener are suitable)

NB **Under no circumstances should the laboratory reagents phenylethene and dibenzoyl peroxide be used in place of commercially available materials in this activity.**

test tubes (75 mm x 12 mm diameter) with rubber bungs to fit x 5
100 cm^3 beakers x 5
glass rod (2 mm diameter)
bunsen burner, tripod and gauze (or alternative way of producing hot water)
0 - 110 °C thermometer
stop clock
paper towels
marker pen (permanent)
well-ventilated laboratory in which to carry out this activity
eye protection

CAUTION Eye protection must be worn.

Resin containing phenylethene (styrene) is harmful. Handle the resin with care; avoid breathing the vapour which is narcotic in high concentration. Make sure you are familiar with the remedial action to be taken in the event of an accident.

Hardener containing dibenzoyl peroxide is irritant and oxidising; prevent it coming into contact with skin or materials other than the resin. Make sure you are familiar with the remedial action to be taken in the event of an accident.

Do not attempt to clean any glassware used in this activity. Dispose of the test tubes and glass rod into a container used for broken glass.

This activity must be carried out in a well-ventilated laboratory.

IMPORTANT NOTE

Pure dibenzoyl peroxide is explosive and its use in school and college laboratories is prohibited. However, the formulations used in commercially available resin hardeners are not considered to be explosive and their use is permitted (see *Risk Assessments for Technology*, CLEAPSS, pp 47-8).

The maximum exposure limit of phenylethene is 100 ppm. It is considered (see *Risk Assessments for Technology*, CLEAPSS, pp 47-8) that provided not more than 250 g of resin is in use this limit is unlikely to be exceeded in a workshop. This mass may need to be scaled down to take account of the smaller volume of a laboratory. In this activity, only part of a 250 cm^3 (225 g) container of resin is likely to be in use. However, it is important to work in a well-ventilated laboratory, and to keep all test tubes and the container of resin stoppered whenever possible, to keep the level of phenylethene vapour low.

What you do

Read through all the steps in these instructions and make sure you understand them before beginning the investigation.

1. Make sure that any seals on the containers of resin and hardener have been broken.

2. Place the rubber bungs securely into the test tubes. Using a permanent marker pen, make a mark on the outside of the wall of each test tube about 1 cm in from the bottom of the bung. Unstopper the tubes but keep each tube together with its bung.

3. Place a pad of 3-4 paper towels on the bench.

4. Fill a 100 cm^3 beaker to within about 2 cm from the top with cold tap water. Record the temperature of the water.

5. Hold a test tube vertically. Hold the plastic tube of hardener vertically over the test tube so that the nozzle of the plastic tube fits into the mouth of the test tube.

6. Carefully squeeze the plastic tube to produce a string of hardener.

   CARE Hardener is irritant; do not get any of it on your skin.

   Continue squeezing the tube until the string of hardener just reaches the bottom of the test tube. With care it is possible to do this without hardener coming into contact with the wall of the test tube.

7. Gently tilt the plastic tube to one side so that the string of hardener breaks away from the nozzle and falls into the test tube. (At this point it is not possible to avoid hardener making contact with the test tube, but take care that this only happens below the line marked on the test tube wall.) Replace the cap on the tube of hardener and set it to one side.

8. Pour resin into the test tube up to the line marked on the tube wall.

   CARE Resin is harmful; handle it with care and avoid breathing the vapour.

   This must be done carefully but as quickly as possible because resin begins to react as soon as it comes into contact with hardener. Replace the cap on the container of resin and set it aside.

9. Using a thin glass rod, stir the contents of the test tube to mix the resin and hardener. (It is not necessary to mix them thoroughly.) This must be done carefully but, again, as quickly as possible. After stirring, place the glass rod onto a pad of paper towels so that any resin mixture is absorbed by the paper.

   CARE Do not get any resin mixture on your skin.

10. Put the rubber bung into the test tube and place the test tube into the beaker of cold tap water.

11. Start timing with a stop clock.

12. After 15 seconds, remove the test tube from the water and invert the tube. While the resin is still liquid it will flow from one end of the tube to the other when the tube is inverted. If this happens, replace the tube in the beaker of water and continue timing.

13. Repeat step 12 every 15 seconds until the resin has set and the contents of the tube no longer flow when the tube is inverted. Stop the clock and make a note of its reading when this happens.

14. Cautiously grip the outside of the test tube. Note whether it feels hot or cold.

15. Replace the tube in the beaker of cold water and set it to one side.

16. Repeat stages 4 to 13 using beakers of warmer water. Suitable temperatures to use are: 25 °C, 35 °C, 45 °C and 55 °C. **Do not** use water hotter than 60 °C. At the end of each experiment the test tube **must** be placed into the beaker of **cold** water used in the first experiment.

17. Record the results from these experiments in a suitable form.

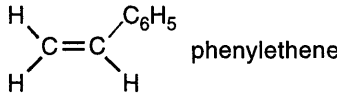
What it means

a. Plot the results from these experiments onto a graph. Use the vertical axis for time (in seconds) and the horizontal axis for temperature (in °C). Draw a suitable line through the points.

b. Explain how your graph shows how the rate of polymerisation depends on temperature.

c. Explain why the method used for these experiments does not lead to particularly accurate results for the dependence of reaction rate on temperature.

d. The formula of phenylethene is given below. Write down the formula of a short section of the polymer chain in poly(phenylethene).



phenylethene

e. Suggest why it was necessary to place the reaction tubes in cold water at the end of all the experiments.

f. If you have learned about entropy changes in an earlier *Science in the Environment* unit you should be able to explain why polymerisation reactions, such as the one studied in this investigation, can only occur if they cause heating.

i) Explain why joining together a very large number of monomer molecules to form a small number of polymer molecules leads to a decrease in disorder of energy and, therefore, to a negative entropy change.

ii) Explain why heating leads to an increase in disorder of energy and therefore to an entropy increase.

iii) What overall change in entropy must accompany any process which is taking place?

iv) Explain why polymerisation reactions can only take place if they cause heating.

CATALYSTS

A catalyst is a substance which alters the rate of a reaction without itself undergoing any permanent chemical change. So it is not used up in the reaction and it does not appear in the chemical equation. Normally this means that only a small quantity of catalyst is needed in comparison with the reactants, and you can expect to be able to recover the catalyst at the end of the process.

Catalysis is different from the other factors which speed up chemical reactions. A catalyst is not like heat or light; these are forms of energy, whereas a catalyst is a substance. And unlike the other substances in a reaction (the reactants), a catalyst is not used up.

Catalysts do take part in reactions (they must do, otherwise they would have no effect), but they are used and regenerated during the reaction. This can cause their appearance or their texture to change, even though they remain the same chemically. Catalysts are therefore not used up in a reaction and may often be readily recovered and reused. Sometimes, however, a catalyst is poisoned by impurities in the reactants or deactivated by other physical or chemical changes at some stage of the manufacturing process. Recovery of the catalyst in active form may or may not then be economically feasible.

For chemists, catalysis is one of the most fascinating aspects of chemical reactions: whether they are occurring in an industrial process, in the laboratory, in the environment, or in the cells of living organisms. Life as we know it would not be possible if there were no catalysis. Most of the proteins that are coded for by DNA are catalysts which, by determining what reactions can take place, steer the biochemistry and therefore the functioning of all living organisms.

Many industrial catalysts have been discovered by accident. Much research is directed towards finding out how catalysts work, and how they can be made more effective.

How catalysts work: in general ...

An energy profile diagram for a reaction, such as the diagram in Figure 1, shows how the presence of a catalyst can speed up a chemical reaction.

The reactants and products are the same whether or not the reaction is catalysed; so the energies at the start and finish are the same for both the uncatalysed and the catalysed reactions. However, under the same conditions of temperature and concentration, the catalysed reaction is faster. This means that a greater proportion of collisions lead to reaction, which in turn means that more particles possess sufficient energy to react.

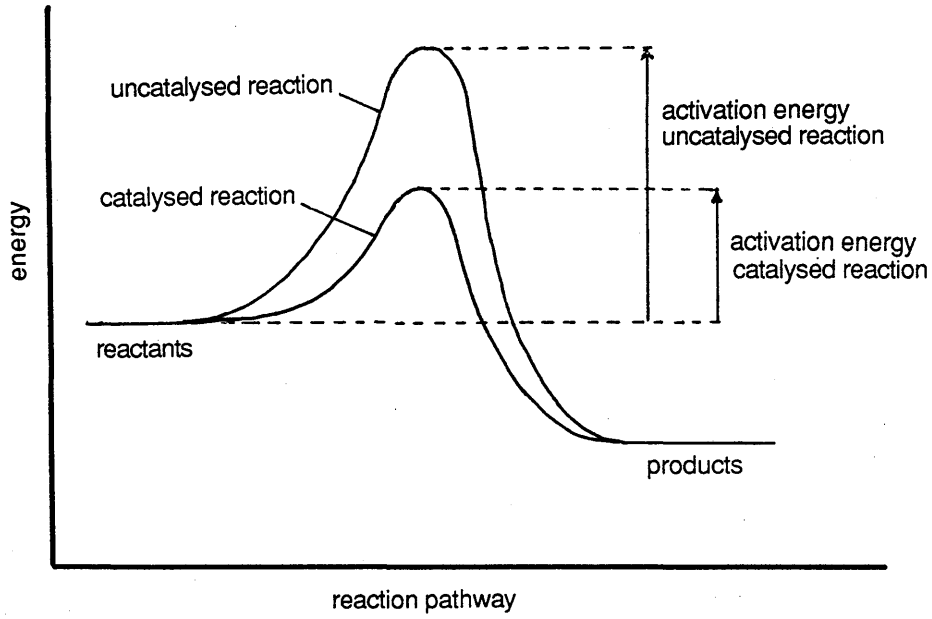


Figure 1 The effect of a catalyst on the energy profile for a reaction

The catalyst does not affect the energies of the reactants and products; it does not give them energy to react, and the way energy is distributed among their particles is the same with or without the catalyst. So an increased number of collisions which lead to reaction can only arise if the activation energy is lower for the catalysed reaction than for the uncatalysed reaction.

If Figure 1 represents a reaction that is reversible, then the presence of the catalyst lowers the activation energy barrier by an equal amount for both the forward and the reverse reactions. Therefore both are speeded up equally. The concentrations at which forward and reverse rates become the same are therefore unaffected and there is no change to the position of chemical equilibrium.

The activation energy is the energy needed to bring about the bond breaking and bond reforming changes that occur in a chemical reaction. The lower activation energy of the catalysed process means that these bond breaking and reforming changes are different: in other words that, even though the products are the same, the reaction is taking a different route. With this greater insight into how chemical reactions take place, a better definition of a catalyst is that it is a substance which increases the rate of a reaction by providing an alternative mechanism with a lower activation energy.

... and in particular

All this is general and applies to any catalyst; if we want to be more specific about how a catalyst works and how it can be improved, we need to know the details of the mechanism for the particular reaction concerned, and the role of the catalyst in it. In other words, each reaction has to be considered separately.

1

As a reversible reaction proceeds, the rate at which the reactants are used up slows down for two reasons. What are these reasons?

2

Many industrial processes involve reactions which are reversible. Under the conditions normally employed these stop well short of the equilibrium position: ie, the extent to which reactants are used up is much less than is ultimately possible. Suggest why.

3

Although a catalyst does not affect the amount of product which a reaction mixture contains at equilibrium, use of a catalyst can lead to the formation of more product in many industrial processes based on reversible reactions. Under what conditions can this occur.

The production of poly(ethene) by addition polymerisation of ethene provides a good illustration of how a catalyst functions. Two different types of process are used to make poly(ethene). One process involves a catalyst; the other does not.

The sequence of reactions by which poly(ethene) is made can be divided into three stages. The first stage involves production of radicals which start the process off. This stage is called ***initiation***. In the second stage, ethene molecules add onto these radicals giving progressively lengthening hydrocarbon chains which are still radicals. This stage is called ***propagation***. Chain growth stops in the third stage, ***termination***, by loss or gain of hydrogen atoms from the long-chain radicals to produce polymer molecules.

The same three stages occur in the presence or absence of a catalyst, but the mechanisms are different in the two cases, and when a catalyst is used poly(ethene) production takes place under conditions of much lower temperature and pressure.

The gas phase process for poly(ethene) production

Poly(ethene) is made without the use of a catalyst in a high temperature, high pressure, gas phase process. Ethene gas is compressed using a pressure of 1500 atm - 3000 atm, and heated to 200 °C to 300 °C for several hours with a trace of oxygen. Under these conditions radicals form, in an initiation stage, from reaction of oxygen with ethene.

These radicals then react with ethene molecules to form new radicals (see Figure 2) in the first step of the propagation stage.

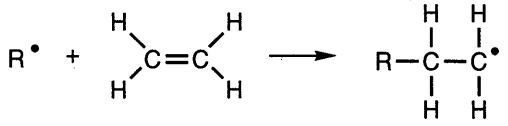


Figure 2 The first step in the formation of a radical chain in the uncatalysed production of poly(ethene)

Here R represents the group of atoms which forms the radical and which, after reaction, becomes built into the product. The dot at the end of the formulae represents an electron which is not paired with another electron in a covalent bond: there is therefore an odd number of electrons around the atom concerned.

Each bond indicated in Figure 2 consists of a pair of electrons, one from each atom, shared between atoms. There are therefore seven electrons in the outer shell of the right hand carbon atom of the product - two shared electrons in each of the three C–H bonds, one contributed by the carbon atom and one by the hydrogen atom, and the lone unshared electron

represented by the dot. In contrast, every other carbon atom in the chain has eight shared electrons, two in each of the four C–H bonds.

In each step of this radical chain polymerisation reaction, the carbon atom at the growing end of the chain gains a share in another electron, and therefore completes its outer shell of eight electrons, when a two-electron bond forms with a carbon atom of the added monomer unit. The electron contributed by the monomer unit to this bond is made available by breaking the double bond and forming a single bond in its place. This frees two electrons. One electron takes part in the carbon-carbon bond already mentioned, between the polymer chain and the added monomer unit. The other turns up unshared on the new terminal carbon atom.

The new radicals can react with further ethene molecules to continue the polymerisation process:

$$R\text{–}CH_2\text{–}CH_2^{\bullet} + CH_2{=}CH_2 \rightarrow R\text{–}CH_2\text{–}CH_2\text{–}CH_2\text{–}CH_2^{\bullet}$$

$$R\text{–}CH_2\text{–}CH_2\text{–}CH_2\text{–}CH_2^{\bullet} + CH_2{=}CH_2 \rightarrow R\text{–}CH_2\text{–}CH_2\text{–}CH_2\text{–}CH_2\text{–}CH_2\text{–}CH_2^{\bullet}$$

Chain branching in ldpe production

However, as polymerisation proceeds, another type of reaction - hydrogen abstraction - becomes increasingly likely. In hydrogen abstraction, the carbon atom at the end of a growing chain completes its outer shell of electrons, not by attacking and bonding to an ethene molecule, but by removing and bonding to a hydrogen atom which is already part of a radical chain. The end of a growing chain can loop back and take a hydrogen atom from its own chain, or it can abstract a hydrogen atom from another radical chain. Both possibilities are summarised in Figure 3.

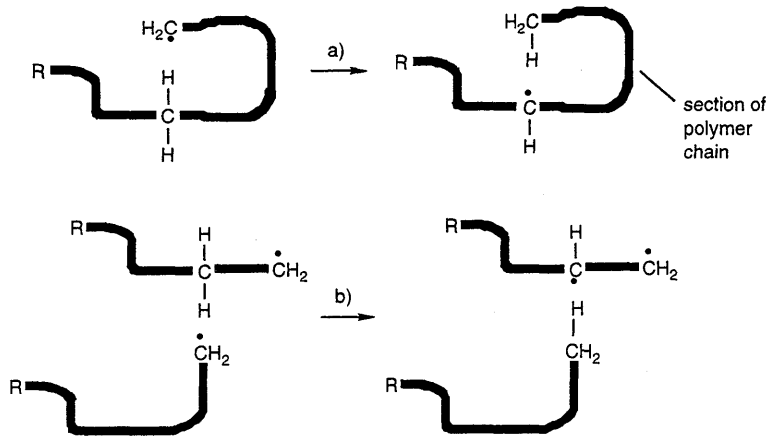


Figure 3 Illustration of hydrogen abstraction from a) the same chain, b) a different chain

Whichever type of hydrogen abstraction occurs, the result is to produce a radical chain which goes on to grow from a point some way along the chain. The growing chain therefore has a side-chain attached.

Hydrogen abstraction involves only radical chains (ethene molecules are not involved). Its rate rises as polymerisation proceeds and the concentration and length of radical chains increases. On the other hand, as polymerisation proceeds the rate of the chain growth process decreases because the concentration of ethene falls. Hydrogen abstraction therefore competes with chain growth during the propagation stage.

Hydrogen abstraction occurs repeatedly, so that polymer chains are formed with side-chains on about 5% of carbon atoms. The result is a form of poly(ethene) containing molecules with a highly branched structure. Such a molecule is illustrated in Figure 4, using a line to represent the polymer chain.



Figure 4 Illustration of the branched structure of a poly(ethene) molecule made by the uncatalysed route

The presence of side chains has important consequences for the properties of poly(ethene). The side-chains keep the polymer molecules apart in the solid, leading to a material with a low density, which is soft and flexible. That is why it is called low density poly(ethene), abbreviated to ldpe.

Catalytic production of poly(ethene)

Poly(ethene) is also made in a catalytic process using a temperature of around 80 °C and pressures up to 30 atm. Compounds of the transition metals, titanium and chromium, are used as catalysts. They are in the form of fine grains of solid in suspension in a liquid (usually 2-methylpropane, hexane or heptane, which are hydrocarbon compounds found in petrol). Such a mixture is called a 'slurry'.

One commonly used catalyst is prepared, in situ (ie, in the reaction system), from a mixture of titanium(IV) chloride ($TiCl_4$) and triethylaluminium ($Al(C_2H_5)_3$). These react together, as shown below, to form titanium(III) chloride ($TiCl_3$), which is the catalyst, and ethyl radicals ($C_2H_5^{\bullet}$), which are the initiators.

$$TiCl_4 + Al(C_2H_5)_3 \rightarrow TiCl_3 + Al(C_2H_5)_2Cl + C_2H_5^{\bullet}$$

Ethyl radicals then bond onto the surfaces of the catalyst grains (see Figure 5).

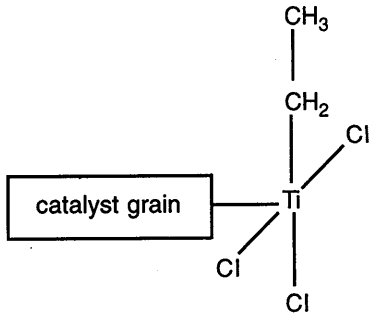


Figure 5 Illustration of an ethyl radical initiator bonded to the surface of a titanium(III) chloride catalyst grain in poly(ethene) production

When ethene gas is bubbled into the catalyst slurry, molecules of ethene bond to the catalyst and then flip over to join onto the ethyl radicals. Figure 6 illustrates this for a single ethene molecule. The process is then repeated with further ethene molecules to form growing polymer chains.

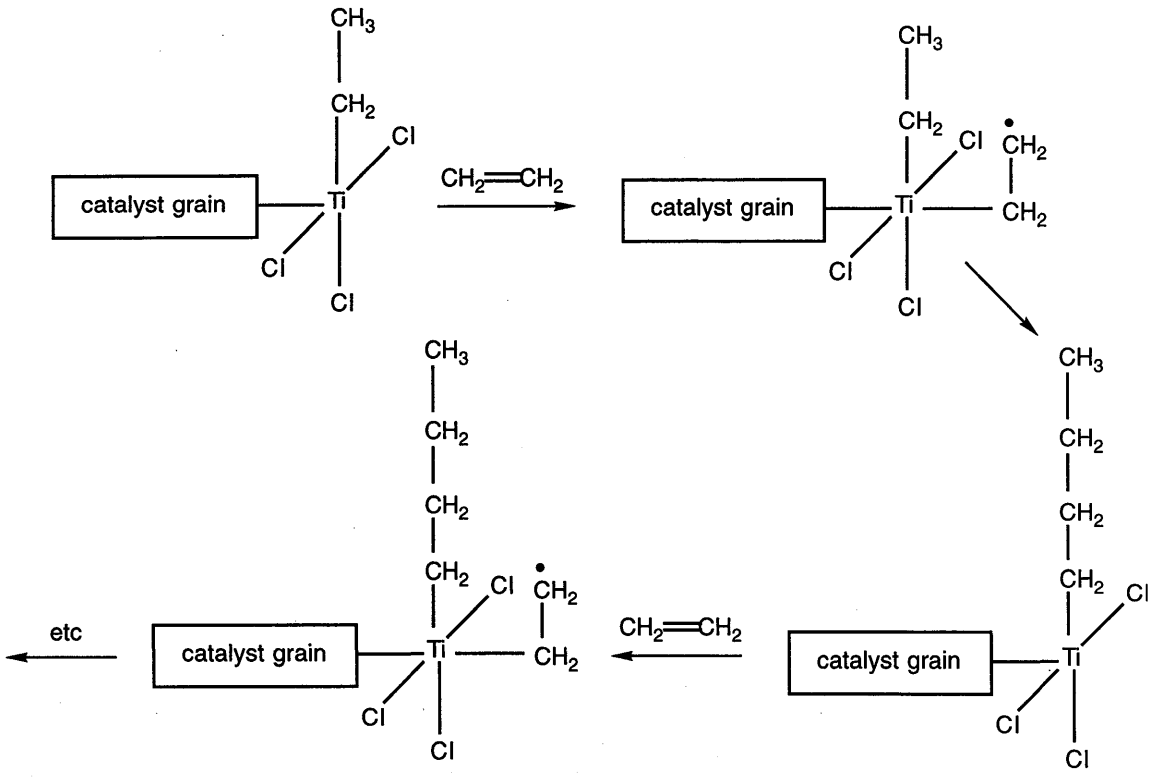


Figure 6 Stages in the growth of a polymer chain in the catalytic production of poly(ethene)

Polymerisation is terminated by the presence of a trace of hydrogen gas in the reaction mixture. This sets the $TiCl_3$ free to catalyse the production of further polymer chains.

Linear chains and hdpe

In the catalysed process for poly(ethene) production the growing point of the polymer chain is always attached to the catalyst surface. Hydrogen abstraction is therefore prevented, there are almost no side-chains and the product consists almost entirely of linear polymer chains (see Figure 7).

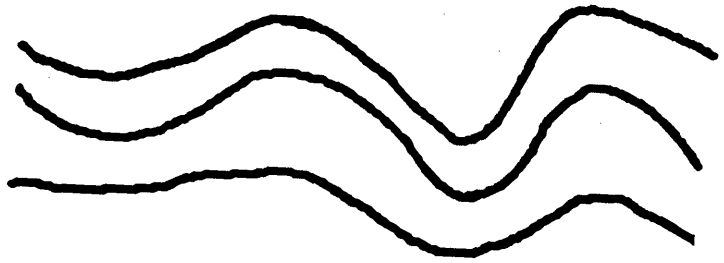


Figure 7 An illustration of the unbranched structure of poly(ethene) made by the catalysed route

The absence of branching means that polymer chains in this form of poly(ethene) can fit more closely together, making the material stronger, denser and more rigid than ldpe. It is therefore called high density poly(ethene), abbreviated to hdpe.

Comparison of the catalysed and uncatalysed routes

The production of hdpe and ldpe illustrates how a catalyst provides an alternative mechanism for reaction. Also, because hdpe production takes place under much milder conditions than ldpe production (80 °C and 30 atm rather than 300 °C and 1500 atm), the alternative mechanism of the catalysed process clearly has a lower activation energy.

Poly(ethene) production also shows how use of a catalyst leads to greater product selectivity. The uncatalysed route gives a product consisting of a mixture of polymer chains with differing extents of branching. A polymer containing predominantly unbranched chains has many uses and is commercially valuable. If such a material had to be extracted from the ldpe mixture a complicated separation process would be required. This would be expensive and would place a burden on the environment in terms of increased use of fuel. Use of the catalyst selects for the desired product, making separation unnecessary.

In some cases, other than poly(ethene) production, poor selectivity can lead to further expense if unwanted product cannot be sold and to a greater environmental burden as a result of disposal.

Advantages of using catalysts

Using catalysts can offer other important economic and environmental advantages in industrial processes. A lower temperature means that less fuel is used for heating. A lower

pressure may mean use of less fuel for driving pumps; it can also mean that equipment is smaller for a given output and is therefore cheaper to build. Because catalysed reactions are faster and more selective, more product can be made per day, which can result in bigger sales.

These economic advantages go hand-in-hand with environmental advantages. Less fuel use results in slower depletion of the world's reserves of fossil fuels (coal, oil and gas), as well as lower releases of the 'greenhouse gas' carbon dioxide. Lower pressure means a reduced risk of accident and of leakages of chemicals. Because catalysts can lead to purer products, less waste is produced. Also separation becomes easier or unneccessary, which can reduce the quantities of solvents which have to be used.

Development of new or improved catalysts is an important way of making industrial chemical processes 'cleaner' and more 'environmentally friendly'. But catalysts themselves can pose environmental threats, as in the case of transition metal catalysts for which great care has to be taken with their use and recovery. The search for alternatives to these, which place a lower burden on the environment, is often a priority.

Types of catalyst

Catalysts can be divided into two classes: homogeneous and heterogeneous. A ***heterogeneous catalyst*** is in a different physical state from the reactants. (Physical state means as a gas, liquid, solid, or in solution.) For example, in the Haber Process to produce ammonia, the nitrogen and hydrogen reactants are gases which are passed over a catalyst of solid iron.

In contrast, a ***homogeneous catalyst*** is in the same physical state as the reactants. For example, in the oxidation of 1,4-dimethylbenzene by oxygen to produce benzene-1,4-dicarboxylic acid (large quantities of which are required for production of polyesters), the catalyst is in solution with the organic reactant. Ethanoic acid is used as solvent; the catalyst is a mixture of hydrobromic acid, manganese(II) ethanoate and cobalt(II) ethanoate.

On the whole, heterogeneous catalysts are more widely used in industrial processes because they are easier to separate from reaction mixtures and are therefore more likely to be reusable. A number of reactions which require acid catalysis are now catalysed heterogeneously by clays or zeolite minerals, modified to be strongly acidic, rather than homogeneously by acids in solution. As well as offering advantages in safety of handling, because they are naturally occurring minerals, clays and zeolites are considered to place less of a burden on the environment on disposal. In other cases, compounds which were previously used in solution as homogeneous catalysts have been bonded onto clays so that they can be used as heterogeneous catalysts.

Summary

- A catalyst increases the rate of a reaction by providing an alternative mechanism with a lower activation energy.
- For a reversible reaction, a catalyst affects the rate at which equilibrium is reached but does not affect the position of equilibrium.
- Catalysts take part in reactions; bonds are formed between a catalyst and the reacting chemicals but the catalyst is (or can be) regenerated at the end of the process.
- Catalysts are important in the chemical industry because products are made more economically (with greater selectivity and/or under milder conditions) using catalysts.
- Catalysts play an essential role in many of the processes in living organisms.
- There are environmental advantages to using catalysts. Increasingly, chemical manufacturing processes are being redesigned to reduce their burden on the environment; the development of new catalysts is an important part of this move.

Things to do

1. Make sure you feel confident about the following important aspects of this item:

   - the terms catalyst and catalysis;
   - the role of catalysts in providing alternative reaction mechanisms with lower activation energies;
   - an example of how a catalyst works at the molecular level;
   - the economic and environmental importance of catalysts.

2. 'A catalyst alters the rate of a chemical reaction without, itself, undergoing any permanent chemical change.'
   What are the limitations of this definition of a catalyst? Use information contained in this item to illustrate your answer.

3. Use a chemistry text book to find out about the use of catalysts in some other important processes: for example

   a. the Contact Process for converting sulphur dioxide into sulphur trioxide, the key step in sulphuric acid manufacture;

   b. the Haber Process for producing ammonia from nitrogen and hydrogen;

   c. the conversion of ammonia into nitrogen monoxide, the key step in making nitric acid for fertiliser production;

   d. catalytic convertors in car exhaust systems;

   e. the manufacture of margarines from vegetable oils.

Pollution & Waste Management I: Cradle-to-Grave Analysis

Professor Roland Clift

"If you concentrate on managing waste, you have failed to see the real problem ... how to reduce the flow of non-renewable materials and energy through the economy"



Professor Roland Clift F.Eng.

Professor of Environmental Technology Centre for Environmental Strategy, University of Surrey

Chairman of the Clean Technology Management Committee of SERC and AFRC

Chairman of the Engineering Research Board of AFRC

Chairman of the Engineering Council Working Party on "Engineers and the Environment"

Address (Part I) to the P&SC on 25th May 1993

I will try to give a general explanation of our thinking on longterm approaches to the problems of pollution and waste. One of my themes will be that public attention tends to be focussed on obvious visible issues—post-consumer waste, for example, and pollution caused by manufacturing activities. However, the solutions to longterm problems of pollution and waste are to be found by taking a much broader view a holistic approach which looks for the reasons why pollution and waste are generated, rather than just trying to suppress emissions or manage waste.

There is a fairly rigorous approach for doing this, and it is called Life Cycle Assessment, or sometimes Cradle-To-Grave Analysis. To understand the idea of Life Cycle Assessment, it may be helpful to compare it with the idea of Integrated Pollution Control (IPC). This was the basis of the 1990 Environmental Protection Act. IPC tries to integrate all the environmental impacts of any manufacturing activity so that the operator cannot, for example, meet standards on atmospheric emissions just by generating more waterborne emissions or more solid waste.

Life Cycle Assessment (LCA) integrates over the life of a product rather than around a manufacturing plant. It is called "Cradle-to-Grave Analysis" because it tries to consider all the environmental impacts, from the primary raw materials right through to ultimate waste disposal. For products which can be reused or recycled, it also accounts for the environmental impacts arising from the recycling. Sometimes this leads to conclusions which are quite contrary to the positions taken by popular environmental pressure groups, and I will give you some examples of that shortly.

I have already mentioned the Clean Technology initiative, so I must also explain what we mean by this. Clean Technology is quite different from the more familiar approach of Clean-up Technology which usually means "End-of-Pipe" pollution control. In essence, Clean-up Technology involves alleviating the pollution or managing the waste, whereas Clean Technology involves doing things differently so that you avoid causing the pollution or generating the waste in the first place.

This obviously involves longterm thinking, because Clean Technology usually means completely new technology rather than fixing up existing plants. Clean Technology also involves looking at the whole Life Cycle, to identify the reasons for pollution or waste generation. The idea of LCA will run right through this talk. Figure 1 illustrates the idea of Clean Technology, and shows another important distinction. Clean-up Technology always costs money, because it means adding something to a factory or a process. Clean Technology can actually reduce costs, so that it can give competitive advantage as well as environmental benefit. I will also give you some examples of that.

Following through the idea of LCA, the waste which we see generated in factories, towns and cities may not be the serious environmental problem. Arguably we have not recognised the real longterm costs of waste management and this has been well illustrated by arguments over such issues as registration of contaminated land and management of landfill sites. However, the Life Cycle approach says that the waste is really evidence of inefficient use of materials. Some forms of pollution are evidence of inefficient use of energy.

The real issue behind this is sustainability. This is an over-used term, and I use it to mean achieving living standards which are acceptable but which can be maintained indefinitely. Concentrating on sustainability means concentrating on use of resources and energy rather than just on waste. Domestic waste is obvious, because it is literally in our own back yards. Resource depletion happens in someone else's front yard, so it is much less obvious to us.

It is high time now that I gave you a concrete example, and a very good example is paper waste. I will look specifically at newsprint, because the issues here are relatively straightforward. Most people perceive old newspapers as a waste which should be recycled.

Now let's follow through that part of the life cycle (Figure 2). To recycle newspapers, you have to transport them to the recycling plant. You then have to pulp them, which consumes energy. In Britain, this means using fossil fuels and emitting carbon dioxide. Then the ink has to be removed. De-inking is a chemical process, which use agents which are not really environmentally friendly. You then reform the de-inked fibre, and this uses more energy yet because the pulp has to be dried.

Thus recycling paper consumes fossil energy, generates pollution, and increases carbon dioxide emissions. This is an example of something which I call profligate environmentalism: recycling makes people feel good and virtuous, but actually it can generate pollution and use energy unsustainably.

So what else might be done with waste paper? We can burn it as a fuel (Figure 3). This reduces our consumption of fossil fuel—and paper is actually much cleaner than fossil fuels. Also, it avoids the chemical loads associated with de-inking. Provided that the paper comes from trees grown by sustainable forestry with proper planned replanting, the CO_2 formed when the paper is burned recycles via the atmosphere into later generations of trees. It is also important that well-designed integrated paper mills consume almost no energy, because they use tree waste as their fuel. This means that burning paper waste as a substitute for fossil fuels leads to an overall life cycle which is sustainable provided that trees are farmed sustainably.

I should also say that some people recommend that waste paper should actually be buried as a carbon sink; but this is more contentious, and puts too much emphasis on the carbon dioxide balance in my view. So I will limit myself to the two options of recycling paper or burning it as fuel.

Which option you prefer depends on how you see waste newsprint. People who recommend recycling see it as waste, and recommend recycling the material content. People who recommend burning, see paper waste as renewable biofuel, and recommend using its energy content. Which is the Better Environmental Option? Recycling reduces the amount of virgin fibre used in the first place. Therefore, it is the Better Option where paper is not produced by sustainable forestry; for example, on the West Coast of North America, where "old growth" forest is being cleared on an appalling Brazilian scale because of deficiencies in forest management in the past.

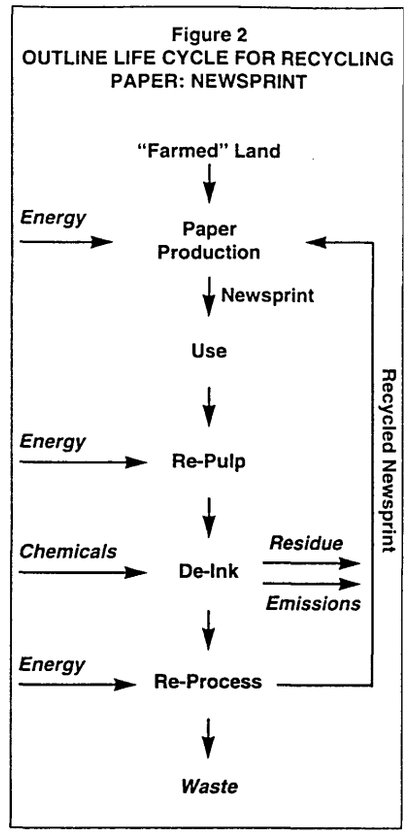


Figure 2
OUTLINE LIFE CYCLE FOR RECYCLING PAPER: NEWSPRINT

This is not the case in Northern Europe, where forestry is based on replanting, so that it is much more like sustainable farming. Trees are farmed, not quarried. So if we recycle paper, we use fossil fuels and chemicals to reduce the demand for farmed forest products in Scandinavia. Also, of course, we shift economic activity and employment from Scandinavia to Britain. Thus recycling paper has economic advantages to us, but it is not the Best Environmental Option

I have gone into this example in some detail because it illustrates some important general points. If you look at the whole Life Cycle, you may reach conclusions which are quite different from those you reach if you only look at the waste. The Best Environmental Option is determined by sustainability of production, not just by management of waste. I will come back to these two general points when I have been through some different examples.

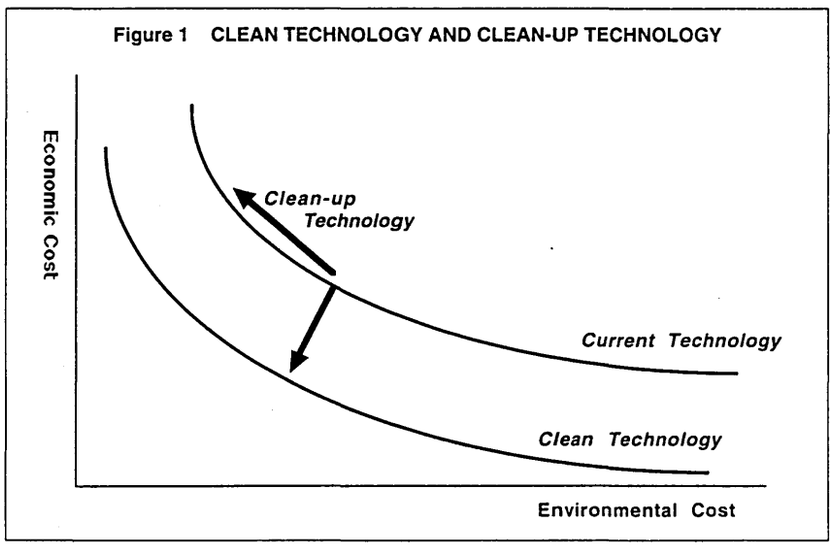
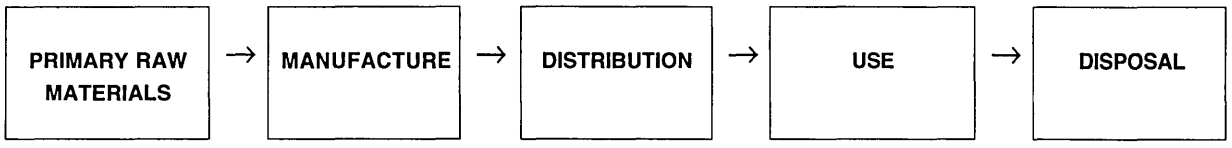


Figure 1 CLEAN TECHNOLOGY AND CLEAN-UP TECHNOLOGY

Pollution & Waste Management I: Cradle to Grave Analysis

Things to do

This paper by Professor Roland Clift first appeared in the journal *Science in Parliament*, Vol. 50, No. 3 in June 1993. Cradle-to-Grave Analysis (also known as Life Cycle Assessment, or LCA) of a product is a technique for considering all the environmental impacts, from primary raw materials through manufacture, distribution and use to ultimate disposal, taking into account the impacts of energy usage at each stage including transport.



Professor Clift argues that carrying out a Life Cycle Assessment of a product is likely to lead to better environmental solutions than just trying to suppress emissions or manage waste.

- Read Professor Clift's paper carefully.

1. In the first section of the paper, Professor Clift introduces several other terms which may be new to the reader. Discuss the meaning of each of the following:

   a. Integrated Pollution Control;

   b. Clean Technology;

   c. Clean-up Technology;

   d. holistic approach;

   e. sustainability.

2. Figure 1 shows the relationships between economic cost and environmental cost of introducing Clean Technology and Clean-up Technology.

   a. Use Figure 1 to explain Professor Clift's point that Clean-up Technology always costs money whereas Clean Technology can actually reduce costs.

   b. Which of the two environmental options do you think might be better adopted by

      i) countries in the Developed World;
      ii) Developing Countries?

      Explain your answers.

3. Professor Clift amplifies his arguments in favour of Life Cycle Assessment by giving examples of the environmental management of different products. Three scenarios he uses are outlined below.

A **Too much emphasis on the disposal of waste leads to the adoption of recycling, even when this is not the best environmental option.**

B **The greatest environmental impact is associated not with the manufacturing phase, but with the use phase of a product.**

C **The environmental impact of transporting waste is a major factor.**

a. List all the products mentioned by Professor Clift in his article.

b. Which of these products falls into each of the categories, A, B and C?

c. What solutions does Life Cycle Assessment offer for each of the products included in your answer to b.

4. Professor Clift goes on to describe some of the policy implications that arise when the whole Life Cycle of a product is considered, rather than just the waste. His arguments centre on the importance of responsibility for the product at each stage in its Life Cycle.

a. What are the advantages of legislation which makes the manufacturer, rather than the consumer, responsible for the product at the end of its use phase?

b. What is meant by the term Life Cycle Partnership?

5. The technique of Life Cycle Assessment can help scientists to work out the best environmental option at each stage in the life of a particular product. Discuss what factors might cause a government or a company not to adopt the best environmental option.

STARVING HUNGRY?

In the developed world, the two words 'starving' and 'hungry' have come to be used as informal terms to describe a healthy appetite for the next meal. Used together, they are what is known as *tautology* in which words merely repeat elements of the meaning already conveyed. Collins Concise English Dictionary defines the two words as follows:

> **starving -** dying from lack of food, or extremely hungry.
>
> **hunger** - a feeling of emptiness or weakness induced by lack of food.

By these definitions, the phrase 'starving hungry' is not only tautologous but also exaggeration. Most people in the developed world do not starve, neither do they go hungry.

Those of us who get enough to eat also have access to the mass media: television, newspapers, magazines, radio and, increasingly, the Internet. Whenever a particular area of the world suffers a famine we receive news of people who are truly starving. A dictionary definition of famine is:

> **famine** - severe shortage of food, as through crop failure or overpopulation.

- Find out from the mass media, including the Internet, which areas of the world are suffering from famines at the moment.
- The causes of modern famines are often complex. What seem to be the causes of the famines you have found out about?

In fourteenth century England, the economy of ordinary people working in the countryside was finely balanced. Although famines did occur as a result of bad harvests, like the ones in 1315 and 1325, people did not, on the whole, starve. But, averaged over a year, they had little surplus food so, at certain times of year, they were hungry, in the true sense of the word.

A contemporary account of hunger can be found in a passage from the long, allegorical poem by William Langland, called *The Vision of William Concerning Piers The Plowman.* Three versions of the poem exist; most likely all of them were written by the same author, whose real name is not known for certain. Even his assumed name may be an allegory, meaning 'the will of all the land'. The poem dates from the late-fourteenth century; certainly phrases from the second version (or B-text) were used in letters to one another by leaders of the Peasants' Revolt, which took place in 1381. The central imaginary character of the poem is Piers Plowman, yet the author of one contemporary history of the Peasants' Revolt mentions him among the conspirators as though he is a real person. Likewise, the modern tabloid press sometimes runs features and news stories about characters from television soap operas!

In one passage from the poem, Langland describes hunger by personifying the condition, which would have been all too familiar to many of those listening to the poem, if not necessarily to the few who could actually read it. Since most people could not read, the poem was designed to be learned by heart, and recited. It is in the form known as alliterative verse. This does not rhyme and has no regular metre. Learning by heart is assisted in other ways. You will notice that each line is divided into two halves which are held together by three, or sometimes four, emphasised words, each beginning with the same letter-sound. Usually the first half-line contains two of these 'alliterative syllables', while the second half contains a single echo of the sound.

Through the character, Hunger, and his demands on the peasants in the poem, Langland gives a vivid account of what it would have felt like as food became increasingly scarce. The leanest time of year was usually the summer, because the main component of the peasant diet was carbohydrate from cereal. For many peasants, their store of grain would run out before the next harvest was gathered, and it is those weeks immediately prior to the summer grain harvest that Langland describes in the extract below, which is from the B-text version of the poem, as edited by the Reverend Walter W. Skeat, in 1866.

- Read the following extract from *The Vision of William Concerning Piers The Plowman* (Passus VI, lines 280-304). Although the poem is written in the Middle English language of the 1370s, it is not difficult to gain a general impression of what the extract means.

'By-hote god' quod Hunger · 'hennes ne wil I wende
Til I haue dyner bi this day · and ydronke bothe.'
'I haue no peny," quod Peres · 'poletes forto bigge
Ne neyther gees nor grys · but two grene cheses,
A few cruddes and creem · and an hauer cake,
And two loues of benes and bran · y-bake for my fauntis.
And ȝet I sey, by my soule · I haue no salt bacoun,
Ne no kokeney, bi Cryst · coloppes forto maken.
Ac I haue percil and porettes · and many kole-plants,
And eke a cow and a kalf · and a cart-mare
To drawe a-felde my donge · the while the drought lasteth.
And by this lyflode we mot lyue · til Lammasse tyme;
And bi that, I hope to haue · heruest in my croft;
And thanne may I diȝte thi dyner · as me dere liketh.'
All the pore peple tho · pesecoddes fetten,
Benes and baked apples · they brouȝte in her lappes,
Chibolles and cheruelles · and ripe chiries manye,
And profered Peres this present · to plese with Hunger.
All Hunger eet in haste · and axed after more.
Thanne pore folke for fere · fed Hunger ȝerne
With grene poret and pesen · to poysen Hunger thei thouȝte,
By that it neighed nere heruest · new corne cam to chepynge;
Thanne was folke fayne · and fed Hunger with the best,
With good ale, as Glotoun tauȝte · and gerte Hunger go slepe.

- Read the account below, which explains in detail the meaning of the passage from the poem. In particular, note the different degrees of hunger described by the poet.

The character, Hunger, is making demands upon the peasants, and swears he will not go away until he has eaten and drunk. Piers Plowman explains that he has no money to buy chickens, geese or pork, but he does have two green cheeses, a few curds and cream, and an oatcake. He also has two loaves, made from bean flour and bran, that he has baked for his children. Here is the first sign that lean times are approaching; the grain is running out and Piers is reduced to baking loaves using the beans grown principally as animal fodder. He goes on to tell Hunger that he has no salt bacon and no eggs, so he cannot make collops. 'Collop' is a word that has almost disappeared from the English language, but it means a thick slice, usually of bacon or ham, fried with eggs. Traditionally, in the North of England, Collop Monday immediately preceded Shrove Tuesday (Pancake Day) and was the last day before Lent on which meat could be eaten; this meal took the form of bacon and eggs.

So Piers cannot lay his hands on much food to stave off Hunger, but he does have parsley and leeks, and many cabbage plants. These were plants that poor peasants like Piers would have been able to grow in their own cottage gardens. His only remaining animals are a cow and calf, and a cart-mare that he uses to take dung to the fields in the dry weather. These are animals he must not slaughter for food. 'By this livelihood we must live until Lammas-time', says Piers.

The old festival, or feast-day, of Lammas falls on 1 August, and marked the start of the grain harvest, so Piers hopes that after this he will have plenty of food in his cottage and that he will be able to eat as he likes.

In the weeks leading up to Lammas, the peasants would have become increasingly hungry, and this is reflected in the behaviour of the character, Hunger. People ate whatever they could lay their hands on, and the poet, Langland, describes them sharing their food. Other poor peasants bring summer produce: peas in the pod (like mange-tout or sugar snap peas today), beans, apples, onions and chervil (a herb similar to parsley), even cherries. They give these to Piers to try and please Hunger, who is becoming more and more insistent. But Hunger just gobbles up this food and asks for more. Fruit and vegetables are nutritious, but they are not filling foods; remember there were no potatoes in medieval England. In desperation, the poor people now try to stave off Hunger with the meagrest soup made of green vegetables and peas. Langland describes them trying to poison Hunger; they are desperate, and Hunger has become an enemy.

Finally, the harvest comes to their rescue. New grain comes into the market and the people are happy, for now they can feed Hunger with the best food and good ale, made from the newly harvested grain. At last, they persuade Hunger to go to sleep. Note this last piece of imagery; the peasants have not banished Hunger for good, for they know that in time he will return.

- Try to imagine always being hungry. Imagine coming home, after a hot day doing manual work in the fields, to a supper of bread made from beans and bran, or perhaps some green vegetables.

- Make a list of everything you eat in one day. You could list what you might eat on an average day, or you may instead prefer to write down everything you eat, as you eat it, on one day in particular. Remember to include all snacks and drinks, and also the quantities of each of the foods you consume.

- To what extent would the menu of your daily intake of food and drink differ had you made your list at a different time of year?

- Discuss whether you are ever really hungry.

Unlike you, at certain times of year the peasants in the fourteenth century poem, *Piers The Plowman*, did not get enough to eat; they suffered from malnutrition. Collins Concise English Dictionary defines this term thus:

> **malnutrition** - lack of adequate nutrition resulting from insufficient food, unbalanced diet or ineffective assimilation.

There still exist in the world today people who are malnourished for lack of food, and also those who suffer malnutrition because their diets are not varied enough to provide them with the vitamins and minerals they need in order to assimilate properly the food they do eat.

The dictionary definition above mentions one further cause of malnutrition, and that is an unbalanced diet.

- What is meant by the term 'balanced diet?

WHAT DO YOU EAT?

The purpose of this activity is to compare your typical daily intake of food with the intake that is recommended as a healthy diet. There are two aspects to this:

- comparison of your daily energy intake with your daily energy needs;
- comparison of the balance of carbohydrate to fat in your diet with the recommended balance.

PART A: Your typical daily diet

You should already have compiled a list of the food you eat in any one day whilst studying Item 2C1.1(a). Use that daily menu again here.

1. Draw up a table comprising six columns.

2. Convert your menu into a list of types of food: eg, tea and toast for breakfast could include tea, sugar, bread, butter and marmalade. List the types of food you eat in any one day in the first column of your table.

3. Estimate the mass of each type of food in your list. Enter these masses in the second column of your table.

PART B: Your typical daily energy intake

4. Find out the dietary energy contained in your estimated masses of each type of food. Enter these energy contents (in kJ) in the third column of your table.

   For most foodstuffs, a value for the energy contained per 100 g is given in the nutritional information displayed on the packaging. Scale this energy value up or down to the mass of the foodstuff that you have estimated you eat. You may need to use the conversion factors given below to find the energy value in kJ if it is given in other units on the packaging.

   1 calorie (cal) = 4.2×10^{-3} kJ 1 kilocalorie (kcal) = 4.2 kJ.

   The dietary energy contents of some foodstuffs which you might buy unpackaged are given in Appendix 1.

5. Calculate your total energy intake from your typical day's diet.

6. How much energy you need to transfer from food each day?

   To answer this question you need to analyse what you do in a typical day. For example, a person doing a non-manual job might spend 8 h sleeping, 8 h doing gentle activity, 4 h sitting and 4 h walking. The energy requirements of these, and other forms of activity, are listed in Appendix 2.

   Using information from Appendix 2, estimate your own energy requirements for a typical 24-hour period.

7. Appendix 3 gives typical daily energy requirements for different types of people. How does the energy requirement you have worked out for yourself compare with these data?

8. How does the energy you need to transfer from your food (ie your energy requirement) compare with your typical daily energy intake ?

   An adult who has stopped growing needs to maintain a reasonable match between energy intake and energy expenditure in order to maintain optimum body weight. Young people who are still growing obviously need energy to build new cells as well as maintaining existing ones, and their energy intake should reflect this additional need. The amount of energy that different people need to transfer from their food does vary from individual to individual. However, if energy intake greatly exceeds energy requirement a person may become obese. Conversely, if energy requirement exceeds food intake a person is likely to lose weight.

PART C: The balance of carbohydrate to fat in your diet

What we eat is just as important to correct nutrition as how much we eat. Current nutritional advice suggests that our diet should provide us with energy as follows:

60% - 70% of our energy intake should be in the form of carbohydrate;
20% - 30% of our energy intake should be in the form of fat.

However, most sedentary people (people who spend most of their lives sitting down) in industrial countries obtain 35% - 45% of their dietary energy from fat. The tasks and questions that follow allow you to estimate the balance of carbohydrate to fat in your own diet.

9. Find out the masses of carbohydrate, fat and protein in your estimated masses of each type of food in your table. Enter these masses (in g) in the fourth, fifth and sixth columns of your table.

   For most foodstuffs, the masses of carbohydrate, fat and protein in 100 g are given in the nutritional information displayed on the packaging. Scale these masses up or down to the mass of the foodstuff that you eat. Similar data for some foodstuffs which you might buy unpackaged are given in Appendix 1.

10. Calculate the masses (in g) of each of carbohydrate, fat and protein in your typical daily diet.

11. The energies transferred in aerobic respiration per gramme of carbohydrate, fat and protein are given below.

Substance	Energy transferred per g in aerobic respiration /kJ
carbohydrate	17
fat	38
protein	15

Calculate the percentage of your daily energy intake which is transferred from each of carbohydrate and fat.

12. Do the percentages of energy obtained from carbohydrate and fat in your diet fall within the recommended ranges? Or, like sedentary people in industrialised countries, is your intake of fat too high?

13. Dietary protein is mainly broken down and reused for the synthesis of body proteins. Excess protein is used to supply energy. We need between1.2 g and 1.8 g of protein per kg of body weight per day for synthesis of body proteins.

    How does the mass of protein that you eat compare with that needed for synthesis of body proteins? Are you also using protein as a significant source of energy? Could you replace protein by carbohydrate in your diet?

PART D: Redesigning your daily diet

14. What you have found out in Parts A, B and C might have shown you that your typical daily diet is not in line with the recommended diet. What, if any, major changes do you need to make to your diet? Suggest ways in which you might adapt your current diet in order to bring what you eat into line with current nutritional thinking.

APPENDICES

Appendix 1

Nutritional information for some foodstuffs which might be bought unpackaged

Foodstuff	Nutritional values per 100 g of foodstuff			
	Energy content /kJ	Mass of carbohydrate /g	Mass of fat /g	Mass of protein /g
bread	1040	50	2	8
eggs	620	0	11	12
beef	1000	0	15	27
lamb	1200	0	34	15
pork	1500	0	42	15
fish	350	0	4	18
fruit	150	10	0	1
tomatoes	74	3	0	1
green vegetables	30	1	0	1
pulses (beans, lentils)	460	17	0	10
peas	210	8	0	5
root vegetables	150	8	0	1
potatoes (boiled)	330	20	0	1
potatoes (fried)	3000	49	38	6
hot drinks (tea, coffee)	80	1	1	0

Appendix 2

Energy requirements (per hour) of different forms of activity

Type of activity	Energy requirement per hour / kJ
lying still / sleeping	300
sitting	400
gentle activity (eg dressing)	600
walking	800
cycling (on level)	1300
physical work (eg sawing wood)	2000
jogging	2400
rowing, running	3400
maximum activity	6000

Appendix 3

Daily energy requirements of different types of people

Type of person		Daily energy requirement /kJ
baby		4 000
children	girl	13 000
(aged 10 years)	boy	15 000
adults	woman	10 000
	pregnant woman	11 000
	man	12 000
	elderly person	8 000

HOW DO YOU EAT?

Millions of people around the world have little choice as to what they eat. They eat what is available. Like the peasant people in medieval England, they eat to live. In contrast, affluent people in the developed world have almost unlimited choice as to what food they eat. Throughout history, as particular civilisations have flourished and food has become plentiful, eating has become a social activity. The way in which food is processed or prepared for the table becomes increasingly important. Increasing numbers of people live to eat rather than eat to live.

In twenty-first century Britain the food industry is huge and complex. Supermarkets and shops stock ingredients from all over the world. Foods that were once seasonal delicacies are available all year round. Many people regularly eat foods that have their origins in different cultures across the globe. Moreover now, as never before, food is a mass media issue. Cookery books abound, and some of them are best sellers; television cooks have joined film stars and pop idols as celebrities; cookery shows attract large viewing figures. Cookery has long been a hobby, but for many people it is now also a form of entertainment. Ironically, research suggests that the more people are bombarded thus by the mass media, the less time they spend actually preparing food for themselves. The demand for ready-made, convenience meals is increasing and people are eating out, or bringing home take-away meals, more and more frequently.

The daily menu you compiled in Item 4C1.1(a) is likely to contrast starkly with the list of foods mentioned in the extract from the fourteenth century poem, *Piers the Plowman*. But even Piers had some processed foods to hand: green cheeses, curds and cream are all processed from milk, salt bacon from pork and ale from grain. Originally, food was processed to preserve it as much to render it palatable. Although today's sophisticated chilled storage and distribution systems enable us to drink fresh milk and eat fresh meat whenever we want, cheese and bacon are still popular foods. These days we look to processed foods like these to add variety and flavour to our diet. Beer is drunk for its alcohol content and its flavour rather than because the water supply is unsafe.

How do you eat? What proportion of your daily diet is raw unprocessed food? How much of what you eat is cooked at home from basic ingredients? How much of your food is processed? How much is in the form of ready-made meals bought from a supermarket and heated at home? How frequently do you eat out, or eat take-away food? Do you eat a few times a day at set mealtimes or do you eat snacks as you feel hungry? To what extent is your eating a social activity? How do your eating patterns compare with those of people a generation ago? What factors influence the way in which you eat?

1. Look once more at the daily menu you prepared in Item 4C1.1(a) and analyse it carefully in terms of the questions posed above.

2. Consider the extent to which the food you eat and the pattern of your daily eating is influenced by your body's nutritional needs.

3. Taking into account the nutritional analysis of your daily diet from Item 4C1.1(b) and your analysis of your own eating patterns from this item, assess whether or not you are eating a balanced diet.

4. One sociological study of eating habits in Britain reported that the lower a family's income the greater the proportion of time spent shopping for and preparing food. Suggest reasons for this finding.

5. Find out about the three major components of food: carbohydrates, lipids and proteins.

CARBOHYDRATES, LIPIDS AND PROTEINS

Food

All living organisms, whether animals, plants, fungi or simple unicellular organisms, require energy to keep them alive. This energy is needed for a variety of purposes; some are listed in the Table 1.

Process	Example
essential processes	movement
synthesis of compounds	attractants: eg, smell in flowers to promote pollination; control chemicals: eg, hormones
manufacture of structures	plant cell walls
homeostasis	maintenance of constant internal temperature in mammals and birds

Table 1 Some purposes for which energy is used in a living organism

Energy is made available to cells by respiration: the transfer of energy from food. Food is a source of stored chemical energy. Without food, cells (and therefore tissues, organs and organisms) have no energy to carry out their functions, and will die.

1

Write down **one** other example for each of the processes listed in Table 1.

Animals and plants differ in the way in which they obtain their food. Plants make their own food by the process of photosynthesis. Animals have to consume ready-made food. Herbivores (eg, rabbits, sheep) eat plants directly; carnivores (eg, herons, lions) eat other animals which have themselves eaten plants.

Animal food consists of carbohydrates, lipids, proteins, vitamins and minerals, water and roughage. Roughage (fibre) is required to assist digestion of the other substances. Water is necessary because the chemical reactions which take place in cells depend on the presence of water. Vitamins and minerals are needed in very small quantities for the healthy functioning of the organism. Most of the diet is composed of carbohydrates, proteins and lipids.

Carbohydrates, proteins and lipids consist of large molecules that are built up from smaller sub-units. The building blocks of carbohydrates are called ***monosaccharides***. Large numbers of monosaccharide sub-units can be joined together to form ***polysaccharides***.

The building blocks of proteins are ***amino acids***. Large numbers of amino acid residues join together to form the polypeptide chains of protein molecules.

Lipids are not built up from large numbers of repeating sub-units. Instead, they consist of a sub-unit of ***glycerol*** combined with one, two or three ***fatty acid*** sub-units.

Carbohydrates

Carbohydrates consist of carbon, hydrogen and oxygen atoms. In the form of glucose, carbohydrate is synthesised in the chloroplasts of plant cells as a product of photosynthesis. The carbon and oxygen atoms come from carbon dioxide, which enters leaves through holes called stomata. The hydrogen atoms are derived from water which is drawn up into the plant from the soil through the roots.

Animals are unable to photosynthesise, so cannot make their own carbohydrate. They must therefore eat carbohydrate which was originally made by plants.

In all carbohydrates, the ratio of hydrogen atoms to oxygen atoms is 2:1, as it is in water. As a result, a general formula for carbohydrates can be written as $C_x(H_2O)_y$, where x and y are integers (whole numbers).

The building blocks of carbohydrates are monosaccharide molecules. These are classified according to the number of carbon atoms in the molecule: in other words, according to the value of the integer, x, in the general formula.

A monosaccharide with three carbon atoms in its molecule (eg, glyceral, which is one of the compounds involved in the chemical reactions in respiration) is called a ***triose***. Trioses have the chemical formula, $C_3H_6O_3$.

A monosaccharide with five carbon atoms per molecule (eg, ribose, which is a building block of RNA) is called a ***pentose***. Pentoses have the chemical formula, $C_5H_{10}O_5$.

A monosaccharide with six carbon atoms in its molecule, such as glucose, is called a ***hexose***. Hexoses have the chemical formula, $C_6H_{12}O_6$.

Hexoses

The molecular structure of the most usual form of glucose is shown in Figure 1. It consists of a ring of six atoms: five carbon atoms and one oxygen atom. The other carbon atom is part of a short, CH_2OH side-chain. The remaining oxygen atoms are all present as OH groups. The remaining hydrogen atoms are bonded directly to carbon atoms of the six-membered ring.

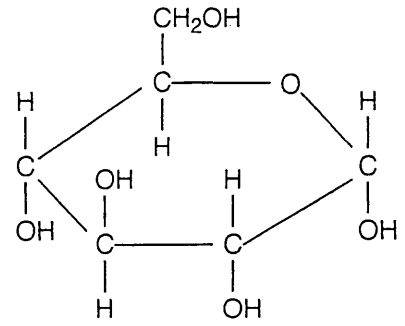


Figure 1 The molecular structure of glucose

Other hexoses, such as fructose and galactose, have the same chemical formula, $C_6H_{12}O_6$, as glucose. But each of these hexoses has its own, particular molecular structure. For example, the structure of galactose is shown in Figure 2.

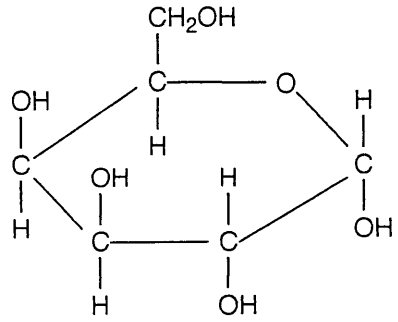


Figure 2 The molecular structure of galactose

The structures of glucose and galactose differ only in the orientation of one of the OH groups. In the representation of the structure of a glucose molecule shown in Figure 1, the OH group on the left of the ring points downwards; in the structure of a galactose molecule shown in Figure 2, this OH group points upwards.

The difference in molecular structure between glucose and galactose is a subtle one, but it is sufficient to make them different compounds. As might be expected, glucose and galactose show some similarities (eg, they both taste sweet), but not all their properties are identical. Because enzyme activity is very specific to the shape and structure of molecules, the difference between glucose and galactose is more striking when they are involved in enzyme-catalysed reactions.

Disaccharides and polysaccharides

Disaccharides consist of two monosaccharide sub-units joined together. Different disaccharides are formed depending on the identities of the constituent monosaccharides. Table 2 lists some common disaccharides.

Disaccharide	Constituent monosaccharides	Occurrence
maltose	glucose + glucose	present in germinating seeds; produced in the 'malting' of barley for brewing
sucrose (commonly known as 'sugar')	glucose + fructose	the form in which carbohydrate is transported in most plants
lactose	glucose + galactose	the carbohydrate present in milk

Table 2 Some common disaccharides

As well as producing a molecule of disaccharide, the linking together of two monosaccharide sub-units also produces one molecule of water. A disaccharide which is produced from two hexose molecules (each with a formula of $C_6H_{12}O_6$), therefore has a chemical formula of $C_{12}H_{22}O_{11}$.

Polysaccharides are polymers built up from large numbers of monosaccharide sub-units. The four most abundant polysaccharides - amylose, amylopectin, glycogen and cellulose - are all polymers of glucose. They differ in the way the glucose sub-units are arranged relative to one another, and in the positions of the links between the glucose sub-units. Information about these polysaccharides is contained in Table 3.

2

The general formula for a carbohydrate is $C_x(H_2O)_y$.
What are the values of x and y in
i) ribose,
ii) glucose,
iii) sucrose?

Polysaccharide	Linking of glucose sub-units	Shape	Function
glycogen	all sub-units arranged in the same way, linked end-to-end, plus many links to the sides of sub-units	very branched chains, folded into compact structure	carbohydrate storage in animals
amylopectin	similar to glycogen, less frequent side links	branched chains, folded into compact structure	carbohydrate storage in plants, constitutes about 80% of starch
amylose	all sub-units arranged in the same way, only linked end-to-end	unbranched chains; coiled into a helix	carbohydrate storage in plants, constitutes about 20% of starch
cellulose	sub-units in alternating arrangement	unbranched chains; uncoiled, straight structure	structural material in plant cell walls

Table 3 The four commonest polysaccharides: all polymers of glucose

Figure 3 contrasts the structures of amylose and cellulose.

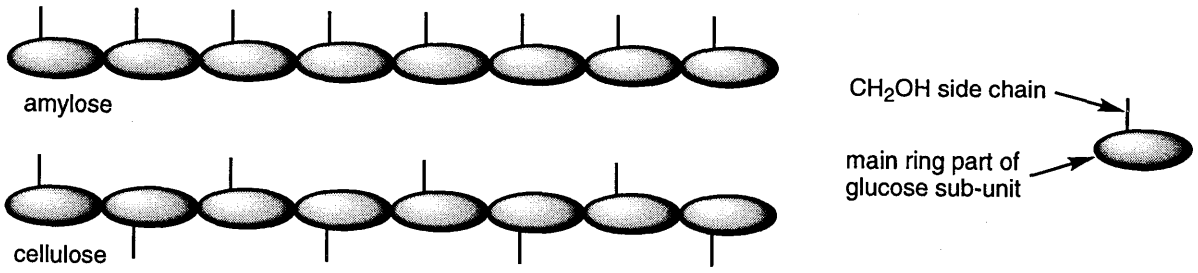


Figure 3 The structures of amylose and cellulose

Figure 4 contrasts the structures of amylose and amylopectin.

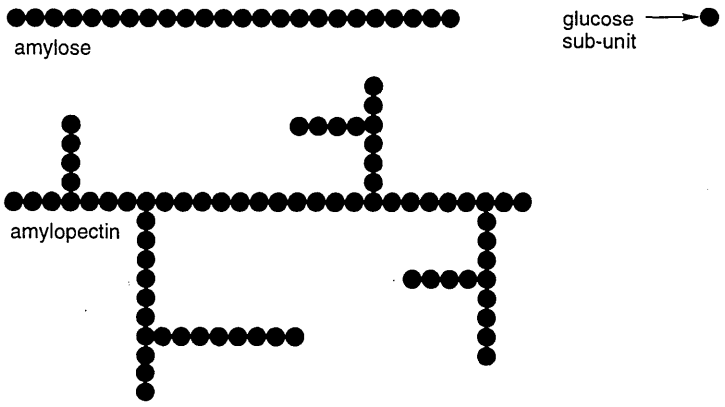


Figure 4 The structures of amylose and amylopectin

Plants synthesise cellulose because it is a structurally useful material. Synthesis of starch or glycogen is a convenient way for an organism to store carbohydrate. Because these polysaccharides are insoluble, they do not affect the concentrations of solutions on the inside or around the outside of cells. When carbohydrate needs to be transported (eg, from the site of its manufacture in leaves to the root system of a plant, or when taking place in chemical reactions in cells), polysaccharides must be broken down into disaccharides or monosaccharides which are soluble. This process requires water to make up for that lost when monosaccharides are linked together. It is therefore a ***hydrolysis*** reaction.

Like most processes in living organisms, the hydrolysis of polysaccharides is catalysed by enzymes. Because the arrangement of the glucose sub-units in starch and glycogen is different from that in cellulose, enzymes can specifically catalyse the hydrolysis of polysaccharides which function as carbohydrate stores without risk of hydrolysing structurally important cellulose.

Lipids

Lipids include several different types of compound: eg, fats, oils, steroids and waxes. They are assembled in the smooth endoplasmic reticulum. All lipids are insoluble in water. This insolubility accounts for many of the functions of lipids in living organisms.

Fats and ***oils*** function mainly as stores of chemical energy in organisms. In mammals, for example, excess carbohydrate can be converted to fat and stored under the skin. Mass for mass, fats and oils yield more energy in respiration than do carbohydrates. They are therefore particularly useful where it is important to keep weight down. For example, fats are stored by migrating birds, and oils are frequently found in seeds which are dispersed by insects or wind.

In mammals, fat acts as an insulator, reducing heat loss. Aquatic mammals, in particular, rely on fat in preference to fur for insulation. Dry fur traps insulating air. In water, when this air is displaced, fur is a much poorer insulator. Fat, packed around vital organs such as the kidneys and heart, also provides protection from physical damage.

Lipid molecules consist mainly of carbon and hydrogen atoms, with only a small number of oxygen atoms. It is their low proportion of oxygen which causes lipids to be insoluble in water. In composition they are not very different from hydrocarbons, which are also insoluble in water.

3

Tristearin, a fat commonly found in animals, has a molecular formula of $C_{57}H_{110}O_6$.

A polysaccharide with a similar number of carbon atoms, built up from 10 monosaccharide sub-units, has a molecular formula of $C_{60}H_{102}O_{51}$.

Calculate the percentage of atoms, which are oxygen atoms, in a molecule of
(i) tristearin,
(ii) the polysaccharide.

Fats and oils have similar molecular structures. Fats are solids at room temperature whilst oils are liquids. Molecules of fats and oils are not built up from repeating sub-units. They consist of a small number, at most three, of ***fatty acid*** sub-units attached to one ***glycerol*** sub-unit.

The glycerol sub-unit is the same in all fats and oils. Its structure is shown in Figure 5. Links to the fatty acid sub-units are through the oxygen atoms.

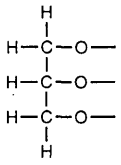


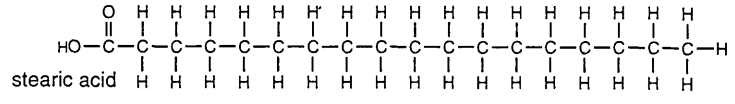
Figure 5 The structure of the glycerol sub-unit in fats and oils

About fifty different fatty acids occur in nature. Some of the most common are listed in Table 4.

Name	Formula	Principal occurrence
oleic acid	$C_{18}H_{34}O_2$	olive oil
linoleic acid	$C_{18}H_{32}O_2$	linseed oil, cottonseed oil
palmitic acid	$C_{16}H_{32}O_2$	palm oil
stearic acid	$C_{18}H_{36}O_2$	human fat, beef fat

Table 4 Some commonly occurring fatty acids

All fatty acids consist of a chain of carbon atoms, terminating in a COOH group, which is the acid part of the molecule. This group forms the link to one of the oxygen atoms of the glycerol sub-unit. Fatty acids differ in the number of carbon atoms in their chain, and in the types of bonds present between these carbon atoms. The carbon atoms in ***saturated*** fatty acids are all joined together by single bonds, whereas ***unsaturated*** fatty acid chains have one or more double bonds between the carbon atoms. Figure 6 shows the structures of a saturated fatty acid (stearic acid) and an unsaturated fatty acid (linoleic acid).



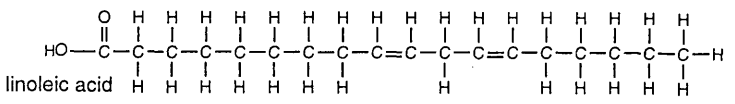


Figure 6 The structures of stearic acid and linoleic acid

Animals tend to make a higher proportion of saturated fatty acids, and plants a higher proportion of unsaturated fatty acids. Medical research suggests that a diet in which most of the fatty acids are saturated (eg, from eating dairy products and meat) can lead to fatty deposits in the arteries, which may lead to heart disease. Unsaturated fatty acids do not seem to cause this effect; so people are encouraged to replace animal fat with plant fat in their diets.

In fats and oils, a maximum of three fatty acid sub-units can be linked to one glycerol sub-unit: one fatty acid sub-unit to each oxygen atom of the glycerol sub-unit. In reality, most fats consist of a mixture of molecules containing two or three fatty acid sub-units. Figure 7 illustrates the structure of a fat with three fatty acid sub-units.

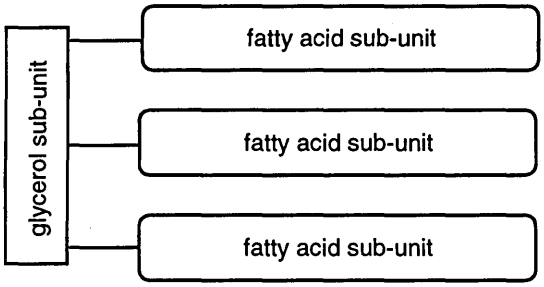


Figure 7 A molecule of a fat containing three fatty acid sub-units

Waxes are lipids made from a sub-unit of a fatty acid, with a very long carbon chain, joined to a sub-unit from a molecule which is much bigger than glycerol and which contains a single oxygen atom. Waxes form an excellent waterproofing layer. Thick waxy cuticles on some plants and insects help prevent desiccation in hot climates.

Steroids are only present in minute quantities in organisms. They can act as hormones (eg, oestrogen and testosterone) and as vitamins (eg, vitamin D). Unlike other lipids, steroids have molecules which consist largely of rings of carbon atoms.

4

Write down **six** functions of lipids in living organisms.

Proteins

Proteins in food are used for growth and repair. Only in exceptional cases, when reserves of carbohydrate and fat have been depleted, will protein tissue be used as an energy source.

The building blocks of proteins are called amino acids. All amino acids contain carbon, hydrogen, oxygen and nitrogen atoms. Sulphur atoms are present in some amino acids. Proteins are built up from about 20 different amino acids. The amino acid sub-units are joined together in long chains, usually between 50 and 2000 amino acid residues long.

An important difference between proteins and polysaccharides is that the chain in a particular protein has a definite length. All molecules of a given protein contain the same number of amino acids joined together in the same order. An almost infinite number of combinations of amino acid sub-units is therefore possible, corresponding to an almost infinite number of proteins.

The complement of proteins in an organism defines the species to which the organism belongs. And small differences between these proteins cause one individual to differ from another individual within the same species. The set of genetic instructions in an individual (its ***genotype***) leads to production of its particular complement of proteins, which defines its unique set of characteristics (its ***phenotype***).

Some of the functions of proteins are listed in Table 5.

Function	Example
enzymes	amylase: catalyses the hydrolysis of starch
protection	antibodies: defend the body against infection
hormones	insulin: controls the metabolism of sugar
contraction	actin: in muscle
storage	ferritin: stores iron in the liver
transport	myoglobin: carries oxygen in muscles
structure	keratin: in hair

Table 5 Some functions of proteins

5

Write down **one** other example, in addition to the one given in Table 5, of each of the following functions of proteins

i) enzymes;
ii) hormones;
iii) transport.

Plants synthesise amino acids by combining carbohydrate molecules with nitrogen atoms taken up from the soil in the form of nitrate ions or ammonium ions. Animals can synthesise some of the amino acids they require; the others must be obtained from breakdown of protein in their food. Humans need to obtain eight amino acids in this way; these are known as the ***essential amino acids***. We can make the other amino acids by a process called transamination which occurs in the liver.

6

Find out the names of the 20 amino acids which occur in human protein. Which eight of these amino acids are essential amino acids for humans?

Protein structure

The general structure of an amino acid molecule is shown in Figure 8.

the R group is different in different amino acids; in the simplest amino acid, glycine, it is a single hydrogen atom

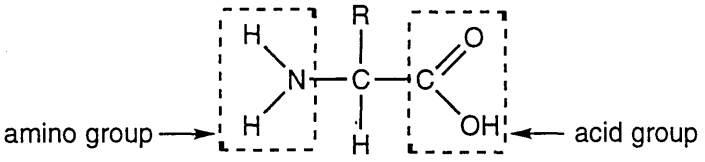


Figure 8 The general structure of an amino acid molecule

Amino acid sub-units are joined to each other by peptide links. The structure of a ***peptide link*** is shown in Figure 9. Proteins consist of chains of large numbers of amino acid sub-units joined together by peptide links. They are therefore also known as ***polypeptides***.

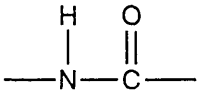


Figure 9 The structure of a peptide link

A molecule of water is produced when two amino acids join together to form a peptide link. Water is therefore needed as a reactant when protein is broken down. This process is another example of hydrolysis.

The sequence of a given number of particular amino acid sub-units in a polypeptide chain is called its ***primary structure***. The primary structure is coded for by the DNA of the cell in which the protein is made. The correct sequence of amino acids is assembled at a ribosome on the rough endoplasmic reticulum. Figure 10 shows part of the primary structure of the protein, insulin.



Gly = glycine; Ser = serine; His = histidine; Leu = leucine,
Val = valine; Glu = glutamic acid; Ala = alanine

Figure 10 Part of the primary structure of insulin

Polypeptide chains in proteins are frequently found to be either twisted into a helix, or stacked side by side in a sheet-like arrangement. These two structures constitute the ***secondary structure*** of a protein. Secondary structure arises from weak interactions between peptide links of amino acid sub-units which are some distance apart in the polypeptide chain. It can therefore be a general feature of any protein. Figure 11 illustrates how secondary structure arises.

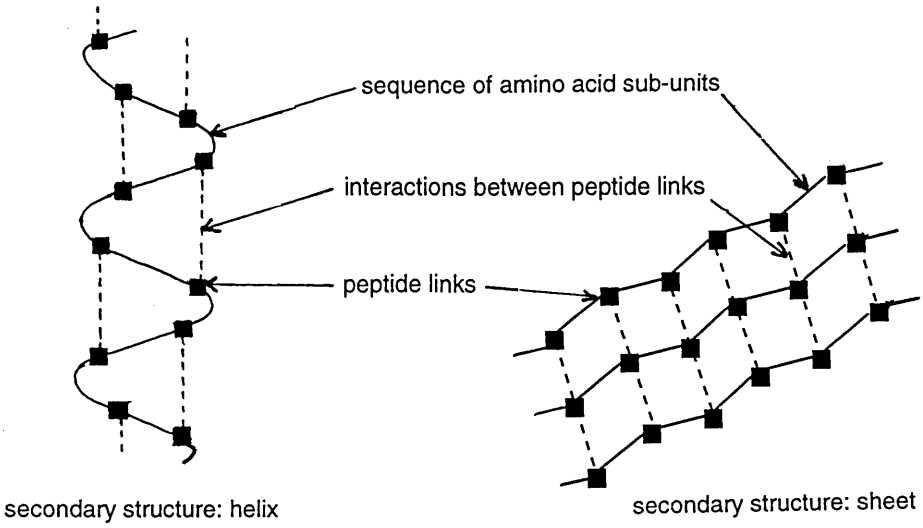


Figure 11 Secondary structure in a protein arises from interactions between peptide links which are some distance apart in a polypeptide chain

The polypeptide chain of a protein, with its regions of helices and sheets, is usually twisted further into a complex, three-dimensional shape. This precise structure, unique to the protein and essential for its activity, is known as the ***tertiary structure***. Tertiary structure results from interactions between the R groups of particular amino-acid sub-units. It is therefore specific to a particular protein. Both strong (ionic and covalent) and weak interactions are involved.

7

How far apart in a protein chain are the interacting peptide links in
i) a helix,
ii) a sheet?

Some proteins are made of several, separate, polypeptide chains folded together. The way these chains are arranged relative to one another is known as the ***quaternary structure*** of the protein. Haemoglobin, the oxygen-carrying protein in blood, consists of four such polypeptide chains.

Representing the three-dimensional structures of proteins

Using a full chemical structure for a large, biologically-important molecule such as a protein, can lead to a very complex representation. Often, the mass of detail in such a representation can obscure the very aspect of the structure which the user wishes to look at: eg, secondary structure.

To overcome this difficulty, other ways of representing the structures of large molecules are employed. Two of these are ribbon diagrams and space-filled structures.

A ***ribbon diagram*** shows only the protein chain, as a ribbon. It shows the secondary structure clearly. Figure 12 shows a ribbon diagram for chymosin (also known as rennin), an enzyme which coagulates milk and is used in cheese-making. To make the secondary structure clearer, only the regions of helix and sheet are shown as ribbon in this representation.

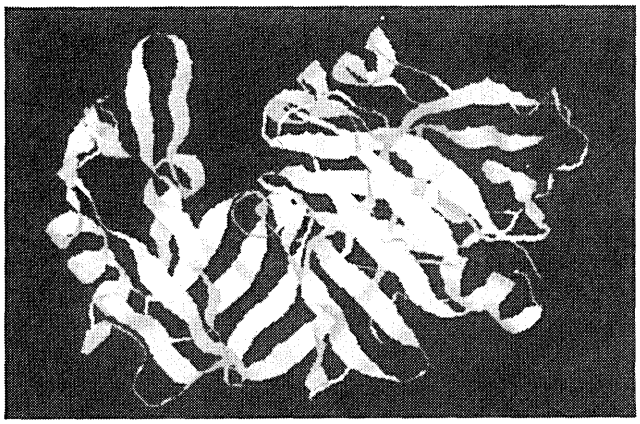


Figure 12 A ribbon diagram for the enzyme chymosin

In a ***space-filled structure***, the side group of each amino acid sub-unit is represented by a sphere. Space-filled structures show tertiary structure clearly. Differently coloured spheres can be used for different side groups. In this way the positions of particular amino acids (eg, those in an enzyme active site) can be revealed. Different colours can also be used for side groups with similar properties (eg, those which bond strongly to water). Regions of a protein molecule which are likely to behave in a particular way can therefore be seen. Figure 13 shows a space-filled structure for chymosin. The active site shows clearly as a deep cleft in the top of the structure.

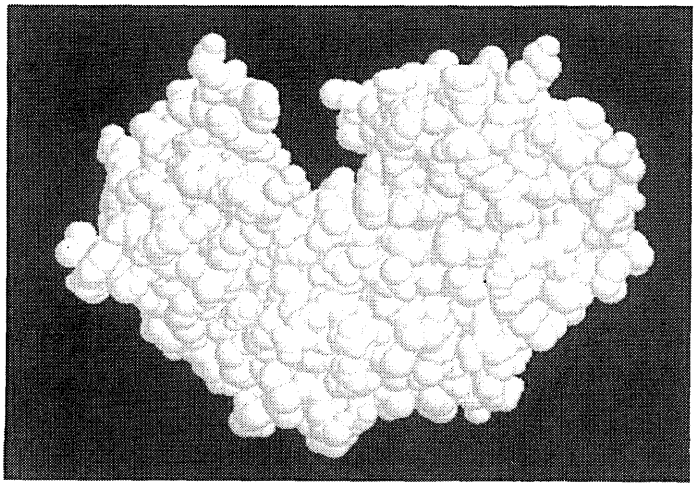


Figure 13 A space-filled structure for chymosin

Summary

- Carbohydrates, lipids and proteins are the major, solid constituents of food.
- Carbohydrates and lipids in food are used principally as sources of energy. In organisms, a major function of both types of substance is as an energy store.
- Proteins in food are used principally as sources of amino acids.
  Organisms use them mainly for growth and repair.
- Plants synthesise carbohydrate in the form of glucose from photosynthesis. Animals must obtain carbohydrate by eating plants or other animals which have, themselves, eaten plants.
- Monosaccharides are the single units of carbohydrates. They are soluble in water and can be transported in solution around an organism.
- Polysaccharides are polymers of monosaccharides. They are insoluble in water but can be hydrolysed into monosaccharides.
- Lipids are insoluble in water. They contain a low proportion of oxygen atoms. Fats and oils consist of a glycerol sub-unit attached to a maximum of three fatty acid sub-units.
- Proteins are polymers built up from amino acid sub-units. Twenty amino acids commonly occur in proteins.
- A protein consists of a definite sequence of particular amino acids: the primary structure of the protein.
- Protein chains form regions of helix and sheet - the secondary structure - as a result of weak bonding between peptide links.
- The overall, three-dimensional shape of a protein - the tertiary structure - results from interactions between side groups on amino acids in the protein chain.
- The structures of proteins (and other large molecules, such as DNA) can be conveniently represented by ribbon diagrams and space-filled structures.

Things to do

1. Make sure you are confident about the following important aspects of this item:

   - the basic structures and cellular roles of carbohydrates, lipids and proteins;
   - the primary, secondary and tertiary structures of proteins;
   - ribbon and space-filled models of proteins.

2. Describe **two** similarities and **two** differences between polysaccharides and fats.

3. Describe **two** similarities and **two** differences between polysaccharides and proteins.

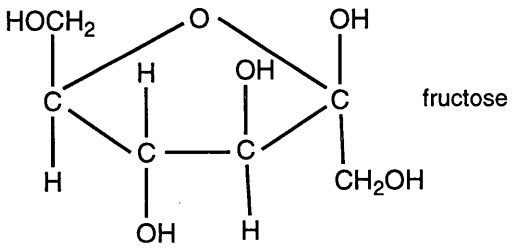
4. Comment on the following statements about foods.

   a. Foods rich in carbohydrate are good energy stores.

   b. Foods containing fats are bad for your health.

   c. You must eat meat in order to have a balanced diet.

5. A chemical structure for the monosaccharide, fructose, is shown below.



   a. Write down the molecular formula of fructose.

   b. Is fructose a pentose or a hexose?

   c. Describe **two** ways in which the structure of fructose shown above differs from the structures of glucose (Figure 1) and galactose (Figure 2).

6. Camels live in desert regions of the world where both water and food can be in short supply. A camel's hump functions as a store of both of these substances. The Table below contains data about a typical fat and glycogen. Both can be used as a food store in an animal. Both yield water as a product of aerobic respiration.

Substance	Energy transferred, per gram of substance, in aerobic respiration / kJ	Volume of water produced, per gram of substance, in aerobic respiration / cm^3	Density / $g\ cm^{-3}$
fat	38	1.11	0.92
glycogen	17	0.56	1.2

a. Use the data in the Table to calculate which is the better store of energy, a hump consisting of fat or a hump consisting of glycogen.

b. Use the data in the Table to calculate the volume of water which can be made available, per cm^3 of stored substance, from a camel's hump

i) when water is the substance stored in the hump;

ii) from aerobic respiration of fat stored in the hump;

iii) from aerobic respiration of glycogen stored in the hump.

c. Camels are extremely well adapted to life in the desert. What substance is stored in a camel's hump? Explain your decision.

7. Mussels attach themselves firmly to rocks by threads which have a waterproof coating made of protein. This protein has a simple composition, being made up from repeating sequences of just six amino acid sub-units. An unusual aspect of this protein is that it has no secondary structure.

a. What term is used to describe the sequence of amino acid sub-units in a protein?

b. What is meant by *secondary structure* in proteins?

c. Explain what is meant by *tertiary structure* in proteins.

d. Suggest why the protein on mussel threads provides a better coating by not having secondary structure.

FROM PLOWMAN TO PLOUGHMAN'S



The simple meal of bread and cheese, washed down with beer, has been common fare in England for hundreds of years. The fourteenth century poet, William Langland, describes his character, Piers the Plowman, as having to hand, among other foods, two green cheeses and two loaves of bread made from beans and bran. Only later in the summer, after the grain harvest was 'good ale' available to Piers and his fellow peasants. By contrast, manorial servants were often fed somewhat better and records show that, in 1289, carters on Fering Manor in Sussex were provided with ample food, including each day a morning meal of rye bread with ale and cheese. The modern equivalent of that meal, garnished with salad and enlivened with pickles, can be found on the menu of almost every country pub. We call the meal a Ploughman's Lunch.

The three main constituents of a Ploughman's Lunch: beer, bread and cheese, are all processed from raw ingredients. Carbohydrate-rich beer and bread are made from cereal grains whereas the protein-rich food, cheese, is made from milk. In each case the processing involves some kind of enzyme activity.

1. What would have been the most likely reasons for converting

   a. grain into ale;
   b. grain into bread;
   c. milk into cheese;

   in the fourteenth century?

2. To what extent are those reasons still relevant today?

- Read on to find out more about the processes involved in making beer, bread and cheese.

BEER AND BREWING

Beer differs from **ale** in that it is flavoured with **hops**, which also help preserve the beer. So modern beer tastes a good deal more bitter than old-fashioned ale. But hops are not a recent addition; herbs have always been used to flavour ale, and hops in particular were already being used by Continental brewers in the thirteenth century. However, the practice was viewed with suspicion in Britain and considered by many to be an adulteration of good English ale. As late as 1512, the authorities in Shrewsbury forbade the use of 'that wicked and pernicious weed'. Andrew Boorde, physician to Henry VIII, believed ale to be the natural drink of the Englishman, and made him strong. But Continental tastes eventually won the day and modern English beer, though tangibly different from Continental beers, and traditionally drunk at room temperature rather than chilled, does contain hops.

Both beer and ale are made from the alcoholic fermentation of grain by the enzymes present in the yeast, *Saccharomyces*, which is added during the processing. Alcoholic fermentation is the chemical change that occurs when cells obtain energy by anaerobic respiration, converting glucose into alcohol (ethanol) and carbon dioxide. In the production of beer and ale, alcohol is the desired product but the carbon dioxide gas bubbling off during the process adds a palatable fizz to the drink.

Before enzymes in the yeast can bring about fermentation, some of the starch must be broken down to produce simpler sugars from which the yeast can obtain glucose. In the first stage of making either ale or beer the grain is moistened and allowed to germinate. Amylase enzymes already present in the grain begin to convert starch in the grain into sugars. After a couple of days the germination is stopped by heating the grain in a kiln. The product, which is called **malt**, is ground to a flour known as **grist**. The grist is added to water and warmed, and enzyme activity continues until all the starch has been converted to sugars, a process known as **mashing.** The sugar solution, or **wort**, is filtered to remove grain debris, then hops are added if beer is to be the product. The resulting liquor is then boiled. Once cooled and strained to remove the hops the wort is transferred to a vat and yeast is added. The fermentation process can then begin.

Modern beer is made from barley, and this would also have been the grain of choice for medieval brewers. But in those times people would have had to use whatever grain was available. At Bolton Priory, for example, so little barley was grown that most of the canons' ale was brewed from oats.

Today the grain residues left over after the mashing process are incorporated into animal feeds. A medieval brewer would reuse the grain again and again to produce worts of decreasing sugar concentration. These in turn were fermented to **brew** beer having three different strengths: the first batch of liquor produced 'strong beer', the next, 'weak beer' and finally, '**small beer**' which would have been scarcely intoxicating at all. This multiple use of the malt was the real advantage of beer over ale. Strong beer was approximately equivalent in alcoholic content to most modern beers and could be kept for up to a year. The existence of these different strengths of beer probably explains the vast quantities which contemporary documents tell us were drunk, for instance, at harvest time.

- The Babylonians are thought to have been the first people to brew alcoholic drinks from grain, around 8000 years ago. Use a good dictionary to find out the meanings and origins of the brewing terms printed in **bold** in the above text.

3. To what culture(s) do the brewing terms you have looked up owe their existence?

4. The terms 'mash' and 'brew' have both come to be used to describe the tea-making process. Consider their meanings and decide which term is the more accurate.

- Many of the smaller breweries hold open days, or will allow small parties to visit by prior arrangement. This is a good way to find out more about brewing.

BREAD AND BAKING

The earliest bread was made, over 6000 years ago, by crushing cereal grains, mixing them with water and baking the resultant dough on hot stones in the embers of a wood fire. This was unleavened bread; the first yeast dough was almost certainly made by accident when, for some reason, a batch of dough was left uncooked for some time and became contaminated by yeast organisms in the air. The resulting risen bread would have had an attractive spongy texture and a better flavour than that of unleavened bread.

The baking of bread, like brewing, involves alcoholic fermentation of yeast. In bread-making, however, the useful product of this chemical reaction is carbon dioxide gas, which bubbles through the dough and causes it to rise. This, together with the kneading process which developes the proteinaceous gluten content of wheat, improves the texture of the bread. The alcohol formed during the reaction vaporises during baking.

In medieval times, pure wheat bread, with the bran sieved out but still containing the nutritious wheat-germ, was a luxury food eaten only by the wealthy. It was known as manchet. Manorial staff were sometimes paid in wheat or other grain but, because wheat had such a high value, these better-off peasants would undoubtably have sold at least some of their wheat allocation to pay for larger quantities of a cheaper kind of grain. Flour made from a mixture of wheat and rye was called maslin, and maslin bread was still being eaten in Tudor times. The bread eaten by poor medieval peasants such as Piers the Plowman would have been coarse and brown, and made from whatever grain people could get. In the lean weeks before the summer grain harvest, we are told that Piers was reduced to baking loaves from bean flour and bran. The contemporary and somewhat derogatory term for this type of loaf was 'horse-bread' because the beans used to make the flour were primarily grown as fodder for animals.

Thus white bread became a symbol of wealth and status. Ever more efficient methods of refining flour were developed until, towards the end of the twentieth century, mass-produced white bread had lost most of its nutritional value and flavour. The pendulum has now swung back and more tasty whole grain, and even mixed grain, breads are eaten not by poor people but by those who are comfortably-off and conscious of their health.

However, hand-made white bread can be delicious and can be made to the following traditional recipe. Unbleached white bread flour (675 g) and a little salt (15 g) are mixed to a soft dough with warm water (about 0.5 l) to which has been added a little fresh bakers' yeast (15 g). The dough is left in a covered bowl until it has risen to twice its original volume (about 2 hrs). It is then thoroughly kneaded on a floured board, placed into a buttered baking tin and allowed to reach double its original volume again (about 1 hr). The dough and tin are placed in a very hot oven (220 °C) then for a further twenty minutes with the oven turned down a little (to 205 °C), the bread being cooked when, taken from the tin, it sounds hollow when tapped.

- Find out how mass-produced white bread is made and how its ingredients differ from those listed in the traditional recipe for white bread given above.

5. Given your knowledge of the process of alcoholic fermentation, describe in terms of enzyme action what happens to bread dough as it rises.

6. How can the factors affecting the rates of these enzyme-catalysed reactions be manipulated to decrease the time it takes to make bread?

- Quick bread-making methods are convenient for home cooks and reduce the cost of producing bread on a large scale, but at the cost of flavour. You might try making some bread of your own using fresh yeast and letting the dough mature slowly.

CHEESE and CHEESE-MAKING

To make cheese, milk, which contains 88% water, must be separated into curds and whey. Curds are solid, containing mainly the milk protein, casein, together with lipids. Whey is mainly water but also contains the sugar, lactose, and some other milk proteins.

One method of separating milk is to introduce certain bacteria which produce enzymes that convert lactose into lactic acid. This is what happens when milk turns sour, and it is likely that the first cheese was made accidentally. This type of soft cheese would keep for longer than milk, which is less acidic and contains more water. But the method of making cheese which is almost universally used today was also known in ancient civilisations. This second method makes use of the enzyme, chymosin, which in turn is found in a substance called rennin, secreted by the stomach linings of calves. Rennin is thus not a micro-organism but an example of a cell-free enzyme. How the discovery that rennin curdles milk was made is not recorded but it is known that the stomachs of slaughtered animal were widely used as storage bags. It is possible that the first rennin-curdled cheese was also made by accident if, for instance, a batch of lactic cheese had been stored in the stomach of a freshly-slaughtered calf.

Today, milk is first soured by lactic acid-producing bacteria and then further curdled, either using rennin obtained from yeast which has been genetically modified or by enzymes obtained from the mould, *Mucor miehei*. The two green cheeses listed in *Piers the Plowman* would have been made using calf rennin, and the term 'green' refers not to their colour but to the fact that these were very young cheeses. In fact, green cheese is little more than clumps of salted curds pressed together, and the similarity between the appearance of the Moon's surface as seen from Earth and that of a green cheese is remarkably similar, hence the old rhyme.

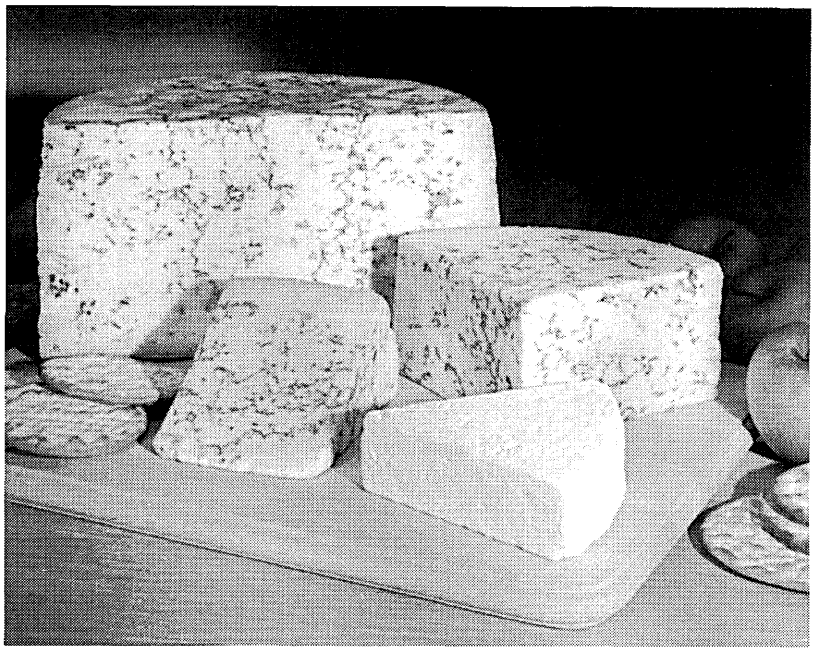
Different types of cheese are made using different recipes, but the resulting cheese depends also on the composition of the milk used, which in turn depends on the diet eaten by the herd that supplies the milk. Originally, sheep as well as cows were kept for milk and it is possible today to buy some cheeses made from sheep's milk, and also goats' milk. Until cheese was first made in bulk in large creameries in the mid-nineteenth century, all cheese was made on farms or in homes and was hugely variable in both character and quality. In England, the pasturelands north and west of the Tees-Exe line produced better milk for cheese-making than the south and east of England, as a glance at a list of names of English cheeses that have remained available until the present day will show.

Cheese owes its extreme diversity even among cheeses of the same type, made at a similar time to the same recipe in the same creamery, to the fact that each green cheese is pressed and then left to mature under carefully controlled conditions of temperature and humidity. During this ripening process any starter lactic acid bacteria remaining from the earlier part of the process quickly die off because the environment within the ripening cheese is anaerobic, and also too acidic for them to survive. As they do so, other bacteria residual in the cheese begin to flourish under these different conditions and if they are the right kinds of bacteria they will bring about chemical changes that will enhance the flavour and texture of the cheese. The result should be a cheese that will gradually improve with ripening, and different types of cheese take different lengths of time to become fully mature. Generally speaking, the faster a cheese ripens the more acidic it becomes and this tendency has on the whole thwarted efforts to speed up the overall cheese-making process.

The final character and quality of the cheese depends largely on the activity of the different micro-organisms that have flourished within it at the different stages of its production. All the cheese-maker can do is to monitor conditions that he or she can control. The ripening cheeses are sampled at intervals and decisions made about whether a particular batch is best left to mature further or best sold young as mild cheese.

- Find out more about the modern manufacture of cheese and about enzyme processes.

CHEESE-MAKING TODAY



This activity is based on the two articles, *Davidstow Creamery* and *Denhay Farms*.

- Read the two articles carefully and then use information from the articles to help you complete the following tasks and questions.

1. In what ways are the locations of the two creameries similar?

- For each of the two creameries, draft a flow chart to outline the cheese-making process from the point at which milk arrives at the creamery to the point at which mature cheddar cheese is ready to sell to customers.

2. a. Identify and label any raw materials used in the cheese-making process.

   b. Add to your charts information about use of energy throughout the process.

   c. Identify and label the useful products, by-products and waste products made during the process.

3. Discuss the similarities and differences between the two processes.

- Consider the scale of operation and efficiency at the two creameries.

4. a. Use the production figures quoted by each of the creameries to compare the scale on which each one is working.

   b. For each creamery, calculate the volume of milk required for the production of 1 kg of cheese.

   c. Comment on the efficiency of use of the raw material, milk, at the two creameries.

   d. Comment on the efficiency of energy use at the two creameries.

- Most large supermarket chains carry a number of different types of cheddar cheese, including a Mature Farmhouse Cheddar and a Mature Cheddar made in a big creamery. Look carefully at the chill cabinet containing cheese next time you are at a big supermarket.

5. a. Which type of cheddar cheese occupies the highest niche in the market?

   b. Suggest reasons why Denhay Farms Ltd. aim for the top of the market with their product.

   c. Suggest reasons why Davidstow's cheese can successfully occupy the slightly lower, Mature Cheddar niche?

   d. Why do you think that both creameries aim to sell to supermarkets?

- Only high grades of cheese meet the legal standards for mature cheddar. In addition, the supermarket buyers exact high standards from the two creameries, and graders from different supermarkets will be looking for slightly different characteristics in the mature cheddar cheese that they sell. A big creamery like Davidstow sells its cheese to a number of different supermarket chains, offering different buyers cheese with slightly different characteristics.

6. Make a list of factors that a supermarket shopper, such as yourself, might make when deciding which type of cheese to select from the shelf.

- The type or make of cheese preferred by an individual is largely a matter of personal taste. Buy a selection of different grades and makes of cheddar cheese from different supermarkets.

7. a. Use your knowledge of scientific investigation to plan and carry out a blind cheese-tasting experiment using the different types of cheese you have bought. Involve as many people as possible in your experiment.

   b. Write a report of the experiment you have devised, the results generated by your experiment and your analysis of those results.

- The operation at Denhay Farms makes use of a traditional agricultural cycle.

8. a. Draw the agricultural cycle using information in the article.

   b. Suggest ways in which Denhay Farms could use that cycle as the basis for an advertising campaign.

- Although the two creameries operate on different scales, and one is based on the farm, both produce sizeable quantities of cheese and sell to supermarkets. There exist cheese-makers who produce very small quantities of cheese. They need to produce a speciality that can command a high price: perhaps a cheese of unusual character.

9. a. Some people say that cheese from unpasteurised milk has a better flavour than that made from pasteurised milk. Suggest reasons why this might be true.

   b. What are the disadvantages of making cheese from unpasteurised milk?

   c. Suggest reasons why both Davidstow Creamery and Denhay Farms pasteurise their milk before making it into cheese.

- Imagine that a smallholder in a remote part of the West Country has a herd of dairy cows and wishes to add value to the milk by making it into cheese. The smallholder has found in an old book the following recipe for a type of cheese no longer made.

BATH CHEESE

> Take 2 quarts of new milk and add, while at 90 °F, just as it comes from the cow, sufficient rennet to bring it to curd in four hours. When the curd is firm and does not adhere to the finger laid upon it, take it out of the setting vessel in slices with a metal saucer and place it in layers in the mould, 4 in by 4 in by 2 in high, until full - the mould should stand upon a straw mat. When the liquid has drained sufficiently, place a clean mat and board over the mould and turn it rapidly. This plan repeated will by degrees make it so solid that the mould can be removed without the cheese falling about. Then sprinkle fine salt over it, spread it with a feather, and place it on a dry shelf in a fairly warm room (63 °F) to ripen it, turning it daily; when a find white mould has covered it it is fit to eat.

10. a. Compare the recipe for Bath Cheese with the way in which cheddar cheese is made. What do you think the cheese might look and taste like?

    b. Rewrite the recipe in modern terms, incorporating hygienic equipment.

    c. Assuming that the cheeseroom and the equipment you have suggested can satisfy legal requirements of health and safety, assess the suitability of this process for very small-scale production on the smallholding.

    d. Compared with mature cheddar cheese, how long do you think Bath Cheese will keep?

    e. Because the smallholding is in a remote area it is not really feasible to sell Bath Cheese on-site, as at the Denhay Farm Shop. What other retail outlets could the smallholder find for Bath Cheese?

    f. Design a distinctive wrapper suitable for Bath Cheese.

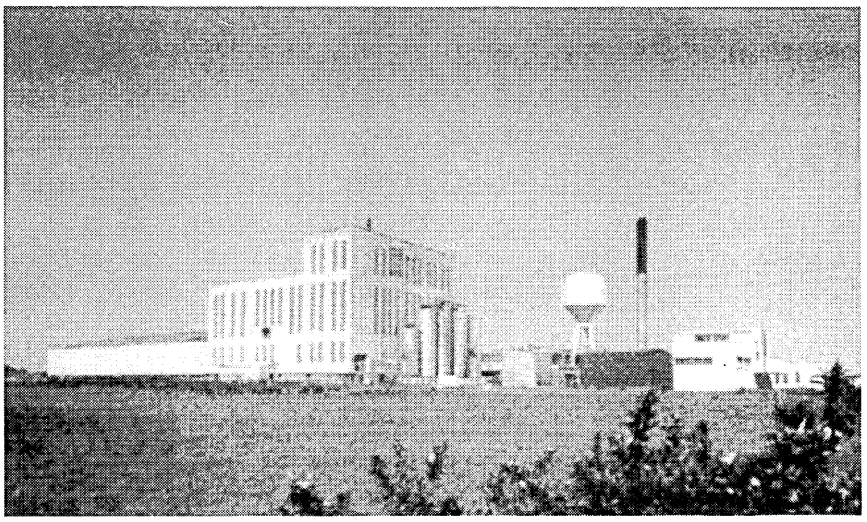
    g. Discuss the feasibility of advertising and even selling Bath Cheese on the Internet. Could Bath Cheese be safely mailed to customers, and if so, under what conditions? How would it need to be packaged? How quickly would it need to be transported?

    h. Once you have decided whether the smallholder should merely advertise, or also sell on the Internet, design some Web pages on behalf of the smallholder. You might even discuss how you would actually put such pages onto the Web.

CHEESE-MAKING TODAY

Davidstow Creamery

The large-scale production of mature cheddar cheese.



Dairy Crest Ltd.'s creamery, at Davidstow in North Cornwall, makes cheddar cheese on a large scale - around 30 000 tonnes of cheese per year from 300 000 000 litres of milk. North Cornwall is best known for its magnificent coastline, but inland of the holiday resorts, the wide, rolling pasturelands have traditionally supported dairy farming. North Cornwall, however, is far from the main centres of population and so before the days of refrigerated bulk transport there was insufficient local demand for the vast volumes of liquid milk produced here. Milk products, such as butter, cream and cheese keep for longer than milk and travel better, and so it is not surprising that a large creamery has grown up here.

Davidstow Creamery is built on the site of an RAF camp and hospital that lay adjacent to an airfield built during the Second World War. The site was purchased, originally by Cow and Gate, in 1950 and developed initially for the transfer of milk. But soon afterwards cheese-making began as a means of smoothing out the peaks and troughs in milk production - which tends to be at a maximum in the Spring.

In 1962, a purpose-built cheeseroom was installed and the company bought a number of farms in the area. The 5 000 pigs kept on these farms were fed the whey which is left over after the cheese-making process.

But, as the scale of production at the creamery increased, it was decided instead to extract the lactose from whey, and sell it. Lactose is used principally by the pharmaceutical industry as a carrier for the active ingredients in tablets. Thus a lactose extraction plant was added in 1968 and remained in operation until the latest refit of the creamery, in 1992, when a whey drier replaced it. Whey powder is now widely used in the food industry as a replacement for dried skimmed milk, and offers a higher return than lactose. Because, whey powder contains about 14% protein as well as 70% lactose, it also finds use as an animal feed.

Whilst liquid whey is highly susceptible to contamination by microbes, dried whey powder is fairly stable, if correctly processed, and has a shelf life of up to 1 year.

Thus, Davidstow Creamery converts milk, which keeps only for a matter of days, into cheese, which keeps for up to a year. The highly unstable by-product, whey, is converted to more stable dried whey powder, for which there is also a market.

In essence, both processes remove water, first from milk and then from whey. That water is not wasted, but is recycled and reused to preheat some of the whey, and for cleaning the plant. This recovery of water is crucial, since South West Water would not be able to supply enough water for the creamery. Water leaves the creamery via a drain, and is carried to Dairy Crest's own effluent plant a mile or so away from the creamery. The treated effluent is discharged into the River Inny at a point two miles downstream from the effluent plant. The River Inny, a salmon river, rises on Davidstow Creamery land. In terms of biological loading, the effluent plant is of a similar size to that needed to serve a town the size of nearby Bodmin. The effluent plant needs to be, and is, efficient.



CHEESE-MAKING TODAY

Davidstow Creamery is a very large cheese-making enterprise. Thus the area from which milk is collected, or 'milk field', is wide, covering most of Cornwall, North Devon and the Plymouth area. Seventy percent of the milk supply is contracted directly and collected by Dairy Crest's own tankers and drivers. Other sources supply an additional and varying amount dependent upon availability and, occasionally, milk is bought in from other food processing companies.

Generally speaking, milk is collected one day and used in the creamery the next. At each farm the tanker driver checks the colour, smell and temperature of the milk, and takes a sample before allowing the milk on board. Having already been refrigerated at the farms, the milk is taken by refrigerated tanker to the Davidstow site and stored in one of eight insulated silos. Inside these, the milk is agitated to keep the fat evenly distributed throughout the milk.

The cheese-making process uses whole milk, and the fat and protein content of milk tends to fluctuate depending on time of year. The consumer wants the quality of the product to remain constant, however, so it is sometimes necessary to standardise the milk before it enters the cheeseroom. In any case, all the milk is pasteurised to current legal requirements in a continuous pasteuriser before it enters the cheeseroom.

Inside the cheeseroom there are 10 oval-shaped vats, rather like gigantic stainless steel roasting tins, with entry ports on the top and pipework above. Each of these vats holds 22 500 litres. Cheese-making at this stage is a batch process, but overall the process can carry on continuously because the different vats are at different stages

In the first stage of the cheese-making process, a starter culture of bacteria (usually a mixture of *Lactobacilli* and *Streptococci*) is added to the milk. Enzymes in these bacteria begin to convert lactose in the milk to lactic acid. Different starters produce different characteristics in the cheese. Ninety per cent of cheese production in this creamery is cheddar, to a mature cheddar recipe, but for 2-3 days per month production is turned over to Red Leicester cheese.

Conditions are set up to allow for production of a cheddar that will ripen and mature well. Obviously, the aim is for a consistent product, but it is impossible to tell exactly what the cheese will be like until the first grading, which is done when the cheese is 2 months old. However, production parameters are kept constant to ensure maximum possible consistency.

After 30 minutes, when the milk is sufficiently acidic for rennin to act, a bucketful of 'vegetarian rennet' is added. The preparation used contains the enzyme, chymosin, produced by fermentation of yeast. An alternative is made from the mould, *Mucor miehei.*, but different coagulating agents act in slightly different ways on the milk, and this does affect the flavour of the cheese produced. So changing the type of rennet is not a step that can be taken in a hurry.

The milk is left to set for 50 minutes, until it becomes a solid mass. The processes taking place in each vat are controlled by computer, but at this stage the 'set' is checked by one of the cheese-makers and the program restarted manually. Once set, the curds are cut by knives which rotate inside the vat. The contents of the vat are then scalded to 39 ^{o}C to drive off some of the moisture from the curds. The knives then rotate in the opposite sense, blunt-ends first, to stir the curds to stabilise them, and then the slurry of curds and whey is pumped out into the cheddaring machine.

The term 'to cheddar' means to allow particles of curd to clump together as is their natural tendency when newly made. Cheddaring produces a uniform waxy texture characteristic of cheddar cheese.

At Davidstow Creamery, the cheddaring process is done by machine. Whilst on the machine, the curds move continuously forward on a belt and the whey falls through the mesh from which the belt is made. The whey contains some fats, and about 2000 litres of cream per day is separated from the whey and made into whey butter, which is sold to the catering industry.

By the time the curds leave the cheddaring machine, they are three-and-a-half hours old, and have clumped together, giving a texture not unlike that of cooked chicken breast.

The lumps of cheddared curd enter a chip mill, salt is added automatically and mixed in, then the curds are piped by vacuum-release pumps to the tops of towers with a rectangular cross-section of 28 cm by 36 cm. The vacuum-release action blocks the curds together and pulls out any excess whey. The curds undergo 27 cycles of the pump, then blocks of the resulting green cheese are guillotined off, bagged in polythene and heat-sealed.

From the milk tanker to this stage the cheese has so far not been touched by humans, although samples are taken at intervals during the cheese-making process and these are analysed for acidity, to check that the process is going to plan.

The polythene-wrapped blocks of green cheese are scanned by metal detectors, weighed, date and bar-coded before going to the packaging machine. This builds a cardboard box around each pack.

The cheeses are then cooled rapidly before being sent to store in batches on pallets, although every fifty-first cheese made is kept separate for sampling, the first samples being taken when the cheese is two months old. Some of the cheese is stored at the creamery, but most of it is taken in refrigerated lorries to another, bigger, store.

During the ripening process, the smooth, waxy texture of cheddar cheese should develop, as should the flavour of the cheese. To produce Mature Cheddar, a block is checked at 5-6 months. If, when the cheese is sampled, it shows signs that it will not go on to mature well, it is sold as Mild Cheddar. Davidstow Vintage Cheddar is ripened for 10-12 months, and is a smooth, full-flavoured cheese with a high value.

Rigorous standards of content and quality are imposed on cheese-makers by law but, in addition, the creamery must also satisfy the requirements of the supermarkets, who are Davidstow Creamery's principal customers. O

CHEESE-MAKING TODAY

Denhay Farms

The production of mature farmhouse cheddar cheese.

Denhay Farms Ltd., in Dorset, make high value products based on the milk industry, the principal one being mature cheddar cheese, which is hand-made at a small creamery on the farm, situated in the hilly pasturelands north of Bridport. This area of clay soils and high rainfall grows lush grass, and has a long tradition of dairy farming. Originally, each farm would have made its own butter and cheese, some to eat and some to sell at market. In this former, cottage economy, butter was made from cream and the skimmed milk used to make a local variety of cheese known as Blue Vinny. This blue-veined delicacy is now being made again in the region, but on a very small scale. Denhay Farms Ltd. produces Mature Farmhouse Cheddar, for which there is far greater demand. Most of this cheese is destined for the supermarket shelf but some goes to smaller shops and delicatessens. Cheese is also sold direct to the public from the farm shop and by mail order.

Thus Denhay seeks to add value to its milk production by converting the milk into cheese. In addition, the cheese made can be stored for 12-18 months, whereas milk is far more perishable, staying fresh for only 3-4 days. Milk contains 12% solids and 88% water. Coagulating milk to make curds reduces the water content and gives the produce a longer shelf-life.

Denhay Farms Ltd. operates a cycle of farming that includes pigs as well as cows. Cows graze on the pastures, although some additional fodder in the form of cereals and soya protein is bought in. The cows produce milk which is used mainly to make a whole milk cheese, cheddar. Most of the whey produced during the cheese-making process is fed to 750 sows and their piglets, and the manure from these pigs is used to fertilise the pastureland grazed by the cows. Thus Denhay Farms produces its own bacon and air-dried ham as well as cheese. Cheese has been made in the creamery at Denhay since 1958.

Currently, the scale of the operation here is a modest 700 tonnes of cheese per year, using 7 000 000 litres of milk. A traditional farm recipe is used and the cheese hand-made six days per week in a batch process. Six people are employed in the cheeseroom.

Ninety-five per cent of the milk used to make Denhay Cheese comes from Denhay's own milk, with the remaining 5% coming from cows on a neighbouring farm. Thus the cheese-makers have control over their 'milk field', including the feeding regimes of the cows. Different cheese recipes are used at different times of year to make the cheddar cheese. This is because the milk itself changes in composition and character on a seasonal basis.

As the milk comes in from the farm it is passed through a continuous-flow pasteuriser, which raises the temp-erature of the milk to 77.4 °C for 19 seconds, and then rapidly cools the milk. Older style batch pasteurisers used to heat a vat of milk up to 60 °C for 20 minutes The milk is kept in a store-room in insulated tanks held at temperatures below 5 °C, preferably between 2-3 °C. These storage silos are colour-coded, and the oldest milk is used first.

In the cheeseroom, milk goes into one of two open vats, and a freeze-dried mixture of starter bacteria is added from a packet. The milk is kept quite warm, at 33.3 °C, and allowed to ripen for an hour. Then microbial rennet, made from the mould, *Mucor miehei*, is added and the milk stirred for just 3 minutes. The milk is allowed to set for 45-50 minutes until it coagulates.

Once the milk is set, the stirrers at the centre of the vat are rotated with their knife-edges forwards and the curds cut until they are the correct size. Cutting of the curds takes 7 minutes. Then the stirrers again rotate in the opposite sense, with their blunt ends forwards, and steam is introduced into the vats to cook the curds at a temperature of 40 °C.

The curds are cooked slowly, for 45 minutes, to allow whey to escape and the curds to harden. After 45 minutes the acidity of the mixture is analysed by back titration and, if it is correct, a valve in the vat is opened and the curds and whey move onto a table.

The table has a perforated central section with a weir at either end to allow the whey to run off. The whey is pumped off at intervals during the forthcoming process. On the table, the curds are stirred four or five times using stainless steel shovels to remove still more of the whey. Then the curds are 'channelled out', or heaped up at the sides of the table, and allowed to amass into large lumps. These lumps of curd are then cut and hand-cheddared, that is, turned and stacked up again to press more whey from them, and to allow the curd particles to clump together. The cheddared curds have the consistency of chicken flesh, firm and fibrous.

When the cheese-maker decides that cheddaring is complete, salt is added to the curds on the table, to prevent unwanted bacterial growth and for flavour. The curds are stirred again and lifted by hand into an overhead chip mill, which cuts the cheddared curds into small pieces. The green cheese is then packed into moulds.

Two batches of cheese are made each day, one in each of the two vats. At the end of the working day the vats are cleaned out, and then work resumes again at 5 am the next morning. The staff work a 6-day week so a total of 12 batches of cheese are made per week. The current plant has been in use at Denhay since 1976.

Any whey produced prior to the curds being salted is sent to a storage tank whence it can be pumped out and fed to the pigs. The whey squeezed from the curds after salting cannot be

CHEESE-MAKING TODAY

fed to pigs, and this goes to an effluent disposal plant where it is discharged. Liquid washings and unsalted cheese waste from the creamery can be irrigated back onto the fields.

Two forms of Mature Farmhouse Cheddar cheese are made at Denhay. Eighty per cent of the cheese produced is in block form, for supermarket sales.

To make block cheddar, the cheese-makers at Denhay pack green cheese into rectangular moulds lined with plastic netting, and then place a lid on the top of each mould. The moulds are then placed in a horizontal gang press for 24 hours, to press out any excess whey. After this time, the blocks of green cheese are removed from the moulds, wrapped in cellophane and brown paper, and placed between wooden slats where they are further pressed. The cellophane provides an airtight barrier, and this method of producing large rectangular blocks gives cheese without a skin or rind, which can be cut by the supermarkets and vacuum-packed into the small rectangular blocks displayed in the chilled cabinets in supermarkets. Each rectangular mould can be cut into twenty 1 kg blocks of cheese, or a corresponding number of smaller blocks.

The remaining 20% of the cheese produced at Denhay is made into traditional, cylindrical cheeses. In this case, cylindrical moulds big enough to hold 25 lbs (11.4 kg) of cheese are lined with hessian cloth. The green cheese is packed into the moulds and tapered plastic lids are put on. The moulds are stacked into the gang press and left overnight. The next morning, the cheeses are taken from the moulds, the hessian is removed and the whole cheeses bathed for 30 seconds in hot water. This is to produce a rind. The cheeses are then re-bandaged with hessian and replaced in the gang press for a further 24 hours.

After this time, the hessian bandages are taken off. The use of hessian has gives the outside of each cheese a textured surface, and onto this is smeared lard. Each cheese is bandaged again, this time with finer-textured muslin, followed by two further layers of lard and muslin bandages. As the rind develops, the cheeses become encased in an air-tight coating.

In the packing room, which is sterilised each morning, the block cheeses receive their wrappings of cellophane and brown paper. Each block is weighed and labelled with the date, the vat number and the weight of the block.

After the cheeses have been pressed they are then bound; they are surrounded with wood and these casings fastened tightly with steel straps. Thus Denhay's block cheese is stored under considerable pressure. Block cheese is stored at a temperature of 10 °C, whereas the cylindrical cheeses are stored at 12 °C.

On the surface of these traditional round cheeses, blue-grey *Mucor* mould grows as the rind develops. These cheeses are turned from top to bottom whilst in storage, twice weekly when young, decreasing to once weekly when older. This is because, as these traditional, unwrapped cheeses sit on the storage shelves, the bases are at a greater pressure than the tops.

Whatever the kind of cheese, two samples from each vat are set aside for grading.

In addition to the block cheeses and traditional, round cheeses, Denhay produces some 4 lb, muslin-wrapped cheeses which are also cylindrical in shape. These special-ities are mainly for the gift market, most being sold around Christmas.

To improve efficiency, this small company belongs to a consortium of 11 farmhouse cheese-makers, which can benefit from bulk buying.

Denhay Farms Ltd. sells only its prime, mature cheeses, the aim being to meet the standards designated for Farmhouse Cheddar. This must be made on a farm, and a high proportion of the milk used must be from that farm. The cheese must be made to a traditional recipe, including the hand-cheddaring of the curd; it must be matured for at least 9 months, and independently graded.

Denhay products occupy a niche towards the top of the market, the major customers being a number of big supermarket chains.

ENZYMES

Enzymes are catalysts for biochemical reactions: the chemical reactions that take place in biological systems. Enzymes are produced by the cells of all living organisms, and control the rates of the reactions within the cells. Enzymes can also be extracted from cells and used to bring about and speed up manufacturing processes. For a very long time, such processes have been used to make beer, cheese and bread. More recently the use of enzymes has been extended to include the manufacture of single compounds such as pharmaceuticals.

The general catalytic properties of enzymes

Enzymes show the same general catalytic behaviour as inorganic catalysts. Thus, an enzyme speeds up the rate of a reaction without being used up itself. This happens because an alternative mechanism is available for the reaction when the enzyme is present. The activation energy in this alternative mechanism is lower than that in the uncatalysed mechanism. Therefore, more molecules possess the energy needed for reaction and the reaction takes place faster. The enzyme is involved in the mechanism of the catalysed reaction but it is also regenerated. So, overall, it is not consumed.

1

List the factors, other than use of a catalyst, that can affect the rate of a chemical reaction.

Figure 1 shows how a catalyst lowers the activation energy of a reaction.

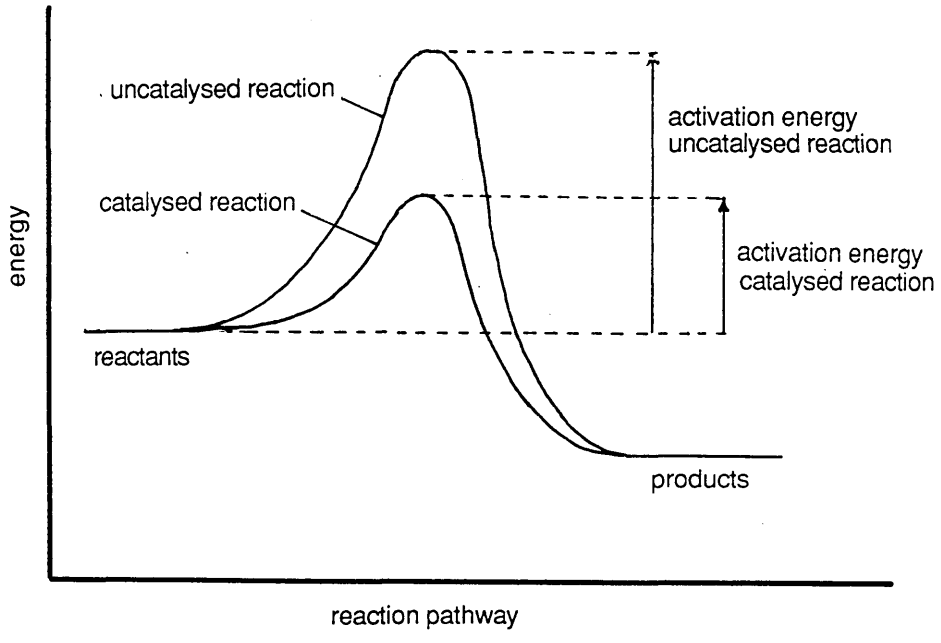


Figure 1 The lowering of activation energy for a reaction in the presence of a catalyst

Figure 2 shows how, because activation energy is lowered, a greater proportion of molecules is able to react when a catalyst is present. Note that Figure 2 does not accurately represent the effectiveness of enzyme action. Enzymes increase reaction rates by factors in excess of 10^6, not by factors of four.

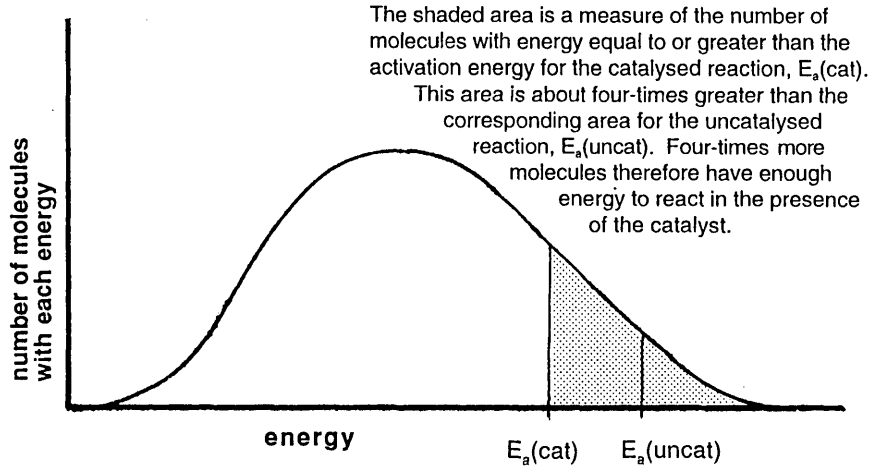


Figure 2 The effect of lower activation energy on the number of molecules able to react

Differences between enzymes and inorganic catalysts

Enzymes catalyse reactions of organic compounds. Other reactants (such as water or oxygen) may be involved, but it is the change to the organic compound which is of interest. This compound is referred to as the ***substrate***.

Enzyme catalysis differs in three ways from inorganic catalysis. Enzyme action is

- effective only over a narrow range of temperature and pH;
- specific to a particular substrate or type of substrate;
- stopped or slowed down by the presence of certain other compounds.

All three of these differences can be explained by the fact that enzymes are proteins.

Enzyme structure

Enzymes are proteins. An enzyme therefore consists of a chain of amino acid residues, which is arranged into a particular three-dimensional structure. This is the tertiary structure of the enzyme. In one part of the enzyme, the structure is folded into a cavity into which the substrate molecule (or part of it) can fit. This cavity is called the ***active site***.

Figure 3 shows a space-filled model of the enzyme chymosin. The active site is clearly visible at the top of the structure.

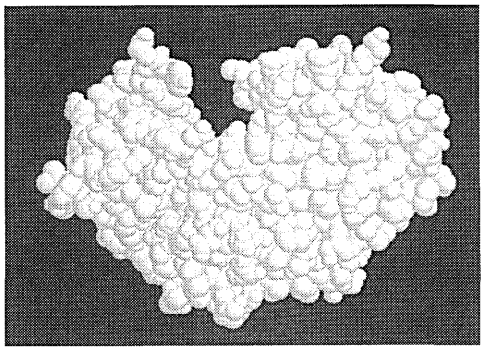


Figure 3 Space-filled model of the enzyme chymosin

The specificity of enzyme action

As a substrate fits into an active site, bonds begin to form between it and the enzyme. The structures of both the substrate and the enzyme adjust slightly in order to maximise this bonding. This process, in which the shapes of the enzyme and substrate are moulded to one another, is called ***induced fit***. The result, when the substrate has fitted into the enzyme, is an ***enzyme-substrate complex***.

In forming the enzyme-substrate complex, the structure of the substrate alters in such a way as to lower the activation energy for the reaction. The products formed from the reaction do not bond with the enzyme. They therefore vacate the active site, leaving it free for another substrate molecule to enter.

This general model of enzyme catalysis, known as the ***lock and key mechanism*** is shown in Figure 4. The active site of an enzyme is constructed in such a way that only molecules of particular compounds have the correct structure to fit and react. So, the enzyme resembles a lock and the substrate a key.

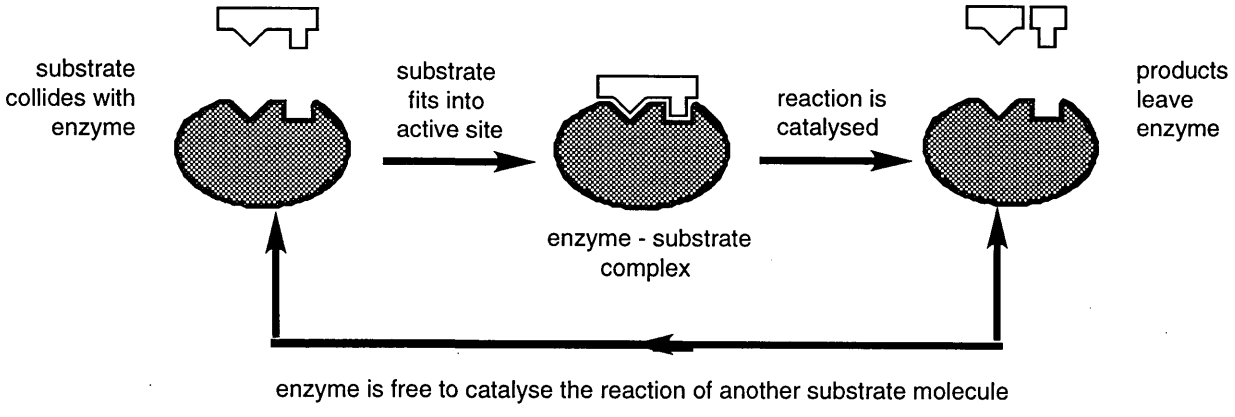


Figure 4 The lock and key mechanism of enzyme catalysis. In this example, a large molecule is split into two smaller molecules by the action of the enzyme.

The effects of temperature and pH on enzyme action

Figure 5 shows how the action of an enzyme and that of an inorganic catalyst change with temperature.

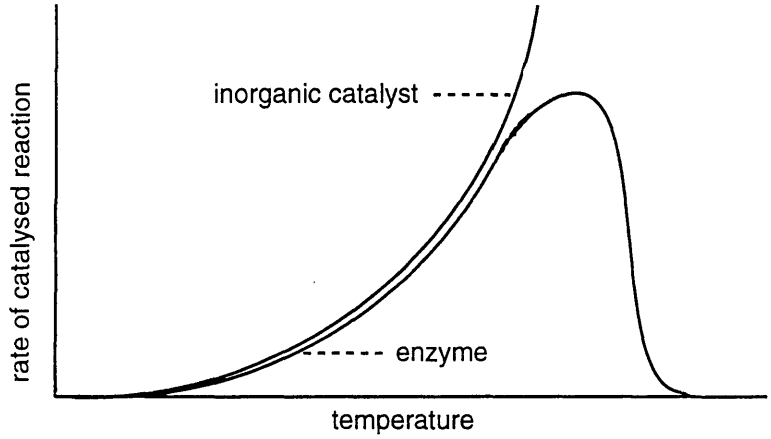


Figure 5 The effect of temperature on the action of an enzyme and an inorganic catalyst

Up to a certain temperature, both types of catalyst behave in the same general way: the rate of the catalysed reaction increases with increasing temperature. Above this temperature, the catalysts behave differently. The action of the enzyme is impaired by increasing temperature, and eventually stops altogether. This happens because temperature affects the tertiary structure of an enzyme.

2

Explain why, in general, increasing the temperature increases the rate of a chemical reaction.

The tertiary structure of an enzyme is held in place by bonding between different parts of the protein chain. Much of this bonding is weak, and begins to break when the enzyme is heated. The tertiary structure therefore begins to fall apart, changing the shape of the active site and preventing formation of the enzyme-substrate complex.

Figure 6 shows how enzyme activity changes with pH. Most enzymes exhibit peak activity in neutral solution, close to pH = 7. There are exceptions: for example, the digestive enzyme pepsin which works best in an acidic environment such as is found in the stomach.

3

Explain how pH is related to hydrogen ion concentration.

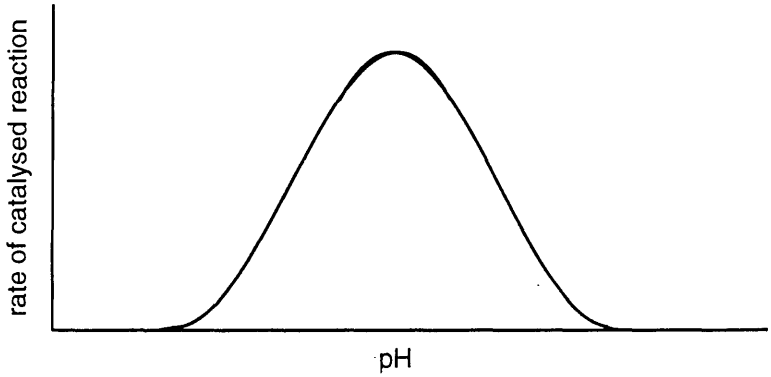


Figure 6 The effect of pH on enzyme activity

The dependence of enzyme action on pH can be explained in terms of the effect of acid or alkali on groups of atoms in the active site. Changes in pH cause these groups to gain or lose H^+ ions. The new groups that are formed are unable to bring about a reaction in the substrate.

At extremes of pH, an enzyme's tertiary structure is destroyed, and with it the active site and enzyme action. The weak bonds which hold the tertiary structure of an enzyme in place are formed between groups of atoms present at different places in the protein chain. Some of these groups can gain H^+ ions if the pH falls, or lose H^+ ions if the pH rises. This causes the chemical nature of the groups to change, and results in them being no longer able to bond with their counterpart groups.

The loss of weak bonding, whether by pH change or by increase in temperature, leads to the same result: a loss of enzyme activity. When this happens the enzyme is said to be ***denatured***.

Concentration effects

Enzyme concentration As long as there is excess substrate, adding more enzyme to a reaction mixture means that more substrate can react in a given time. The rate of reaction therefore increases in step with increasing enzyme concentration as shown in Figure 7.

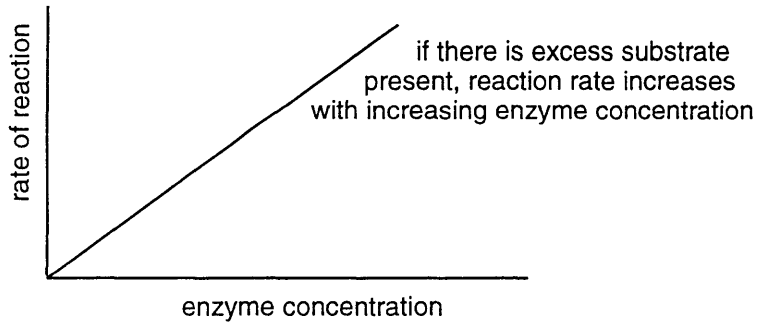


Figure 7 The effect of enzyme concentration on rate of reaction

Substrate concentration Figure 8 shows how reaction rate varies with substrate concentration.

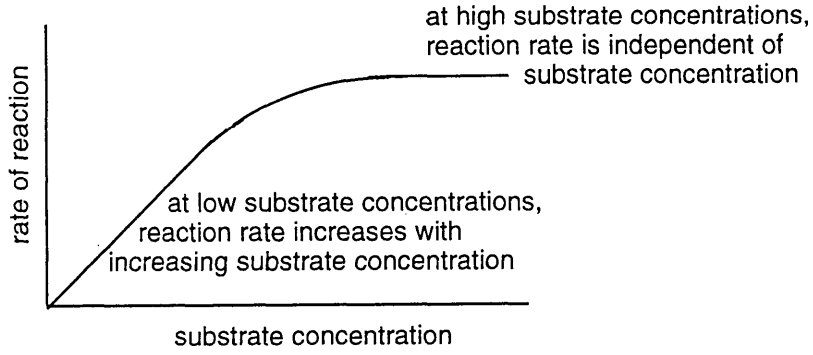


Figure 8 The effect of substrate concentration on rate of reaction

At low substrate concentration, reaction rate increases in step with increasing substrate concentration. Under these conditions, more active sites are available than there are substrate molecules to fit into them. An increase in the number of substrate molecules therefore means that more enzyme-substrate complexes can form; so reaction can occur to a greater extent.

When substrate concentration is high, all active sites are occupied. In the presence of more substrate molecules, therefore, no more enzyme-substrate complexes can form and no further increase in rate of reaction can occur. In such circumstances, where there is saturation of the enzyme, a substrate molecule cannot react until an active site becomes free. It is therefore the availability of active sites, not the availability of substrate molecules, that controls the rate of reaction.

The point at which adding more substrate ceases to increase the rate of reaction differs from enzyme to enzyme. For some enzymes it is reached at very low substrate concentration; with other enzymes, substrate affects reaction rate even at high substrate concentrations. Both effects are used to control the rates of the chemical reactions that take place in cells. Some of these reactions are controlled by the production or destruction of enzyme; others by the release or removal of substrate.

4

Suggest why, in a commercial manufacturing process, it is desirable to use an enzyme that remains effective at high substrate concentrations.

Inhibition

The action of an enzyme can be stopped or slowed down by the presence of a substance other than the substrate. This is called inhibition. A compound that brings about inhibition is called an ***inhibitor***. There are two ways in which a compound can inhibit enzyme action: ***competitive inhibition*** and ***non-competitive inhibition***.

Competitive inhibition Figure 9 illustrates competitive inhibition.

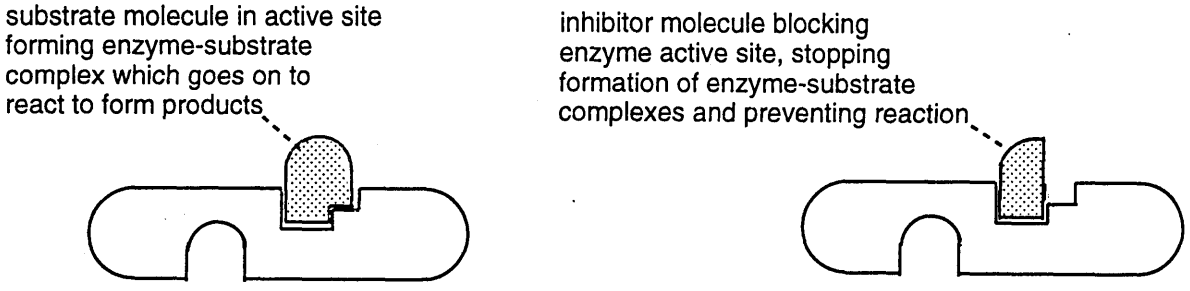


Figure 9 Competitive inhibition

In this case, inhibitor molecules are able to fit into and bond with the active sites. Inhibitor molecules therefore compete with substrate molecules. However, the enzyme is unable to bring about a reaction in the inhibitor molecules. This means that inhibitor molecules remain bound to the active sites, blocking them and preventing access to substrate.

Non-competitive inhibition Figure 10 illustrates non-competitive inhibition.

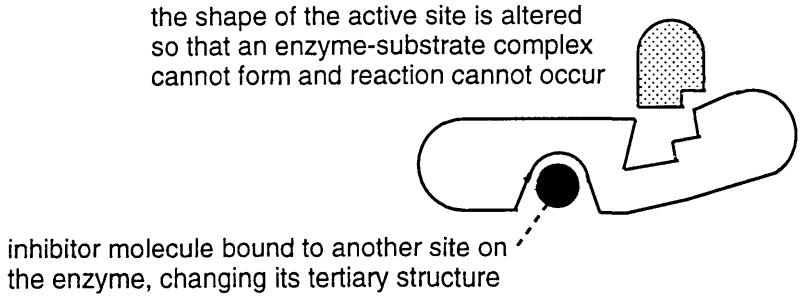


Figure 10 Non-competitive inhibition

In this case, inhibitor molecules and substrate molecules do not have similar shapes, and the inhibitor does not fit into the active site. Instead it binds at another point in the tertiary structure of the enzyme. The inhibitor therefore does not compete with the substrate. However, when an inhibitor molecule binds, it causes the shape of the enzyme to change. This alters the shape of the active site so that substrate molecules can no longer fit and reaction is prevented.

Both forms of inhibition are used in cells to control reaction rates. These are slowed down by release of inhibitor molecules, or speeded up by their removal.

Enzymes in industry

Our use of enzymes to make products that are of value to us is almost as old as the history of settled human civilisation itself. The Babylonians began brewing beer around 8000 years ago. Bread and cheese were being made by other, early societies 6000 years ago.

Throughout most of history, bringing about an enzyme-catalysed process has required the use of a micro-organism (typically a bacterium or yeast) which produces the enzyme. For example, both beer and bread are made using enzymes in *Saccharomyces* yeast.

The use of micro-organisms to provide enzymes that bring about desired chemical changes has recently been significantly extended. One example is the use of *Thiobacillus* bacteria to catalyse the conversion of insoluble copper compounds into soluble copper compounds. This greatly

facilitates the extraction of copper from certain of its ores. Another example has been the use of *Alcaligenes eutrophus* bacteria to manufacture a biodegradable plastic.

The use of micro-organisms in this way looks set to expand further in the future. Possible applications are the production of hydrogen from biomass and of methane from coal, both by bacterial action. Hydrogen is a sustainable fuel. Methane gas can be much more easily extracted from the ground than can coal, and bacteria could 'mine' coal seams that could never be mined by humans.

But there are disadvantages to using microbes to bring about enzyme catalysis. One is that much of the substrate is used up in the growth of the microbial population. The percentage of substrate that is converted into desired product can therefore be low. This disadvantage can be eliminated if 'cell-free' preparations of enzymes are used. For the most part, this is a new technology. However, cheese-making is one process in which the use of cell-free enzymes has been employed for thousands of years.

Simply using an enzyme that has been extracted from the cells of an appropriate micro-organism is seldom effective. Even if enzyme activity is not lost (which it often is), the enzyme itself is lost because it is mixed in with the product. These difficulties can be overcome by 'immobilising' cell-free enzymes: attaching them to, or encapsulating them in, an inert support such as a plastic. Glucose isomerase, an enzyme which brings about the conversion of glucose into fructose, is used industrially in a form in which it is encapsulated in otherwise dead cells.

The major uses of immobilised enzymes are in washing powders, the food industry and fabric treatment. Biological washing powders contain proteases, amylases and lipases: enzymes which break down proteins, starch and fats which stain the washing. These enzymes have been modified to work at the temperatures employed in washing machines. In the food industry, starch is broken down into glucose by amylase and glucoamylase enzymes. The enzyme, glucose isomerase, is then used to convert glucose into fructose. Fructose is widely used as a sweetner, particularly in soft drinks and confectionery, because it tastes much sweeter than glucose.

In the textile industry, enzymes are used for 'desizing' and 'bio-stoning'. Size is a coating used to protect thread during weaving. It needs to be broken down and removed, by 'desizing', to produce the finished fabric. The stonewashed appearance of jeans was traditionally achieved by abrasion of the denim by stones. The same effect is now produced by 'bio-stoning' using enzymes.

Immobilised enzymes can be recovered when a process is over. The product is therefore free of enzyme, which itself can be recycled. In addition, many enzymes become more stable when immobilised. They can therefore be used over a wider range of reaction conditions. These and other characteristics give enzyme catalysis distinct advantages over other forms of catalysis or the use of more severe reaction conditions. The use of enzymes in industry looks set to continue to expand rapidly in the future.

Summary

- Enzymes are proteins and catalysts.
- The tertiary structure of the protein gives the enzyme a precise three-dimensional shape. Part of this forms the active site where catalysis takes place.
- A substrate molecule fits into and interacts with groups present in the active site, forming an enzyme-substrate complex.
- An enzyme can only catalyse a reaction in a molecule with precisely the structure necessary to form an enzyme-substrate complex.
- When it is possible for molecules other than those of the substrate to bind with an active site, they competitively inhibit enzyme action.
- Molecules can bind to parts of an enzyme other than the active site and can non-competitively inhibit enzyme action.
- Enzyme action reaches a maximum at particular values of temperature and pH.
- When temperature becomes too high, or when pH becomes too high or too low, enzyme action is impaired or stopped. This happens either because the tertiary structure is destroyed, or because the properties of groups in the active site are altered.

Things to do

1. Make sure you are confident about the following important aspects of this item

   - that enzymes are proteins which behave as 'biological catalysts';
   - the specific nature of enzyme action;
   - the factors which can affect enzyme action;

2. Our senses of taste and smell are thought to arise from a process which is similar to the lock and key mechanism of enzyme catalysis. The process, called molecular recognition, involves those molecules which are responsible for taste or smell and receptors in the mouth or nose. In this case, the molecules do not react; instead, they bring about changes in the receptors which cause signals to be sent to the brain.

   Describe **two** similarities and **two** differences between molecular recognition and the lock and key mechanism.

3. Enzymes from bacteria which live on the ocean floor may have the potential to bring about chemical reactions under unusual temperature conditions. Some of these bacteria survive at relatively high temperatures near hydrothermal vents. Other bacteria live on the cold ocean floor, away from the vents. A chemical reaction could be made to occur very quickly if it were both catalysed by an enzyme and carried out at a high temperature. A reaction that could be made to take place at a reasonable rate at a low temperature, by using an enzyme, could also be advantageous.

   a. Suggest **one** advantage of using an enzyme to catalyse a chemical reaction in a commercial manufacturing process

      (i) at a high temperature;

      (ii) at a low temperature.

   b. Explain why many enzymes catalyse a reaction of only one compound.

   c. Explain why enzymes lose their activity at high temperature.

   d. State **one** other way in which the activity of an enzyme can be lost.

4. The conversion of glucose into glucose-6-phosphate is the first step in all reactions of glucose in living organisms. This reaction is catalysed by the enzyme glucokinase. The data in the table below show how the rate of this reaction depends on glucose concentration.

Glucose concentration / g dm^{-3}	Initial rate of production of glucose-6-phosphate / g dm^{-3} s^{-1}
0.9	0.18
1.8	0.36
3.6	0.58
5.4	0.68
7.2	0.72
9.0	0.72

a. Plot a graph of rate (horizontal axis) against glucose concentration (vertical axis).

b. Describe how the rate of the reaction depends on glucose concentration

(i) at low glucose concentration (eg, 1.0 g dm^{-3});

(ii) at high glucose concentration (eg, 8.0 g dm^{-3}).

c. Explain why the dependence of rate on glucose concentration changes as the glucose concentration increases.

d. The action of glucokinase is inhibited by 6-deoxyglucose (the structure of which differs from that of glucose in that the CH_2OH group of glucose is replaced by a CH_3 group in 6-deoxyglucose).

(i) Which type of inhibition is likely to be occuring in this case?

(ii) Suggest how inhibition could be caused in this case.

INVESTIGATING THE EFFECT OF TEMPERATURE ON THE RATE OF AN ENZYME-CATALYSED REACTION

Introduction

The rate of an enzyme-catalysed reaction increases with increasing temperature for the same reason as for any other chemical reaction. But with enzymes, this increase occurs only up to a point. If the temperature is raised beyond this point, the reaction rate decreases sharply, falling to zero if the temperature is increased too far.

The coagulation of milk to form junket - one of the first stages in making cheese - is a convenient example of an enzyme-catalysed reaction to investigate. A number of enzymes can be used to make junket. Rennin (correctly called chymosin) is the enzyme that has traditionally been used. More recently, preparations of enzymes from *Mucor miehei* have become available, and are used in making many 'vegetarian cheeses'.

What you need

Rennin (obtainable from most supermarkets: eg, Stone's West Country Essence of Rennet, produced by Ernest Jackson & Co Ltd, Crediton, Devon)
OR *Mucor miehei*, (obtainable from health food shops: eg, available as VegeRen, produced by Just Wholefoods, Cirencester, Gloucestershire)
Milk - full fat, homogenised, pasteurised
250 cm^3 beakers x 2
25 cm^3 measuring cylinder
1 cm^3 graduated pipette
Pipette filler
Boiling tubes (25 cm^3 test tubes) x 10
0 - 110 °C thermometer
Stopclock
Bunsen burners, tripods and gauzes x 2

CAUTION Eye protection must be worn.

Commercial preparations of the enzyme **must** be used.
Do **not** attempt to make up a preparation from the enzyme in powdered form.

What you do

Read through all the steps in these instructions and make sure you understand them before beginning the investigation.

In this investigation you will be using two beakers of hot water. One is kept at 40 °C throughout the investigation. The temperature of the water in the other beaker is raised, in stages, from 40 °C to 80 °C. Be careful when heating water with a Bunsen burner.

Although junket is a food, do **not** eat or taste any junket made in this investigation.

1. Place a boiling tube into a 250 cm^3 beaker. Using a measuring cylinder, add 10 cm^3 of milk to the boiling tube. Add water to the beaker until the water level lies about 1 cm above the level of milk in the tube.

2. Warm the water until its temperature reaches 40 °C. You can use the boiling tube to stir the water gently to ensure that it is heated evenly. Keep the temperature of the water as close as possible (±2 °C) to 40 °C throughout the investigation using gentle heat from the Bunsen burner.

3. Place about 50 cm^3 of water into another 250 cm^3 beaker. Warm the water to 40 °C, then use gentle heating to keep the temperature close to this value. Using a graduated pipette, put 1 cm^3 of enzyme into an empty boiling tube and place it in the warm water for about 5 minutes so that the enzyme can warm up to 40 °C.

4. Pour the sample of warm milk from its boiling tube into the tube containing the enzyme. Start timing using a stopclock.

5. Gently swirl the enzyme/milk reaction mixture to ensure that it is mixed. Then place the tube back into the water that had been used to warm the milk sample.

6. At 1 minute intervals, carefully remove the tube containing the reaction mixture from the warm water and check to see if junket has formed.

   Fully formed junket is a firm, homogenous, yoghurt-like mixture. Do not shake the reaction mixture or it will separate into solid and liquid. In this state it is difficult to decide when the reaction is complete.

   First, to find out if junket is still forming, carefully rotate the tube. The contents will move about in the bottom of the tube if the milk is still coagulating. Then, if you think junket might have formed, carefully tilt the tube. Fully formed junket will stay in place.

7. Record the time taken for junket to form at 40 °C.

   If the reaction is not complete after 10 minutes, record the extent to which junket has been formed. Partially-formed junket is fairly firm but has a curdled appearance, with solid and some liquid visible. It would pour out of the tube if it were to be inverted. If no reaction has occurred, the tube will still contain milk.

8. Repeat the investigation using four other samples of milk and four other samples of enzyme. Make sure you allow time for a milk sample to warm to 40 °C before you use it.

   Each time you repeat the investigation, increase the temperature of the water used to heat the enzyme by 10 °C. What you will therefore be doing is making junket at 40 °C, but using enzyme that has been heated to 40 °C, 50 °C, 60 °C, 70 °C and 80 °C.

What it means

a. Draw up a table containing three columns for your results. The columns are for
   - the temperature to which the enzyme was heated;
   - the time taken;
   - the consistency of the mixture when that time was reached.

b. Explain your results in terms of the effect of temperature on enzyme activity.

PACK 4: THE TECHNOLOGICAL ENVIRONMENT

NOTES AND ANSWERS TO QUESTIONS

4A1.1 Howards End Revisited

Notes

The purpose of this activity is to bring to students' attention the existence of the technological networks on which their lives depend. This is done through the context of the writings of the author, E M Forster, particularly his novel, *Howards End*, which was first published in 1910, and in which Forster makes reference to many of the technological networks existing at that time. The illustrated article, *Howards End Revisited*, which describes a visit to the real places that Forster wrote about in the novel, brings together these and other references. Using this, together with an OS 1:25 000 map of the area, students can trace the networks that Forster describes, and follow the development of these and other networks up to the present day. Students who have not read *Howards End* may wish to do so, though the activity does not depend on them having done so.

Answers

2. a. One of the 'parks of politicians' may have been Knebworth House (230208) and Park, which are shown on OS Pathfinder Sheet 1073, though uppermost in Forster's mind was probably Hatfield House, the seat of successive earls and marquesses of Salisbury. Hatfield House lies some miles south of the area covered by the map.

   b. The map is marked TUMULI at 237236, to the east of the railway line as it approaches Stevenage Station. These are the six Roman burial mounds shown in the photograph on the first page of the article.

   c. 'Hilton' is Old Stevenage.

   d. The 'High Street' is the road running north-south through Old Stevenage; it then becomes the B197.

3. The Great North Road approached Stevenage from Knebworth along what is marked on the map as Stevenage Road. It ran close to the tumuli, then followed what is now the pedestrian walkway past the Police Station and the buildings marked Offices. A modern bridge over the dual carriageway links this with another stretch of the Great North Road, before becoming Old Stevenage High Street. It then ran out of Old Stevenage along what is now the B197, to Gravelly.

4. There appears to be the remains of a former station at 229256.

5. Starting from the old station, Margaret Schlegel walked to the Bowling Green, which is marked on the map as a triangular open space (233255). From here, she walked along the Chestnut Avenue, now a footpath, to the church at The Bury. She proceeded along the lane, past what is now a cemetery, to Rooks Nest House.

6. Rooks Nest house is the property marked Howards on the map.

7. The article tells us that Forster makes the following references to the following technological networks in his writing:

   the telegraph network;

   the railway system;

   road systems, before the coming of the railways
   and after the advent of the motor car;

   early electric power supply networks;

   the water supply to which Rooks Nest House was eventually connected.

8. The map reveals evidence of the networks that would have existed at the time Forster wrote Howards End: for example, the railway and the Great North Road described in Mrs Munt's journey to Hilton, and the Chestnut Avenue and the road to Weston taken by Margaret Schegel. The circular structure to the west of the railway line, just south of the tumuli is a gasometer (this can be verified from the photograph in the article taken from the pedestrian walkway to the station); parts of central Stevenage would have had a piped supply of town gas at the time Forster wrote Howards End. However, the line of pylons to the north of Rooks Nest House was not built until the 1920s. In the early part of the twentieth century, Rooks Nest House was still supplied with water from a tank on the roof.

9. a. Much of the rail network in Britain dates back to the nineteenth century, and the main east coast line (and the branch to Hertford) shown on the map are no exception. Many lines were taken out of use in the 1960s; stretches of dismantled railway track are marked on the map, between Standon (395225) and Buntingford (364293). There is no evidence on the map of new railways under construction.

   b. By contrast, the road network in Britain has developed over hundreds, and even thousands, of years. It is difficult to tell, just by looking at a map, the precise age of a road: some footpaths and bridleways are relatively modern and some major roads follow the course of ancient trackways. However, a number of Roman roads are marked on the map, and it is fairly safe to assume that winding lanes linking small settlements are of ancient origin. The course of the Great North Road, which was hugely important prior to the railways, when long distance transport was by horse-drawn coach, is somewhat obscured by more modern networks serving Stevenage New Town. The main route to the north is now along the A1(M), which passes to the west of the town. Other recent roadbuilding includes the network of roads giving access to new housing estates. This programme is still under way as new building continues on the edge of the New Town.

   c. In Forster's day there was a single line of pylons across the valley to the north of Rooks Nest House. Now there are two high voltage power lines, both of which converge, along with other lines, at the transforming station at Wymondley (205268).

   d. The water supply network that can be traced on the map post-dates the local system that Forster describes Rooks Nest House being connected to, after many years of prevarication on the part of the landlord. An underground reservoir

(248254) at Pin Green stores water for use by the inhabitants of Stevenage. The purpose of the water tower on this site, as of other water towers in the vicinity (eg at Aston (275237) and at Wymondley (215271) is to raise the head of water (and thus the pressure). The modern water supply system also includes pumping stations, such as the one (282234) north east of Aston.

Wells are denoted on the map by a blue 'W' and springs, by 'Spr', also in blue. Springs occur when water stored in the rocks (ground water) finds its own way out of the ground. A well is a shaft sunk into water-bearing rock. Both wells and springs, however, give an indication of the natural supply of ground water in an area. Water supply systems make use of ground water supplies, and also of water from the river and canal networks. In some countries, the water supply network includes water purified from seawater.

10. A list of currently available technological networks might include the following:

NETWORK	POSSIBLE CLASSIFICATION
road	
rail	
air flight paths	
shipping routes	
navigable waterways	TRANSPORT
cycleways	
bridlepaths	
footpaths	
water supply	WATER
sewerage	
gas supply	
oil supply	FUEL/POWER
electric power	
telephone/fax	
postal service	
optical fibre network	COMMUNICATION
cable television	
Internet/WWW	

This classification, which is along tangible lines, does not include the distribution of goods, which can be by road, rail, sea or air. Neither does it include methods of broadcast communication, such as the mobile 'phone networks, broadcast radio and television which nevertheless depend for their operation on a network of transmitting and receiving stations, as well as the receivers owned by individuals.

11. It may be advisable for students to approach the task of listing advantages, disadvantages and possible environmental impacts of each of the networks as a group effort, splitting the task between a number of people and then pooling ideas. Alternatively, the task could be adapted to create a number of different personal assignments for students.

12. a. In the first extract Forster predicts that, with the development of powered flight, the sky will become as pestilential as the roads. It appears that he thinks, in 1908, that already the roads are too busy, and possibly noisy and smelly. He is looking at aesthetic aspects of air and road travel. He goes on to equate the advent of powered flight with an end to peace, and in doing so is thinking about ethical and political aspects of technological development.

Forster asserts in the second extract that the countryside is irreplaceable because, whilst people make towns, it is made by Time. There is an aesthetic judgement being made here: Forster clearly finds countryside more attractive than he does towns.

In the third extract, Forster addresses a social aspect of the building of new towns and new housing: that people need good housing. But he is torn between the desire to fulfil a social need and his own aesthetic sense which, once again, leads him to mourn the loss of the English countryside.

b. This activity provides an opportunity for students to put forward scientific arguments for and against the opinions expressed by Forster in the three passages. Approached thoughtfully, and with some further research, the activity could form the basis of an extended assignment for students.

Regarding the first extract, in answer to Forster's description of the roads in 1908 as 'pestilential', students might find and describe statistics about the increase in road traffic during the present century. They might also discuss the pollution associated with road traffic and weigh the disadvantages against the benefits of increased personal mobility and availability of goods as a result of road systems. Students could then discuss, with the benefit of hindsight, the accuracy of Forster's assertion that the new technological civilisation would bring an end to peace.

Students might argue, regarding the second extract, that not only the towns but also almost all the countryside in Britain has been influenced, often over many centuries, by human activities of various kinds. They might find examples of the history of the use of a particular piece of land, perhaps locally.

NB It might interest students to design and carry out a simple pyschological study of what types of landscapes different people find aesthetically pleasing, and which they find unattractive. Is there, for instance, a correlation between the 'age' af the landscape someone is asked to look at, and their reaction to it? Do some people prefer the scenery of towns to that of the countryside. What aspects of country scenery do people tend to find attractive and why? An investigation of this sort, well-researched and carried out scientifically, might form an extended assignment.

In the case of the third extract, students might discuss the environmental impact of building new towns, as opposed to regenerating city centres or building at the outer limits of existing towns and cities,

4A2.1 Networks of power

Notes

This set of tasks are based on the article *Networks of Power.* However, students may also find helpful the information in Item 4A2.3 *Electricity Supply* when answering these tasks.

Answers

1. The practical drawbacks of a fragmented electricity supply system would be that each supply company would need reserve power stations in case of breakdowns, and thus the consumer would be charged more for electricity so that the company could meet the capital and running costs of these. Also, the fact that supplies produced by the different, independent companies were at different voltages and frequencies meant that, in the case of a breakdown, consumers could not be supplied from another company's power station ie an electricity supply network would have been impossible.

2. Immediately a national system was introduced electricity supply became more efficient, and the cost to the consumer was reduced.

3. Because, by the outbreak of the Second World War, there existed the means of coupling together the regional grids, it was possible to supply electricity to areas that had suffered bomb damage from areas where power stations were still operational.

4. Meeting the increase in demand by increasing the capacity of the existing 132 kV grid would have meant the building of more lines. Replacing the existing grid with a 275 kV 'supergrid' involved fewer lines and could be designed to carry an even higher voltage should demand for electricity increase further.

5. The building of the 275 kV 'supergrid' enabled electricity to be transported more cheaply than before. The cost of transporting electricity was then lower than the cost of transporting the fuel to generate it. Thus new power stations were located close to coalfields and oil refineries in contrast to older ones, which had been built close to consumers.

6. Students will need to look at geography text books, environmental atlases or at booklets issued by the power generation companies to find the location and types of power stations in Britain.

7. It is possible that plans for a 1 MV 'super-supergrid' for the UK have been scrapped because demand for electricity has not been as great as had been predicted some years ago.

8. An artist was brought in to design an aesthetically pleasing transmission tower (pylon) for use in the first, 132 kV grid, and the pylons were designed to be spaced at such a distance that the curves of the conductors resembled the lines of a suspension bridge, which are quite leasing to the eye.

The decision to create a new 275 kV network reduced the number of power lines needed to meet the increasing demand for electricity.

The routing of lines has required increasing care as the awareness of the public of the need to preserve landscapes has increased.

Substations have been camouflaged and landscaped using earthmounds and/or trees.

400 kV 'twin' conductor circuits have replaced some of the 'quad' lines, reducing the visual impact of the conductors themselves.

Much of the lower voltage supply system, and a smaller proportion of the high voltage supply network, has been routed underground.

9. All the pylons are designed to carry a double circuit of three-phase supply.

The distance between conductors of the same circuit is roughly equal. This is presumably to do with the prevention of electrical discharge to the ground, through the air, and is thus a safety measure.

The height from which the lowest conductor is suspended is the same for designs from all countries except Russia, where it is lower. The height above the ground of the lowest conductor is again a safety factor, although this is dependent not only on the height of the arm of the pylon, but also on the spacing of pylons. It is possible that the Russian pylons are designed to be sited closer together than the other pylons in the diagram.

10. The article describes the original 132 kV pylons as being 21 m high, and those designed to carry the 275 kV supply as being twice as tall as that. An average two-storey house is about 10 m tall and a sizeable tree, such as a mature conifer or beech, can grow to a height of about 15 - 20 m.

11. Public awareness of the need to preserve the landscape and to minimise the visual impact of made structures on the environment have made it progressively more difficult for the electricity supply industry to negotiate new routes for power lines. More recently, worries about possible health risks from the electric and magnetic fields associated with power lines have further increased environmental concern.

12. 'Double circuit' means that two separate supply circuits being carried by the same power line.

An 'alternating current' is one in which the direction of flow of electrical charge changes with time.

A 'three-phase' supply is one comprising three different waveforms of alternating current, each of which is out of step with the other by a third of a cycle.

'Conductor' is the term given to a single overhead cable.

13. It was necessary to fit longer strings of insulators to pylons when power lines were upgraded from 275 to 400 kV to increase the distance between the conductor and the arm of the pylon, which is also made of conducting material. The greater the voltage the greater the distance over which a flashover (artificial lightning discharge) can occur.

14.



'single line' 'twin line' 'quad line'

For the 'twin' and 'quad lines', spacers between the conductors are placed at frequent intervals along the line.

15. A single circuit of a 400 kV 'quad line' has three bundles of four conductors and thus carries 4 times the power of a single circuit of a 132 kV power line, which comprises single lines,

In addition, since power is proportional to voltage and 400 kV is roughly 3 times 132 kV, each of the 400 kV conductors can carry 3 times the power of a 132 kV conductor made of the same material and of the same design.

That the article quotes the figure of 18 (rather than 12) times the power means that improvements must have been made to the conductivity of the conductors, thus reducing power losses in transmission.

16. To be able to replace 400 kV quad lines with 400 kV twin lines and retain the same amount of power to be transported means that still further improvements to the conductivity of the conductors must have been achieved.

17. The role of the CEB in the operation of the first national grid was to construct a national gridiron of high voltage transmission lines connecting the major power stations, to control the amount of power generated in each of these, to buy the power in bulk and then to sell it back to the different distribution companies as required.

18. Information about the National Grid Company and the Regional Electricity Companies can be found in literature produced by each.

The address of the National Grid Company is Burymead House, Portsmouth Road, Guildford, Surrey, GU2 5BN.

Contact addresses and telephone numbers of the Regional Electricity Companies can be found in telephone directories.

19. Information from this item, and from 4A2.2 *Out in the Field* is sufficient for students to build up the following picture of electricity supply.

Power stations generate three phase supply, usually at 20 kV. This is stepped up for transmission, by means of a step-up transformer, to either 275 kV or 400 kV. The supply is then transmitted via the national grid to a main substation where it is stepped down to 132 kV. From this point, distribution is the responsibility not of the NGC of the Regional Electricity Companies. The 132 kV lines lead to an grid supply point, where the voltage of the supply is reduced further (usually to 33 000 V) for further distribution across country, or direct to industry. Intermediate substations reduce the voltage still further, to 11 000 V. This supply is either carried by overhead lines supported by wooden poles or by underground cables to final distribution substations. Supplies for isolated houses and farms (these are sometimes three-phase supplies at 415 V) are taken off the 11 000 V lines and stepped down by means of small transformers on poles. At the final distribution substation the voltage is reduced to 240 V for domestic consumption and carried either underground or overhead lines supported by wooden poles. These normally carry four conductors (three carrying the three phases (lines) plus a common return conductor). Usually just one 240 V line (ie one phase) goes to each house.

From this information students can design and draw a flow chart, the artistic sophistication of which might vary according to the time being allocated to the task and to the artistic talent of individual students.

4A2.2 Out in the field

Notes

This activity is in effect a field trip on a page. If students go out in the field to look at the power aspects of the electricity supply network for themselves it is vital that they observe the safety guidelines given at the beginning of the item.

Answers

1. B shows a telegraph pole carrying telephone wires On the pole in the photograph these radiate out from the pole, coming very close together at the pole itself, where there are no insulators.

   C shows a pole carrying 240 V power lines. These are bare conductors and are insulated from the pole itself by ceramic discs.

2. The 11 000 V poles shown in the photographs differ from those carrying 240 V in that, for the most part, the conductors are arranged in a triangular configuration, and are further apart. Also, larger insulators separate the conductors from the arms of the poles. Both of these differences in design are necessary because the higher voltage supply creates a stronger electric field than the lower one.

3. Whilst an 11 000V overhead line consists of bare conductors electrically insulated by the air, an 11 000 V underground cable would need to be covered in insulating material. This is because the earth is a much poorer electrical insulator than the air.

4. Supplies to farms and isolated houses are taken from 11 000 V lines, and stepped down, often in the case of farms to 415 V, by means of a small transformer mounted on a wooden pole.

5. The following parts of the equipment are insulators: the pole itself (wood), the discs separating the bare wire from the pole(in this case, glass) and from the transformer casing (ceramic), and the material (plastic) covering the cable leading from the transformer.

   The following parts of the equipment are conductors: the bare wires (mainly aluminium), the transformer casing (steel) and the core of the cable leading from the transformer.

6. The supply is routed underground a few metres outside the perimeter fence of the intermediate substation. Underground cable is insulated, where as overhead conductors are made of bare wire, so by routing cables underground as they converge on a substation prevents the occurrence of electrical discharges through the air.

7. The design of tension towers allows the conductors to be kept at the right degree of tautness and also for the line to be disconnected should problem occur.

8. Insulators on either side of a tension tower isolate electrically isolate the conductors on either side of the tower. Electrical contact between the two sides of the tower is made via the looped conductors on each arm of the tower.

9. The single conductor running along the tops of pylons is an earth wire linking the pylons together ensuring the pylons are all at zero potential.

10. The danger is from the electric field produced by the power line. A person approaching the overhead conductors by climbing a pylon would be electrocuted.

11. The rod-shaped structure immediately beneath the last insulator of a string is designed, should the pylon be struck by lightning, to act as a lightning conductor. A discharge would be made through the air from the arm of the pylon to the upturned metal rod rather than through the insulating discs, thus avoiding damage to the latter.

4A2.3 Electricity supply

Notes

There are no tasks and questions associated directly with this item, though students will need to use information from the item to help them carry out tasks associated with Item 4A2.1 *Networks of Power.*

4A3.1 Invisible networks

Notes

This item has been written in the form of an article designed for students following a specialist physics course. It is an opportunity, therefore, for non-specialist science students to interpret text written in scientific terms. The tasks and questions will help students develop their understanding of electric and magnetic fields.

Answers

1. The presence of the natural electric field surrounding the Earth creates electrical discharges (characterised by flashes and crackling noises) at high altitudes, especially on sharp ridges and at the ends of ice picks. This concentration of electrical charge around pointed objects also manifests itself as St Elmo's Fire, which sometimes occurs at the tops of ships masts. People standing in strong fields may find that their hair stands on end.

2. a. i) The electric field beneath a storm cloud is about 200 times greater than the Earth's natural field on a fine day.

   ii) The electric field beneath a 400 kV power line is about 600 times greater than the Earth's natural field on a fine day.

3. a. The annotations to the diagram should point out the porcelain insulator discs, with corrugated undersides to maximise the distance along which current might track. The corrugations are on the undersides rather than the tops of the insulator discs to prevent build up of dirt and moisture, which might conduct current. A note should also be made of the metal cap cemented to the top of each porcelain disc and the metal pin cemented to the underside. These metal parts increase the tensile strength of the insulator string.

   b. It is important to clean the discs from time to time to prevent the build up of dirt which allows current to flow across their surfaces.

4. a. The danger from electric field associated with power lines is that of electrocution: ie electrical discharge through a person's body to earth, which can cause death from heart failure or severe burns.

   b. Many fishing rods now contain a proportion of carbon fibre. This material is a good electrical conductor. There is thus a danger, from holding a long, pointed, conducting object in an electric field, of an electrical discharge from the power line to earth, though the fishing rod. The person holding the rod is in danger of being electrocuted; so pylons sited close to rivers and lakes carry a special warning to anglers.

5. a. The magnetic field beneath overhead power lines is normally less than the Earth's own magnetic field.

b. The principle difference between the Earth's magnetic field and man-made magnetic fields is that, whilst the former is unidirectional, the latter are alternating.

c. The magnetic field at ground level decreases sharply in strength with distance from the power line.

6. a. In a three-phase supply the magnetic field associated with one conductor is partially cancelled by the field from a neighbouring conductor in which the current is flowing in the opposite direction at any time.

b. Three-phase conductors arranged vertically, and in an inverted configuration, produces the smallest magnetic field.

7. The insulation surrounding underground cables prevents the electric field from field extending into the surrounding earth, and there is no accumulation of charge at ground level above the cable.

The magnetic fields in the vicinity of underground high voltage cables are larger than those close to overhead lines. This is because cables carrying the different phases have to be separated to prevent overheating, and the magnetic fields do not cancel out as effectively as for overhead lines.

8. b. Devices incorporating electric motors create higher fields than other electrical devices.

c. The magnitude of magnetic field created around an appliance also depends on the amount of iron in the design of the appliance. Lightweight appliances containing little iron allow more of the magnetic field to escape. Thus the magnetic field surrounding a vacuum cleaner, which has a fairly heavy duty motor, is likely to be less than the magnetic field surrounding an electric can opener but greater than the field surrounding a washing machine. A sensible estimate would be a few hundreds of μT.

9. Item 4A 3.3 gives some insight into recent investigations into the possible effect on health of alternating magnetic fields. In addition, materials on this topic are available from the EMF Unit burymead House, Portsmouth Road, Guildford, Surrey, GU2 5BN.

4A3.2 Fields, forces and motion

Answers (Things to do)

2. a. Speed = 180×10^3 m $h^{-1} \div 3600$ s h^{-1} = 50 m s^{-1}.

b. Travelling at 50 m s^{-1}, a train would have to push away a 50 m column of air every second.

c. The volume of air pushed aside in 1 s = 50 m x 10 m^2 = 500 m^3.

d. The mass of air is approximately 500 kg.

e. The speed of the air increases from zero to 50 m s^{-1} in 1 s.
The acceleration is therefore 50 m s^{-2} .

f. Force (in N) = mass (in kg) x acceleration (in m s^{-2}).
Therefore the force exerted by the train is:
500 kg x 50 m s^{-2} = 25 000 N (or 25 kN).

g. Work (in J) = force (in N) x distance moved in direction of force (in m).
Therefore the work done in 1 s = 25 000 N x 50 m = 1 250 000 J
(or 1 250 kJ or 1.25 MJ).

h. Power (in W) = work done (in J) per second.
Therefore the power needed by the train to move the air is 1.25 MW.

i. Energy is also used to overcome friction: eg, between the train and the air, the air moved and the surrounding of the air, or between the moving parts of the engine. Power is also needed, in practice, for lighting, heating, air conditioning, making hot drinks in the buffet car, etc.

3. a. The field lines show the direction of the force which would act on a positive charge placed in the field.

b. i) The field lines point towards the base of the cloud. Therefore this must be negatively charged since a positive charge placed in the field would be attracted to a negative charge.

ii) Overall the cloud will be electrically neutral; the top of the cloud is therefore likely to be positively charged.

iii) The field lines point away from the ground which must therefore be positively charged.

c. Field lines are closer together where the electric field strength is greater.

d. Electric charge is carried by electrons which are negatively charged. The force causing these to flow to the ground will be greater where the field lines are closest.

e. The safest places to shelter are those where the field lines are furthest apart: eg, between the factory and the trees or between the trees and the hill.

f. Because field lines are closer at tall features in the landscape it would be safer to crouch down rather than to stand if caught in a thunder storm.

Answers (Tasks)

1. i) ".. doubled."

ii) ".. 1 m s^{-1}."

iii) ".. 1 m s^{-2}."

iv) ".. 0.5 m s^{-1}."

v) 60 m.p.h. = 0.0167 miles per second. The average acceleration over 10 s is therefore 0.00167 miles per second per second.
Alternatively this can be expressed as 0.00267 km s^{-2} or as 2.67 m s^{-2}.

2. i) Objects of the same mass experience a force six-times greater on Earth.

ii) Identical masses will have an acceleration six-times greater on Earth.

3. a. i) At 6 m the apple has twice the potential energy it has at 3 m.

ii) A 150 g apple has twice the potential energy of a 75 g apple on the same branch.

b. i) At the same speed a train has more kinetic energy because it has a greater mass than a car.

ii) The kinetic energy of a cyclist is four-times greater at 20 km per hour than at 10 km per hour.

4. i) Two protons would experience a repulsive force because they carry identical charges.

ii) The charge on an electron is of the same size but opposite charge to that on a proton. Two electrons would therefore experience a repulsive force of the same magnitude as that between two protons.

iii) A proton and an electron would experience an attractive force of the same size as the repulsive forces in i) and ii).

4A3.3b Types of epidemiological studies

Answers

TASK 1

a. It cannot be assumed that working as a barman increases the risk of becoming an alcoholic. It could well be that alcoholics spend longer in bars and are therefore more likley to take up jobs as barmen. An important aspect of establishing a link between a factor and a medical condition is sequence: exposure to the factor must preceed onset of the condition for it to be a cause.

b. It cannot be assumed that belonging to a lower socioeconomic group increases the chance of developing a serious disease. It could be that sufferers from such diseases are unable to hold down demanding, higher paid jobs and as a result fall into a lower socioeconomic group. Again, it is important to establish a correct sequence for cause and condition.

TASK 2

b.

	cases		controls	
	men	women	men	women
exposed (smokers)	647	41	622	42
non-exposed (non-smokers)	2	19	27	32

c. The odds ratios are: 14.1 (men) and 2.5 (women).

d. The results show that, for both men and women, lung cancer patients are more likely to have been exposed to cigarette smoke.

e. The results indicate that 'passive smoking' could be a cause of lung cancer. In other words, living or working with a smoker could increase a person's risk of developing lung cancer even though that person does not themself smoke. It is likely that many non-smoking women would have been living with a male smoker, but less likely that a male non-smoker would be living or working with a female smoker.

TASK 3

a. The table is

	exposed to cigarette smoke	not exposed to cigarette smoke
develop lung cancer	133	3
do not develop lung cancer	23636	5436
total	25769	5439

b. Relative risk = $5.16 \times 10^{-3} \div 5.5 \times 10^{-4} = 9.38$

4A3.3c An epidemiological study of low frequency magnetic fields from power lines and childhood leukaemia

1. The odds ratios are

   a. 2.7, for children living in fields of 0.2 μT or above;

   b. 2.9, for children living within 50 m of a power line.

2. Controls were selected so as to be as close to cases as possible with regard to: time of moving into the same area and near the same power line, age and sex. Otherw ise they were selected at random. The technique of collecting past magnetic field

strengths was checked using present day data. These data were collected in a way which prevented any interference from the operators of the field gauges.

3. a. A very large cohort would need to be selected to ensure that a sufficient number of cases of leukaemia subsequently developed.

b. The reliability would be less if there were very few cases because few more or less cases would make a very big difference to the result.

c. The Swedish epidemiologists took a large sample of children: in fact all those who had lived near to a high voltage power line anywhere in the country over a period of 25 years. They also had access to detailed and complete records of power loads over 25 years and, in the case of leukaemia, good hospital records are kept.

4B1.1 The location of a chemical works: a case study

Notes

This item gives historical and geographical perspectives on the location of one particular chemical works: BP's Grangemouth site. The extract from the OS map reproduced in the item is from the 1:50 000 Sheet 65.

Answers

The following factors can influence the siting of a chemical works.

LAND There should be a suitably sized area of land available, preferably with room for expansion should this become necessary. The site should flat and a suitable distance away from residential areas. The land should be as inexpensive as possible to buy.

WATER A supply of water is usually needed for cooling and dilution of waste materials, which may need to be discharged, suitably diluted, into a water course. A deep water navigable waterway is an advantage if raw materials are to be brought in, or products transported out, by ship.

SKILLS The chemical industry requires a skilled workforce. It thus makes sense to site a chemical works in an area where there are people who are already hold the same or similar skills rather than relocate large numbers of people to the area from different parts of the country.

RAW MATERIALS Often a chemical works is sited close to a source of one or more of the raw materials it uses, especially if these are bulky and expensive to transport in comparison to their value.

COMMUNICATIONS Good communications are important for bringing in the raw materials, transporting the product away from the works, and for getting the workforce to and from the site from where people live.

The extent to which the BP Grangemouth site fulfils these criteria is as follows:

From the maps and photographs, it is clear that the Grangemouth site occupies an area of flat land on an estuary (the Firth of Forth), and that this is not prime building land, and therefore relatively inexpensive. Despite the large chemical works that has grown up here, there is still room for expansion.

The estuary provides cooling water, and a means of discharging waste.

The OS map extract shows the site to be relatively close to residential areas and to other industrial areas, though the main evidence of the presence of a skilled workforce is from historical infomation rather than from the maps and photographs,

The main raw material, oil, comes from the North Sea fields and is piped from the Forties field to the east coast of Scotland, and then overland to Grangemouth, crossing the Firth of Forth at Bo'ness.

Communications are good. Besides the incoming pipeline, there is a 30-inch pipeline to carry products away from the site and to the (storage) Tank Farm at Dalmeny. The site is well served by roads and railways, and there are three airports within a 75 km radius. Over 75% of the Scottish population live within this radius.

The areas occupied by the three different works: the separation of gas from North Sea oil (A), the petrochemical plant (B) and the refinery (C) can be found by correlating the information given on the annotated aerial photograph with Map 4. The perspective of the aerial photograph might lead the viewer to think that the three works occupy roughly equal areas. On sketching the three works onto the map students will find that this is not so.

The scale of the Map 4 is 1:50 000 (ie 2 cm represents 1 km).

Thus estimates of the areas occupied by each of the sites are as follows:

A About 0.75 km^2;

B About 1.25 km^2;

C About 3.5 km^2.

The initial reason for the existence of a chemical works at Grangemouth was the finding of oil in local coal deposits (and later in oil shales). However, Grangemouth was a suitable site for the reasons described earlier. The Firth of Forth provides water, and a means of transport to and from the site. Before the development of the North Sea oil and gas fields, crude oil from the Middle East would have been brought to the site by tanker ship. When the demand for oil and petrochemicals increased and the site expanded, there was already a skilled workforce in the area so, although the source of raw materials was not local, the site remained viable. Now North Sea oil is used, the source of raw materials is once again closer to home, and oil is piped in to Grangemouth in preference to building a new refinery and petrochemical works on the east coast of Scotland which would be less central in terms of Scotland's population, and which would require large numbers of skilled workers to be relocated.

4B2.1 Making poly(ethene)

Notes

This item gives technical information about the manufacture of poly(ethene) that can also be used in Items 4B2.2 and 4B2.3. The tasks included in this item are designed to help students think more broadly about the chemical industry.

Answers

2. a. Students draw up a pie-chart from the information given in Table 2.

   b. If the entire life histories of products are considered, students will find it hard to find one that can be produced without a contribution from the chemical industry. Even organically grown vegetables are cultivated using manufactured implements with metal parts, for example hoes. To eschew the chemical industry completely would mean reverting to Stone Age technology.

4B2.2 The design of a chemical factory

Answers

COMPARISON OF FUEL AND MATERIALS USE FOR LDPE AND HDPE

FUEL Manufacture of ldpe uses more fuel than hdpe manufacture because higher temperatures and pressures are used. However, there are possibilities for the recovery of heat in a useful form via steam generation in ldpe manufacture. The lower temperature (80 °C) used in hdpe manufacture means that heat recovery using steam is not possible.

MATERIALS Manufacture of ldpe requires only the materials which go into the formation of the polymer. In hdpe manufacture, solvent and catalyst are also required. Recycling can be used to recover most of the used solvent, but catalyst is either left in small quantities in the polymer grains, or destroyed by water after polymerisation has been stopped and catalyst recovery is not practicable.

SAFETY AND ENVIRONMENTAL ASPECTS OF LDPE AND HDPE MANUFACTURE

SAFETY The use of high temperatures and pressures, along with flammable hydrocarbon material, increases the risk of accident in ldpe manufacture. The use of solvent and a catalyst based on chromium or titanium compounds necessitate additional safety requirements in hdpe manufacture.

ENVIRONMENTAL Emissions of hydrocarbon gases, and solvent from hdpe production, are reduced to a minimum by recycling. Most other releases can be made safe by combustion. The biggest hazard is likely to arise in hdpe manufacture from deactivated catalyst, which must be disposed of carefully to avoid environmental damage.

4B2.3 The environmental burden of chemical production

Answers

Among other applications of clean technology, the INNOVENE process incorporates
- internal recycling of solvent from the pre-polymerisation stage;
- use of a small mass of catalyst which is only used in a pre-polymerisation stage (a scaled-down version of the main stage in hdpe production);
- use of a small volume of solvent which is only used in a pre-polymerisation stage (a scaled-down version of the main stage in hdpe production);
- accurate temperature control in the main reactor;
- separation and internal recycling of incompletely formed polymer;
- separation and internal recycling of unreacted gas and liquid feedstock.

All these are examples of technology changes leading to waste reduction at source. The redesign of the process to give polymer granules which each contain a trace of catalyst is an example of a product change which avoids the disposal of concentrated catalyst waste.

Aspects of clean-up technology in the INNOVENE process are
- some hydrocarbon material is collected and burned;
- some catalyst waste from the pre-polymerisation stage is collected and disposed of by containment.

4B2.4 Ethene, poly(ethene) and other hydrocarbons

Answers (Things to do)

2. a. Alkynes are hydrocarbons and therefore, like alkanes and alkenes, are composed of only carbon and hydrogen atoms. Alkynes differ in that there is a carbon to carbon triple bond in their molecules.

   b. Around each carbon atom in ethyne there are eight outer shell electrons. A pair of these is shared with a hydrogen atom. The remaining six electrons are shared with the other carbon atom in a triple bond (three shared electron pairs).

   c. The bond angles are 180°.

3. a. $C_2H_4 + Cl_2 \rightarrow C_2H_4Cl_2$

   b. $C_2H_4 + HBr \rightarrow C_2H_5Br$

4. a. The repeating unit is $-CHCl-CH_2-$.

   b. $-CHCl-CH_2-CHCl-CH_2-CHCl-CH_2-CHCl-CH_2-$.

Answers (Tasks)

1. a. Names of the unbranched alkanes are
C5: pentane C6: hexane C7: heptane C8: octane

2. a. Molecular formulae are: ethene, C_2H_4; propene, C_3H_8.

   b. The general formula for alkenes is C_nH_{2n}.

3. a. The prefix but- indicates that a molecule contains 4 carbon atoms.

   b. The prefix pent- is used for molecules containing 5 carbon atoms.

4. a. $C_2H_4 + H_2 \rightarrow C_2H_6$

   b. In ethene, each carbon atom forms four bonds - one to each of two hydrogen atoms, and a double bond to the other carbon atom. The two single bonds to hydrogen remain when ethane forms, but the double bond is replaced by a single bond to the other carbon atom and another single bond to a third hydrogen atom. In a hydrogen molecule, each atom has a single bond to a second hydrogen atom. This is replaced by a single bond to a carbon atom when ethane forms.

5. a. The products are:
butane and ethene;
propane and propene;
hexane and ethene.

   b. Octane could also be cracked to form:
pentane and propene; butane and butene;
pentene and propane; hexene and ethane.
Appropriate equations should be written.

6. Addition polymerisation of alkenes occurs at both ends of the C=C double bond. The CH_3 group in propene is therefore a side group in the polymer.

4B2.5 Rates of chemical reactions

Answers (Things to do)

2. a. Immiscible means 'do not mix'.

   b. i) Two immiscible liquids form two separate layers when added together, the denser liquid forming the lower layer.

   ii) Two separate layers would form with the solid at the bottom.

c. Shaking or stirring are commonly used to mix such materials.

d. The mixture of oil and vinegar used in vinaigrette dressing is an example of a pair of immiscible liquids. Certain paints or indigestion remedies are examples of mixtures of a solid and a liquid which need to be stirred before use.

e. Mixing exposes all the surface of a solid to reaction. If unstirred much of this surface is out of contact with the liquid. Similarly, breaking down immiscible liquids into a large number of small droplets brings about a greater surface contact between them.

f. When gas is blown through a layer of fine grains of solid, the grains remain close together but float in the gas, moving randomly. Their behaviour is similar to that of the molecules in a liquid, and the gas/solid mixture has the properties of a fluid.

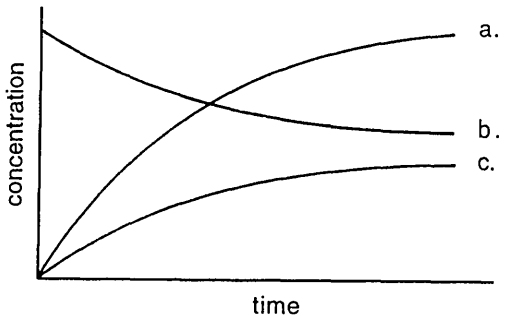
3. b. i) The first half-life is the time taken for the volume of oxygen to rise from 0 cm^3 to 128 cm^3, which is 1200 s. A second half-life, the time taken for the volume to increase from 128 cm^3 to 192 cm^3, can be found from the graph. It is also 1200 s.

A third half-life can be found by starting at any point on the graph and finding the time taken to get from that point to when the volume of oxygen is half way between the point and 256 cm^3. For example, the volume is 100 cm^3 at 850s. The half-life is the time taken to get from this point to 178 cm^3. This volume is produced after 2050 s, and therefore the half-life is 1200s (2050 s - 850 s).

ii) The three half-lives have a constant value of 1200 s which shows that the reaction is first order.

iii) The rate equation shows that this reaction is first order with respect to dinitrogen pentoxide.

4. Expected curves are shown below.



Answers (Tasks)

1. a. i) & ii) In both cases the rate of photosynthesis would be expected to increase. However, photosynthesis does not consist of just one chemical reaction and, in practice, this will only happen as long as other necessary processes are able to take place fast enough to allow carbon fixation and light trapping to respond, unhindered, to the changes made to them.

   b. i) The smaller grains in caster sugar will dissolve faster.

   ii) At the lower temperature of the cold drink sugar will dissolve more slowly.

2. At higher pressure, molecules in a gas are closer together. This means that there are more molecules in a given volume and that the concentration is therefore higher.

3. Features with a sharp profile have a greater surface to volume ratio that flat surfaces and therefore would be expected to corrode more rapidly leaving a featureless lump of stone. In practice, the situation is more complicated and the rate of corrosion also depends on such factors as how quickly rainfall runs off the stone and which planes in the original limestone have been exposed in carving. (Limestone corrodes more rapidly in some directions than in others.)

4. This time concentration must hardly change during the time measurements are taken. This can be arranged by using a large excess volume of acid. Experiments can then be carried out each starting with pieces of marble of a different size.

5. All experiments stop at 240 cm^3 of carbon dioxide. If the acid concentratiion is halved then twice the volume of acid must be used to give the same extent of reaction with pieces of calcium carbonate.

6. i) First order (with respect to only N_2O_5).

   ii) Second order (with respect to NO_2).

7. A catalytic convertor is cold for the first few minutes of use. The rate of the reaction it is catalysing remains slow until the convertor is warmed to its operating temperature by the hot exhaust gases.

8. Without temperature control such reactions would get hotter and hotter, and therefore faster and faster, with the danger that an explosion could occur.

9. A green gas is absorbing red and blue light from the visible region of the spectrum. The energy transferred from green light is insufficient to cause bond breaking in chlorine and therefore does not affect the reaction. In this case, therefore, the lower energy transferred by red light will also not affect the reaction. Only blue light will be effective.

4B2.6 Investigating the effect of concentration on the rate of a chemical reaction

Note

Attention must be paid to the safety warnings in this experiment.
As suggested in part 8, students might profit from practising putting the filter paper into the flask before they begin to take measurements.

What it means

a. Reaction rate can be affected by temperature, pressure, particle or droplet size, light intensity and catalyst, as well as by concentration.

b. All experiments are carried out at the same temperature and pressure - room temperature and pressure. Use of filter paper discs soaked in catalyst ensures that the quantity of catalyst, and its area of contact with the solution, are as constant as possible in different expeiments.

c. It would not be possible to add reasonably constant quantities of catalyst from a spatula.

d. Unless the stock solution of hydrogen peroxide has decomposed to some extent (which is likely), all experiments should produce 200 cm^3 of oxygen in total.

e. Some specimen results are shown in the table which follows.

Volume of oxygen produced / cm^3	10 volume hydrogen peroxide solution Time /s	6.7 volume hydrogen peroxide solution Time /s
10	-	-
20	5	8
30	10	25
40	23	40
50	30	68
60	47	90
70	75	125
80	115	150

f. 50 cm^3 is 25% of the total extent of reaction.

g. The time taken for reaction to produce 50 cm^3 of oxygen increases as the concentration of hydrogen peroxide decreases. The rate, in cm^3 of oxygen per second, therefore decreases as concentration decreases.

4B2.7 Investigating the effect of temperature on the rate of a polymerisation reaction

Note

This activity can only be judged safe when the suggested commercially available materials are used. Under **no** circumstances should laboratory reagents - phenylethene and dibenzoyl peroxide - be used in place of commercially available materials in this activity.

Pure dibenzoyl peroxide is explosive and its use in school and college laboratories is prohibited. However, the formulations used in commercially available resin hardeners are not considered to be explosive and their use is permitted (see *Risk Assessments for Technology*, CLEAPSS, pp 47-8).

The maximum exposure limit of phenylethene is 100 ppm. It is considered (see*Risk Assessments for Technology*, CLEAPSS, pp 47-8) that provided not more than 250 g of resin is in use this limit is unlikely to be exceeded in a workshop. This mass may need to be scaled down to take account of the smaller volume of a laboratory. In this activity, only part of a 250 cm^3 (225 g) container of resin is likely to be in use. However, it is important to work in a well-ventilated laboratory, and to keep all test tubes and the container of resin stoppered whenever possible, to keep the level of phenylethene vapour low.

Attention must be paid to the other safety measures contained in the instructions for this activity.

What it means

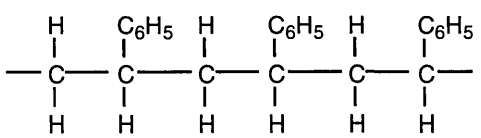
a. Some specimen results are shown in the table which follows. When plotted these give a straight line graph for variation of time for resin to set against temperature. This is fortuitous, such a relationship is not expected from theory.

Time taken for resin to set / s	Temperature / °C
300	24
210	35
105	49
30	60

b. When the resin has set it can be assumed that polymerisation has taken place to the same extent in each of the experiments. Therefore the rate, measured as extent of polymerisation per second, decreases with falling temperature.

c. Some of the main sources of error are as follows.
It is not possible to start timing from the instant the reactants are mixed using the procedure suggested.
Thorough mixing of resin and initiator is not possible.
For the runs at elevated temperature, the mixture will be warming up while the experiment is being timed.

d.



e. Polymerisation leads to the contents of the reaction tubes heating up strongly. Placing the tubes in cold water when measurements have ceased controls polymerisation, preventing the risk of explosion.

f. i) In the liquid state monomers are moving randomly and are therefore disordered. They become more ordered when joined together in a polymer chain. The energy associated with them also becomes more ordered on polymerisation. Since entropy is a measure of the disorder of energy, a decrease in disorder means a decrease in entropy.

ii) Heating leads to an increased distribution of energies among the molecules in a sample of material and therefore to greater disorder of energy and increased entropy.

iii) Any change must be accompanied by an overall increase in entropy.

iv) For polymerisation to take place, and for there to be an overall increase in entropy, the entropy decrease caused by joining together of the monomers must be more than offset by an entropy increase caused by heating.

4B2.8 Catalysis

Answers (Things to do)

2. A catalyst may become poisoned, or have to be destroyed in order to separate it from products at some stage in a process. In both cases it does undergo permanent chemical change. Whatever happens to a catalyst, it always fills the role of providing an alternative route for reaction, of lower activation energy. This therefore is a better definition of a catalyst.

Answers (Tasks)

1. The decrease in concentration of reactants causes the rate of the forward reaction (reactants to products) to decrease. The increase in concentration of products increases the rate at which reactants are reformed from the reverse reaction.

2. Reaction slows down more and more as equilibrium is approached. Less and less extra product is therefore made by waiting. It is economically preferable to stop reactions well short of equilibrium and recommence the process with new reaction mixture which will produce product quickly, rather than wait for slow production of product from the original mixture approaching equilibrium.

3. When a process is stopped well short of equilibrium after a given time, a faster catalysed reaction will produce more product in that time than would a slower uncatalysed reaction.

4B2.9 Pollution and Waste Management I: Cradle to Grave Analysis

Answers

1. a. Integrated Pollution Control is an attempt to integrate all the environmental impacts of a process.

   b. Clean Technology is an approach that avoids causing the pollution or generating the waste in the first place.

   c. Clean-up Technology is the reduction of pollution or management of waste.

   d. A holistic approach is one that considers the process as a whole.

   e. Professor Clift defines sustainability as the achievement of living standards which are acceptable, but which can be maintained indefinitely.

2. a. Figure 1 shows that, for Clean-up Technology, reducing environmnetal cost inevitably means an increase in economic cost: ie by 'climbing up the curve' from right to left, as indicated by the arrow on the figure.

   The arrow showing the move to Clean Technology not only moves towards a position of reduced environmental cost but also to one of reduced economic cost.

   b. i) The operation of processes in the Developed World is likely to fall in the left-hand part of the graph: ie processes already have a relatively low environmental cost. For Clean-up Technology, because the curve is steep in this part of the graph, small reductions in environmental cost lead to massive economic costs. Therefore a move to Clean Technology is the better option: for example, big reductions in environmental cost can be achieved by a move to a cleaner process of similar econonomic cost.

   ii) The operation of processes in Developing Countries is likely to fall in the right-hand part of the graph. Here, big savings in environmental cost can be made for a small increase in ecomomic cost using Clean-up Technology.

3. a. The products mentioned by Professor Clift are: paper (particularly newsprint), agrochemicals, glass, polymer films, domestic and agricultural waste, electric guitars (particularly varnish), degreasing and dry cleaning solvents.

   b. The following products fall into

   Category A: paper, glass;

   Category B: agrochemicals, varnishes and solvents;

   Category C: glass, polymer films, domestic and agricultural waste.

c. The article offers the following solutions for each of the different products.

PAPER: reuse as a fuel may be preferable to recycling.

GLASS: recycling does not reduce environmental burdens if transport is involved - Professor Clift proposes moving waste management closer to the source of the waste to reduce the environmental cost of transport.

AGROCHEMICALS: development of techniques allowing more effective targetting of the pest and thus the application of lower doses iof chemical being released into the environment.

VARNISHES: developing water-based varnishes (although some people point to increased environmental burden associated with the manufacturing phase with these systems).

SOLVENTS: the development of leasing arrangements, where spent solvents are returned to the manufacturer for recycling.

POLYMER FILMS: manufacturing more locally at a number of sites rather than centrally at one site reduces the environmnetal burden of transporting this bulky, low-cost product.

AGRICULTURAL WASTE: again, process locally, rather than transport to a central processing facility.

4. a. Advantages of making the manufacturer rather than than the consumer responsible for the waste are as follows.

It is much easier to identify the responsible person.

It forces the manufacture to design products with a view to re-use and recycling.

It can lead to advances in maintenance practice.

One organisation, the manufacturer, can decide how best to treat the waste.

b. A Life Cycle Partnership involves companies interacting not only with suppliers and customers but with other agents in the life cycle of the product.

5. Answers may include the following:

The best environmental option can sometimes elude a government or company if too narrow a view is taken: for example, German legislation compelling paper recycling by the producer (eg Norway) has enormous environmental costs in terms of transport.

Governments and companies consider economic as well as environmental cost. For example, in the UK, a good deal of recycled paper is produced because the UK does not produce virgin paper pulp, which must be imported. Recycled paper generates profits and provides employment within the UK.

4C1.1a Starving hungry

In this activity, students consider hunger, famine and starvation. It is suggested that they trawl the mass media, and in particular the Internet, for information about modern-day famines and their causes.

The item itself contains an extract from *The Vision of William Concerning Piers The Plowman.* This contemporary account of fluctuating food supply in medieval England vividly describes what it feels like to go hungry. The extract is given in the original Middle English and explained by means of a commentary on the facing page so that any student will be able to understand its meaning.

Students are asked to imagine being really hungry, as opposed to having a good appetite for the next meal. Having read about the diet of a medieval peasant suffering hard times, students are asked to compile a list of everything they eat in a single day. This list will also form the basis of Items 4C1.1(b) and 4C1.1(c).

The term, malnutrition, is introduced towards the end of the item, the point being that even people who are getting enough to eat may still be malnourished if they are not receiving a balanced diet. Item 4C1.1(b) will consider further the idea of a balanced diet.

4C1.1b What do you eat?

Students use the list of what they eat in a single day, which they have compiled in part (a) of this item, as the basis for analysing their own nutrition. First they compare daily energy intake with their daily energy needs. They go on to estimate the balance of carbohydrate to fat in their diet. Finally they are asked to suggest whether they might need to adjust their daily food intake to better suit their nutritional needs.

4C1.1c How do you eat?

The final activity in this item draws together ideas about nutrition from the two previous activities and leads students towards the next item, which is about the chemistry and biology of carbohydrates, lipids and proteins. It also sets the scene for the next cluster of items, which are about aspects of food processing.

Students consider some of the conflicts between eating to supply the body's nutritional needs and eating as a social activity. They are asked to re-assess the list of the food they eat daily in terms of the forms that food takes, and their eating patterns. For the sakes of students who might feel embarrassed that their own eating patterns are in some way disordered, the exercise is presented as a personal one. However, many students may find it enlightening to discuss their eating patterns and preferences with others and teachers are encouraged to adapt the activity at their own discretion.

The purpose of the item as a whole is to encourage students to revisit in a different way ideas about nutrition that they may have met in their earlier years, to apply those ideas to the way they are eating now, and to introduce a more detailed treatment of carbohydrates, lipids and proteins.

4C1.2 Carbohydrates, lipids and proteins

Answers (Things to do)

2. Similarities.
   - Both consist of molecules comprising C, H and O atoms.
   - Both are used as energy stores.
   - Neither affects the concentrations of solutions in living organisms.

   Differences.
   - The percentage of O atoms in fats is very low compared with that in polysaccharides.
   - Polysaccharides are built up from large numbers of the same sub-unit. Fats are built up from small numbers of two types of sub-unit: glycerol and fatty acid.
   - The hydrolysis products of polysaccharides are soluble in water. Those of fats are insoluble.

3. Similarities.
   - Both are broken down by hydrolysis.
   - Both consist of a string of many sub-units.

   Differences.
   - Proteins consist of many different sub-units; in polysaccharides the sub-units are the same.
   - Protein chains have a fixed length; polysaccharide chains have variable lengths.
   - Proteins have a precise shape; polysaccharides do not.
   - Polysaccharides contain only carbon, hydrogen and oxygen atoms. Proteins also contain nitrogen and sulphur atoms.
   - Proteins are not primarily used as an energy source; polysaccharides are a major energy source.

4. a. The statement is true. Foods rich in lipids are, however, even better energy stores. The energy can be transferred more rapidly from carbohydrates than from lipids. This can be important when doing hard physical work or at times of intense exercise.

   b. The statement needs careful qualification. Fat is a good source of energy, and lipids are required for essential functions in organisms: eg, as phospholipids in cell membranes. A diet consisting of a high proportion of saturated fat can be damaging to health. Unsaturated fats are thought to be less damaging.

   c. The statement is not true. There are sources of protein in foods other than meat, and these foods can form part of a balanced diet. However, there is an issue about the intake of essential amino acids. Meat contains all of these. Vegetarian diets which are not properly planned can be deficient in valine. Pulses (eg, beans and lentils) are good sources of valine for vegetarians.

5. a. The molecular formula of fructose is $C_6H_{12}O_6$.

   b. Fructose is a hexose.

c.
- The structure of fructose contains a five-membered ring. Those of glucose and galactose contain six-membered rings.
- A molecule of fructose has two CH_2OH side groups. Molecules of glucose and galactose have only one such side group.
- A molecule of fructose has one carbon atom that is not directly attached to a hydrogen atom. In glucose and galactose molecules, all the carbon atoms are attached to a hydrogen atom.

6. a. Humps of the same size should be compared: ie, calculations done with the same volume of each substance.
For 1 cm^3 of hump: mass of fat = 0.92 g, mass of glycogen = 1.2 g.
Energy released in aerobic respiration:
from fat = 0.92 g x 38 kJ g^{-1} = 35 kJ;
from glycogen = 1.2 g x 17 kJ g^{-1} = 20 kJ.
Therefore, a hump containing fat is the better store of energy.

b. i) Volume of water available from 1 cm^3 of stored water = 1 cm^3.

ii) Volume of water available from 1 cm^3 of stored fat
= 0.92 g x 1.11 cm^3 g^{-1} = 1.0 cm^3.

iii) Volume of water available from 1 cm^3 of stored glycogen
= 1.2 g x 0.56 cm^3 g^{-1} = 0.7 cm^3.

c. Fat is stored in a camel's hump. Fat provides as much water as does stored water itself. Fat is also a store of energy, which water is not. Fat is both a better energy store, and a better provider of water, than is glycogen.

7. a. Primary structure.

b. Regions of helix or sheet caused by interactions between the peptide links in the protein chain.

c. Tertiary structure is the precise three-dimensional shape taken up by a protein. It arises from interactions between side chains on certain amino acid sub-units.

d. The protein covers the thread best in the form of a mat of long strands. It would not cover as well if the chain were twisted back onto itself in the form of helices or sheets.

Answers (Tasks)

1. Other examples include:
essential processes: feeding, reproduction;
synthesis of compounds: pigments, enzymes;
manufacture of structures: bone, muscles;
homeostasis: control of concentrations of solutions or of water balance.

2. i) x = 5, y = 5;
ii) x = 6, y = 6;
iii) x = 12, y = 11.

3. i) There are 173 atoms in tristearin, of which 6 are oxygen atoms.
3.5% of the atoms are therefore O atoms.
ii) There are 213 atoms in the polysaccharide, of which 51 are oxygen atoms.
24% of the atoms are therefore O atoms.

4. Functions of lipids include
- energy stores;
- thermal insulation;
- protection from physical damage;
- waterproofing;
- hormones;
- vitamins;
- phospholipids in cell membranes.

5. i) Chymosin (rennin) is used in cheese-making.
Enzymes are used in digestion:eg, trypsin, chymotrypsin, carboxypeptidase, amylase.

ii) Human growth hormone. BST (used to increase milk yields in cows in some countries).

iii) Haemoglobin - carries oxygen around the body in red blood cells.

6. The 20 amino acids are

glycine,	aspartic acid,	glutamic acid,
tyrosine,	cysteine,	asparagine,
glutamine	serine,	proline,
arginine,	alanine,	histidine,
isoleucine*,	methionine*,	threonine*,
leucine*,	lysine*,	tryptophan*,
phenylalanine*,	valine*.	

The eight, marked with an asterisk, are essential amino acids.

7. i) In a helix, a peptide link interacts with another link that is three links further away in the chain.

ii) In a sheet, the separation of the peptide links is variable. It depends on what happens to the chain before it returns to run alongside itself.

4C2.1 From Plowman To Ploughman's

This item is an introduction to three processes which make use of enzymes: brewing, baking and cheese-making, all of which date from ancient times but which are still important today.

1. a. In medieval times one reason for converting grain into ale would have been to produce a drink that was bacteriologically safe. Whereas much of the water supply was not safe to drink, the water used to make ale had been boiled and the process of fermentation would prevent regrowth of pathogenic organisms. Ale would also have contributed significantly to the daily diet as opposed to its modern day function, which is mainly as a source of alcohol.

   b. Grain was converted into bread, then as now, to render it more palatable. In bread-making, the grain is ground into a flour, mixed with water and baked. Risen bread also contains a leavening agent such as yeast, which contains enzymes. Risen bread is considerably more palatable to eat, both in flavour and texture, than unleavened breads, which are best eaten straight from the oven. Bread was a welcome change from gruels and potages (ie, grain made into porridge or incorporated into soups and stews).

   c. Some milk was made into cheese both to provide variety and add flavour to the diet, and to preserve food. Cheese keeps for up to a year, whereas milk deteriorates and starts to sour after a few days.

2. Today, we drink beer mainly for its alcoholic content and not as an integral part of our daily nutrition. We tend to drink beer over an above an adequate food intake with the result that heavy beer drinkers can become overweight. We certainly do not turn to beer as the only source of potable water.

   Bread remains an extremely palatable way of eating grain, although for most people in the developed world bread is far less of a staple than it used to be. So many other foods are available to us that we tend to eat bread with other foods, rather than eat small quantities of other foods with our bread. This is in many ways a pity, since bread is highly nutritious, and low in fat.

   Although refrigerated storage and transport are available to us, large quantities of milk are made into cheese today. The reasons for this are less to do with preservation of milk and more to do with the flavour of cheese, and its versatility as a component of the modern diet.

3. **Beer** is an alcoholic drink brewed from malt, sugar hops and water.
   From the Old English word: *beor.*

   Ale is an alcoholic drink made from cereal, especially barley.
   From the Old English word: *alu*, or *ealu.*

   Hops are the dried flowers of the hop plant used to give a bitter flavour to beer.
   From the fifteenth century Middle Dutch word: *hoppe.*

Malt is a cereal grain, such as barley, that is kiln-dried after it has germinated by soaking it in water.
From the Old English word: *mealt.*

Grist are malt grains that have been cleaned and cracked.
From the Old English word: *grist.*

Mashing is the steeping of malt grains in water in hot water.
From the Old English word: *mæsc.*

Wort is the sweet liquid from the soaked mixture of warm water and ground malt.
From the Old English word: *wyrt*, meaning root.

Brew is to make beer (ale, etc.) from malt and other ingredients by steeping, boiling and fermentation.
From the Old English word: *breowan.*

Small beer is now rarely used to mean weak beer, but instead people or things of no importance.

Note that all the above brewing terms are derived from Old English words (suggesting that brewing is indeed an ancient process) except for hops, which were introduced later from the continent.

4. Strictly speaking, the term *brewing* describes a process that involves fermentation. It is thus more accurate to describe the tea-making process as mashing, rather than brewing.

   Students are encouraged to find out for themselves how mass-produced white bread is made. This information can be found in text books about food processing. In particular, students should compare the modern Chorleywood Breadmaking Process with the recipe given in the item.

5. In the moist dough, amylase enzymes present in the flour itself begin to break down starch in the flour into simpler sugars. Then, enzymes in the yeast convert the sugars into ethanol (common alcohol) and carbon dioxide. (This processof fermentation is actually anaerobic respiration by which yeast cells obtain energy.) The kneading of the dough has made it stretchy and elastic. Thus as more carbon dioxide is produced, the bubbles get bigger and the dough swells. As fermentation proceeds the alcohol concentration around the yeast cells increases, eventually reaching a level at which most of the yeast cells are killed. When this happens, fermentation ceases and the dough stops rising.

6. Fermentation of the dough can be speeded up by the addition of extra amylase to the flour. Commercially available 'fast action dried yeast' contains amylase.

   Addition of sugar to the dough will speed up fermentation.

   Allowing the dough to rise in a warm place will also speed up fermentation. Too high a temperature will kill the yeast and destroy the action of the enzymes.

4C2.2 Cheese-making today

1. Both Davidstow and Denhay Creameries are located in the West Country, in rural areas of high rainfall and lush pastures that have traditionally supported dairy cows. Both creameries are distant from large centres of population, and it has been convenient not to transport all the liquid milk out of the area but to make the large supply of milk into cheese.

   Even though the process employed in Davidstow Creamery is more highly mechanised than at Denhay Farms, the flow charts drawn by students will show the similarities between the two processes; both, of course, result in mature cheddar cheese.

2. a. Students should include on their flow charts the following raw ingredients: milk, starter bacteria, rennet and salt.

   b. The cheese-making process involves heating the milk, first to get it to the correct temperature for enzyme action to occur, and then to scald and cook the curds. In both cases, heating is done by electricity.

   Davidstow Creamery recycles hot water originally from the milk. It can do this because it removes the water from liquid whey in the whey-drying plant. This hot water is used to pre-heat some of the whey in the whey-drying plant, and for cleaning the plant.

   c. Both creameries produce mature cheddar cheese. However, Davidstow sells some of its cheese, before it has reached full maturity, as mild cheddar cheese.

   Both creameries produce whey as a by-product. At Denhay Farms this is fed to pigs; Davidstow Creamery water is evaporated from the whey, giving whey-powder as a by-product.

   Both processes produce waste water, Davidstow producing much more than Denhay, due to its much greater size, and the fact that it extracts water from the whey, rather than producing liquid whey as a by-product.

3. Both processes are largely similar, producing mature cheddar cheese and a whey by-product. Both use both starter bacteria and a rennet, although in each case the formulations of the ingredients do differ. Both processes use salt, and both send water to waste.

   The process at Davidstow is fully automated and almost entirely computer controlled. The process at Denhay relies more on decisions made by the cheese-maker, and is cheddared by hand rather than in a cheddaring machine.

4. a. Davidstow Creamery produces 30 000 tonnes of cheese each year from 300 000 000 litres of milk.
   Denhay Creamery produces 700 tonnes of cheese each year from 7 000 000 litres of milk.

Thus Davidstow Creamery works at over forty times the capacity of Denhay Creamery (ie, it produces 43 times more cheese per annum than Denhay Creamery).

b. The volume of milk required for the production of 1 kg of cheese is the same for each creamery: 10 litres.

Davidstow Creamery:

300 000 000 litres of milk to produce 30 000 tonnes cheese.
100 000 000 litres of milk to produce 10 000 tonnes cheese.
10 000 litres of milk to produce 1 tonne cheese.

1 tonne = 1 000 kg.

Therefore,

10 litres of milk to produce 1 kg of cheese.

Denhay Creamery:

7 000 000 litres of milk to produce 700 tonnes cheese.
1 000 000 litres of milk to produce 100 tonnes cheese.
10 000 litres of milk to produce 1 tonne cheese.

1 tonne = 1 000 kg.

Therefore,

10 litres of milk to produce 1 kg of cheese.

c. The efficiency of conversion of milk into cheese is therefore the same at the two creameries.

d. It is not possible directly to compare efficiency of energy use since the two creameries operate different processes for the treatment of the whey. Davidstow Creamery does recycle hot water in its whey-drying plant, but drying whey in any case uses much more energy than does simply feeding the liquid whey to pigs, as happens at Denhay Farms.

5. a. Mature Farmhouse Cheddar occupies a higher market niche, and commands a higher price, than does Mature Cheddar made in a big creamery.

b. Denhay Creamery is a much smaller operation than Davidstow Creamery, and is more labour intensive. The product is bound to cost more to make at Denhay than at Davidstow, so Denhay's cheese needs to command a higher price than Davidstow's. It can do this by fulfilling the regulations required of Farmhouse Cheddar as it does.

c. The economies of scale and automation that Davidstow Creamery operate mean that cheese costs less to make at Davidstow than at Denhay. Unlike Denhay Creamery, the operation at Davidstow does not in any case satisfy the criteria for Farmhouse Cheddar, but it can successfully occupy the slightly lower Mature Cheddar niche.

d. Supermarket chains are by far the largest buyers of cheese in the country, and the majority of people buy their cheese from supermarkets. An operation as large as Davidstow Creamery, which is itself part of Dairy Crest Ltd. needs to sell vast quantities of cheese. Distributing this to individual small shops would require Dairy Crest to operate a huge marketing and distribution network that would simply be unworkable. Big supermarkets sell enormous quantities of cheese, and in any case the supermarket chains have their own distribution networks. Although Denhay Farms is a much smaller operation than Davidstow Creamery and could conceivably sell to smaller shops, by selling to supermarkets it also avoids having to run a large distribution network of its own. Some of Denhay's traditional cylindrical cheeses are sold to small delicatessens and the speciality small cheeses are also sold by post.

6. As a shopper one might consider the following factors when choosing a particular type of cheese from the supermarket shelf.

Purpose: is the cheese to be eaten as it is or is it to be used for cooking?
Flavour: does the shopper prefer the cheese to have a mild taste or a strong bite?
Cost: even if a stronger cheese is preferred, is it too expensive?
Packaging: does the way the product is packaged suggest that it will be better than another, similar product?
Other considerations: some people will require the cheese to be suitable for vegetarians, or organically produced. They may prefer cheese that has been made by a traditional method or in the region traditionally noted for this particular type of cheese.

7. It is useful to hold a blind cheese-tasting session, even if a formal investigation is not undertaken. Students should have the opportunity to taste different types and grades of cheddar cheese so that they gain firsthand experience of the types of products they have been reading and answering questions about. The big supermarket chains all carry at least one of the following categories of cheddar: mild, mature creamery and mature farmhouse. You might include a traditional rinded cheddar in the tasting; older people often prefer this whereas most young people prefer polythene-wrapped block cheese.

8. a. The agricultural cycle designed by students should show cows eating grass (with additional cereals and soya protein). The cows produce milk, and the milk is made into cheese, but the by-product of the cheese-making process, liquid whey, is fed to pigs, which are killed and the pork cured as bacon and air-dried ham. Manure from pigs and cows goes back on the pastures to fertilise them. Grass grows, the cows eat the grass, and the cycle begins again.

A well-designed drawing of such a cycle will show these steps clearly and concisely.

b. The traditional manner in which Denhay Farms operates could be used to enhance sales of their products. Students are asked to suggest ways in which the agricultural cycle used at Denhay could be incorporated into an advertising campaign.

Some students may want to make a significant art and design input into this exercise, and if doing so motivates them it should be encouraged. The exercise would work particularly well as a group activity and provide valuable experience of collaborating with others.

9. There exist cheese-making enterprises that are significantly smaller than the one at Denhay Farms. Most small-scale cheese-makers concentrate on making a speciality product, and some in the past have made cheese from unpasteurised milk although regulations make it increasingly difficult for them to do so.

a. Some people say that cheese made from unpasteurised milk has a better flavour than that made from pasteurised milk. One reason why this might be the case is that the flavour of a cheese is influenced by the different micro-organisms present, both in the milk and in the surrounding air. The same milk made into cheese to the same recipe in a different creamery is likely to taste different. The flavour and texture of cheese is partly dependent on the organisms it contains.

Milk is pasteurised in order to destroy pathogenic organisms that might contaminate it. But the pasteurisation process also destroys other, non-pathogenic organisms that might enhance the flavour of the cheese.

b. One obvious disadvantage of making cheese from unpasteurised milk is that pathogenic organisms may be introduced into the cheese and cause disease when the cheese is eaten. Often a cheese containing pathogenic organisms simply will not mature correctly, and its defects then become obvious. But if the cheese is designed to be eaten at an immature stage, the fact that it is contaminated with pathogenic organisms may not be apparent, and an outbreak of food poisoning could ensue.

Pasteurising batches of milk renders them more microbiologically homogeneous than batches of raw milk, making it easier to produce cheese of consistent quality.

c. Larger scale creameries pasteurise the milk before making it into cheese to avoid problems of microbial contamination and variation in quality. To lose a whole batch of cheese on this scale would be highly disadvantageous. When such large quantities of cheese are sold, it is not worthwhile for the producers to risk microbial contamination. Responsibility for an outbreak of food poisoning is usually ruinous to a business of any scale; this includes both the cheese-maker and the supermarkets that sell their product. People expect a supermarket to ensure that what they buy is safe to eat.

10. a. The recipe for Bath Cheese differs from the process used to make cheddar cheese in that no starter culture is added to the milk to sour it. Bath Cheese is, however, set using rennet, although from the long setting time stated, rather less rennet than is used to make cheddar cheese. Although the milk is pre-heated, the curds themselves are not cooked, unlike the process for cheddar cheese. As in the cheddar cheese process, the curds are cut although they are not cheddared. The size of the cheeses made are very small compared with the moulds used for either block or rinded cheddar. Unlike cheddar, the green cheeses are not placed under pressure but are merely allowed to drain. The curds themselves are not salted; salt is merely sprinkled onto the green cheeses once the liquid has drained from them. Bath Cheese is stored at a higher temperature than cheddar cheese; it ripens more quickly and is eaten young.

Compared with cheddar cheese, Bath Cheese is likely to have a mild flavour since it is eaten when immature. The fact that the curds are not cheddared means that the texture of Bath Cheese will be soft and rather crumbly. Although it is made from cows milk, Bath Cheese should resemble the small, country goat's cheeses that are available from some supermarkets. These too have a covering of fine, white mould.

b. This exercise, in which students rewrite the recipe for Bath Cheese in modern terms, will help students consolidate what they have learned about the principles of cheese-making. They should convert temperatures, volumes and dimensions to metric units, and ensure that all the equipment used can be made suitably clean to prevent contamination by pathogenic organisms.

c. Students should come to the conclusion that, compared with making cheddar cheese, the small-scale production of Bath Cheese carries greater hazards, although the size of the cheeses and the simplicity of the process makes Bath Cheese easier to produce on a small scale than cheddar cheese.

d. Bath Cheese will not keep for long periods of time compared with cheddar cheese, since Bath Cheese has a more open texture and is designed to be eaten young.

e. The makers of Bath Cheese could sell their product through specialist food shops in their own locality. They could also consider marketing their cheese as a local delicacy and selling it 'by post', as is done with clotted cream.

f. Students should consider the materials used to make the wrapper as well as the design on the wrapper.

g. If Bath Cheese is suitable for sending by post (or more realistically by courier van), the makers should consider selling on the Internet. Clotted cream is pre-cooled, then placed in a thick polystyrene pack, and dispatched for next-day delivery. It would be feasible to do the same with Bath Cheeses. The retail price would have to include the cost of postage and packaging, so the product would need to be able to command a high price with customers.

h. A page advertising Bath Cheese on the Internet could merely be an extension of other advertising initiatives, and is relatively easy to design and install. A Website which allows the customer to buy directly from the Internet must incorporate a number of safeguards, since customers will be giving credit card details, and also divulging addresses. Students may find it useful to find out generally how selling on the Internet is done.

The whole activity involving the marketing of Bath Cheese could be used as a problem-solving exercise.

4C2.3 Enzymes

Answers (Things to do)

2. Similarities include
   - only particular molecules can bring about an effect;
   - the molecules fit into cavities in the receptor or enzyme;
   - a change occurs to the shape of the receptor or enzyme.

   Differences include
   - a chemical reaction occurs in a molecule when it binds to an enzyme, no reaction occurs when a molecule binds to a receptor;
   - in the case of taste or smell, the process results from a change to the receptor; in catalysis, the process results in a change to the substrate molecule.

3. a. i) A fast rate of production means more profit can be made from sale of the product.

   ii) A lower temperature means savings can be made to heating costs. Also the process will have a lower environmental burden as a result of less use of fuel.

   b. In order to react, molecules have to be able to fit into and bind with the active site. Often only one particular molecule has the correct shape to do this.

   c. The tertiary structure of the enzyme is held in place by bonding between different parts of the protein chain. Some of this bonding is weak and breaks at high temperature, causing the enzyme to lose its shape. The active site is lost when this happens.

   d. Enzyme activity is also lost if pH becomes too high or too low, or if inhibitor molecules are present.

4. b. i) At low glucose concentrations, the rate is directly proportional to (or increases directly with) glucose concentration.

   ii) At high glucose concentrations, the rate does not depend on glucose concentration.

c. At low glucose concentrations, there are always active sites which are empty and available for reaction. As the concentration of glucose increases, collisions between glucose molecules and enzymes become more frequent, leading to the formation of more enzyme-substrate complexes and more rapid reaction.

At high glucose concentrations, all active sites are occupied. An increase in the number of glucose molecules therefore does not lead to the formation of more enzyme-substrate complexes, and there is no increase in rate.

d. i) Competitive inhibition is likely.

ii) The structures of the two compounds are similar. It is likely that 6-deoxyglucose binds to the active site. It is also likely that the presence of the CH_2OH group is necessary for reaction to occur. Molecules of 6-deoxyglucose therefore do not react, but remain in the active site and prevent glucose molecules from forming enzyme-substrate complexes.

Answers (Tasks)

1. Other factors which can affect the rate of a chemical reaction are: concentration of a solution, pressure of a gas, temperature, state of division of a solid reactant.

2. At a higher temperature, a larger proportion of molecules have energy equal to or greater than the activation energy and are therefore able to react.

3. $pH = -\log_{10}[H^+]$. In words: pH is equal to the negative logarithm, to base ten, of the hydrogen ion concentration.

4. Maximum profit is made from maximum production, which means that as much reactant as possible needs to react per hour.

4C2.4 Investigating the effect of temperature on the rate of an enzyme catalysed reaction

Notes

The instructions carry important safety notes about neither eating nor tasting the junket made and about heating the beakers of water carefully. It may be safer, and more convenient, to obtain water at 40 °C by adding hot water from a kettle to cold water in the beaker.

Enzymes are proteins. Some people suffer allergic reactions to particular proteins. Powdered enzyme must not therefore be used. Commercial preparations are readily available and must be used.

What it means

a. Sample results are given in the tables which follow.

With Rennin

Temperature to which enzyme was heated /°C	Time / minutes	Consistency of mixture
40	6	fully formed junket
50	4	fully formed junket
60	2	fully formed junket
70	10	partially formed junket
80	10	milk

With 'VegeRen'

Temperature to which 'VegeRen' was heated /°C	Time / minutes	Consistency of mixture
40	4	fully formed junket
50	2	fully formed junket
60	2	fully formed junket
70	3	fully formed junket
80	10	milk

b. Explanations should make reference to the following points:

- that the number (or fraction) of molecules possessing energy equal to, or in excess of, the activation energy increases with increasing temperature;
- that this leads to an increase in reaction rate with increasing temperature;
- that enzymes are proteins with a precise tertiary structure that is held in place by bonding between different parts of the protein chain;
- that part of the tertiary structure is an active site at which catalysis occurs;
- that some of the bonding which holds the tertiary structure in place is broken when temperature rises above a certain limit, leading to the loss of tertiary structure and loss of catalytic activity;
- that, according to the specimen results, the catalytic activity of both enzymes seems to be retained to beyond 60°C but lost by 80 °C.

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