Chemicals from Salt

Contents: Problem-solving exercises concerning the production of sodium hydroxide and chlorine by electrolysis of salt.

Time: 2 periods or more, depending on the number of problems tackled.

Intended use: GCSE Chemistry and Integrated Science. Links with work on electrolytic production of salt and the uses of chlorine, sodium hydroxide and hydrogen.

Aims:

- To complement and revise prior work on the electrolysis of salt
- To develop awareness of some of the economic and technological problems involved in a chemical process
- To develop awareness of the need to balance different factors in industrial decision-making
- To provide opportunities to practise skills in problem solving and decision-making.

Requirements: Students' worksheets No. 307

Suggested use

The students' notes on 'Chemicals from Salt' should first be read thoroughly, either in class or as a homework, and any queries dealt with. It is assumed that students will be familiar with the principles of the industrial electrolysis of salt from prior work. In school trials it was found that this unit was generally more suitable for use with students in the upper half of the GCSE ability range.

After reading the notes, the class should then be divided up into groups of four or five students. Each group represents a decision-making body from a company ('SALCHEM') manufacturing chlorine and sodium hydroxide. The students can adopt the suggested roles if they wish.

Each group should be given a problem or problems to tackle. One technique successfully used in trial schools was for each group to tackle one or two problems, then report back to the class afterwards. Remind them that as well as needing to maximize profit, a company has a responsibility to its employees, and the local community.

To most of the questions there is no single 'right' answer, but some background notes for teachers are given below.

Notes on the problems

Problem 1

Power cuts are disastrous for electrolysis plants. There would be technical problems and laying-off of workers if the plant had to be shut down, and financial problems due to loss of markets. Many plants have their own generators running full time which can supply the local grid at times of slack electrolysis demand. A reduction in operating rate is preferable to a cut, since the plant will take a long time to start up again after being shut down.

Problem 2

Council site: Upwind of town, which increases danger from chlorine leaks. Wrong side of the town for roads, rail, etc.

Company's site: Near communications, and could help save the railway line. Downwind of the town, and near the industrial estate.

Problem 3

Factors to be considered: Employment of workforce on the PVC plant, loss of money from loss of sales of co-products (hydrogen and sodium hydroxide), cost of 'mothballing' plant, etc.

Problem 4

(a) Chlorine for PVC, hydrogen for margarine.

(b) Transport costs per tonne are high for hydrogen since a road tanker holds only about 1 tonne of the pressurized gas, compared with about 18 tonnes of liquid chlorine.

(c) A pipeline has high capital cost but low running costs which may offset the capital cost if the customer is a large one. The major problem is that with a pipeline the manufacture is tied to customers in one location.

(d) The margarine manufacturers would do well to site their plant as near as possible to the source of hydrogen. This is also true of the PVC manufacturer, though less important due to the smaller transport costs of chlorine.

Problem 5

(a) Extra tanks to store the bleach may be needed, and extra transport is almost certain to be necessary.

(b) Manufacture of bleach is an ideal way of increasing the rate of operation of an electrolysis plant, since bleach production uses chlorine and sodium hydroxide in the same ratio as the cell produces them. The extra hydrogen made is easily disposed of to the usual customers.

Further notes

Reacting quantities The treatment of reacting quantities in the unit assumes no knowledge of the mole. With able students, work involving use of the mole could easily be added.

Other types of cell The unit mentions only the mercury cell, which is the commonest type in use at present. However, environmental problems associated with the mercury cell mean that the chlor-alkali industry (in Europe and the USA at least) are no longer installing new cells of this type. New cells are usually of the membrane type.

Other resources

Technical details of the mercury cell are not given in this unit since they are readily available in a number of chemistry textbooks.

Background information on the chlor-alkali industry is given in the ICI publication *STEAM*, No. 1, available from: ICI Educational Publications, PO Box 96, 1 Hornchurch Close, Coventry, West Midlands CV1 2QZ.

The ICI video programmes 'Alkali' and 'The Electrolysis of Brine' can be purchased from: Argus Film and Video Library, 15 Beaconsfield Road, London NW10 2LE.

The Granada Television series *Chemistry in Action* includes a programme, *Chemicals from Salt 1*, on the electrolysis of brine. It can be recorded off-air for school use. See ITV for Schools annual programme booklet for transmission times.

Acknowledgements Figure 1 reproduced, by permission, from *STEAM*, No. 1; Figure 3 supplied by ICI Mond Division.

CHEMICALS FROM SALT

Alkalis like sodium hydroxide have been important to humans for over 5000 years. Before the Industrial Revolution alkalis were mainly used for making soaps. Later they become important for making steel and glass. A new way of making large amounts of sodium hydroxide became vital.

At the end of the last century it was known that some substances could be split up by passing electricity through them. Salt (sodium chloride) solution could be turned into sodium hydroxide and chlorine in this way. But there were two problems:

1. A plentiful supply of electricity did not exist
2. There was little or no use for the chlorine that is also made in this process.

The first of these problems was solved earlier this century when modern methods of electricity generation came into use. The second problem was overcome as more and more uses were found for chlorine.

In this unit you will be looking at some of the advantages and problems of making sodium hydroxide and chlorine in this way.

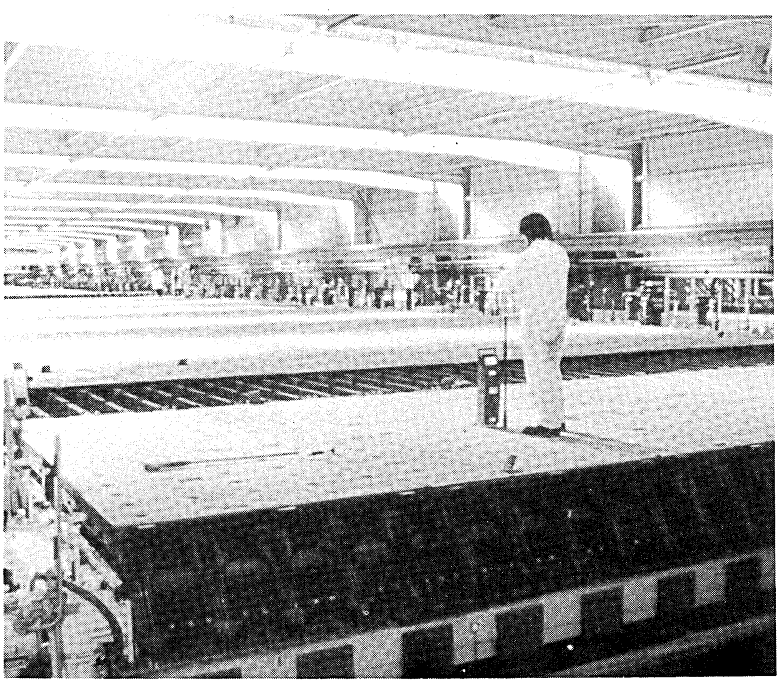

Figure 1 A modern electrolysis plant

Splitting up salt

Electrolysis of salt solution is usually done in a flowing mercury cell. This gives very pure sodium hydroxide. You can find details about mercury cells in a chemistry textbook. The overall reaction is:

$$\text{sodium chloride} + \text{water} \xrightarrow{\text{electrolysis}} \text{sodium hydroxide} + \text{chlorine} + \text{hydrogen}$$

$$2NaCl + 2H_2O \rightarrow 2NaOH + Cl_2 + H_2$$

Figure 2 shows the amounts of the three products made for every tonne(1000kg) of sodium chloride used.

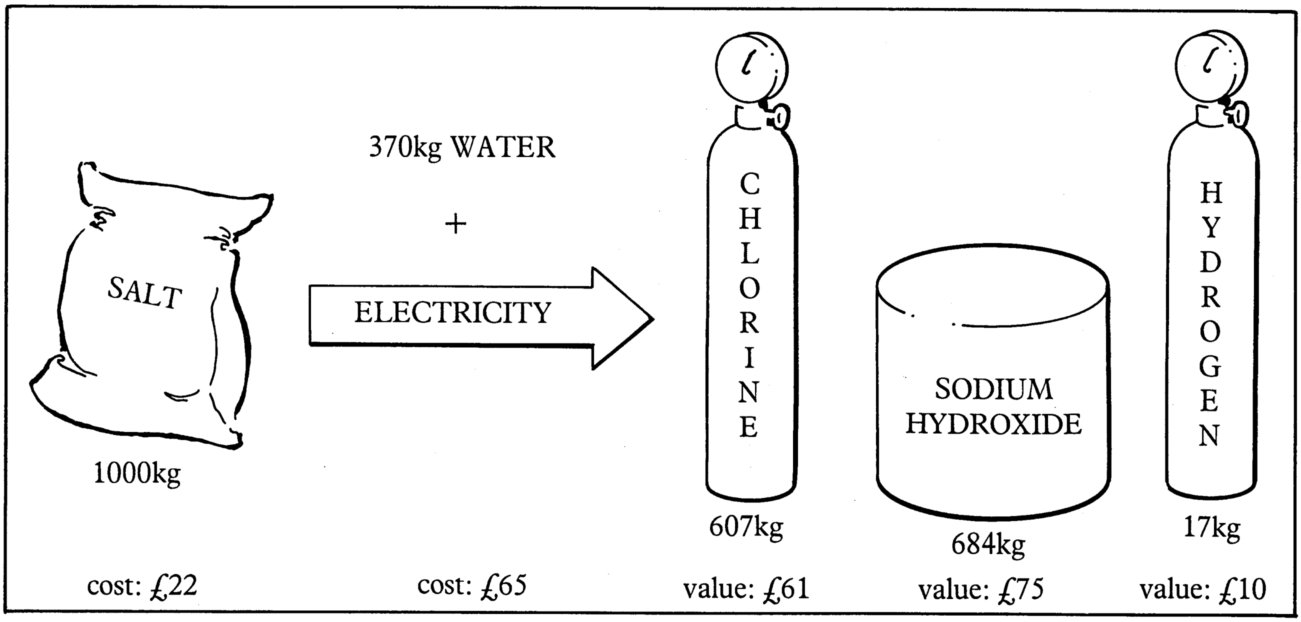

Figure 2 Amounts of products made by electrolysis of 1000kg of salt

Notice how the value of the products is greater than the cost of the sodium chloride and electricity. This *added value* is needed by the manufacturer to pay for equipment, wages and other running costs.

Uses of the products

The three products — sodium hydroxide, chlorine and hydrogen — are all useful. As well as having their own uses, they can be combined together in two important ways.

1 *Making bleach* Sodium hydroxide and chlorine can be made into sodium chlorate(I) (sodium hypochlorite), which is sold as a solution. Sodium chlorate(I) is a strong oxidizing agent, and is very good at killing bacteria. It is used in industry and in the home, where its common name is **bleach**.

2 *Making hydrochloric acid* Hydrogen and chlorine react together to form hydrogen chloride. This is made into hydrochloric acid by dissolving it in water. The hydrochloric acid made in this way is very pure, and can be safely used in the food and pharmaceutical industries.

The major uses of all these products are shown in Figure 4 on the next page.

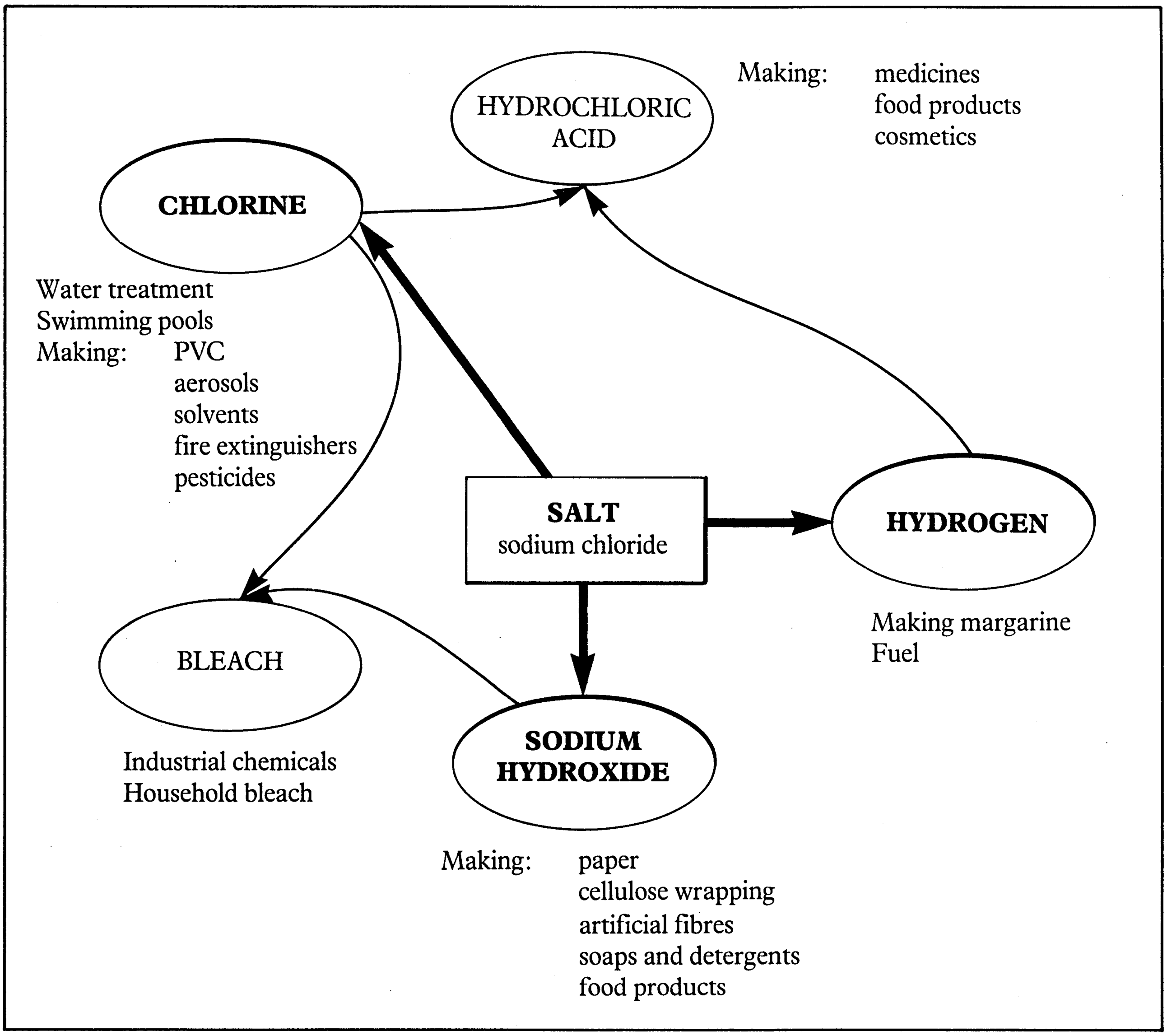

Figure 4 Uses of some of the chemicals made from salt

The quantity problem

Chlorine, sodium hydroxide solution and hydrogen are **co-products** made together in the electrolysis cell. They are produced in fixed amounts. This means that you cannot change the amount of chlorine formed when you make one tonne of sodium hydroxide solution. To run the plant economically, all the co-products must be sold or used. We have already seen that the quantities produced are as shown in figure 5 on the next page.

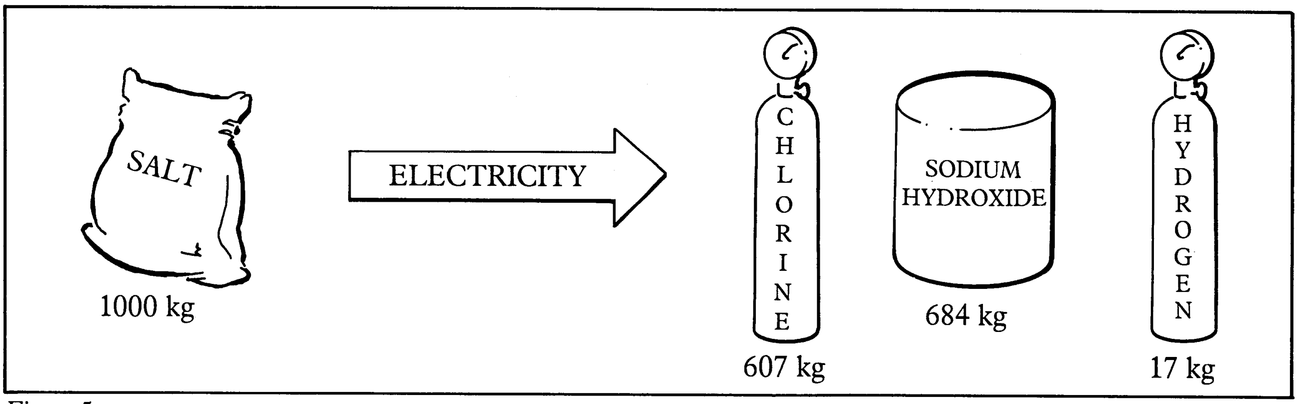

Figure 5

Bleach and hydrochloric acid can be made in any amount that the manufacturer chooses. The right amounts of the things that make them must always be used (Figure 6).

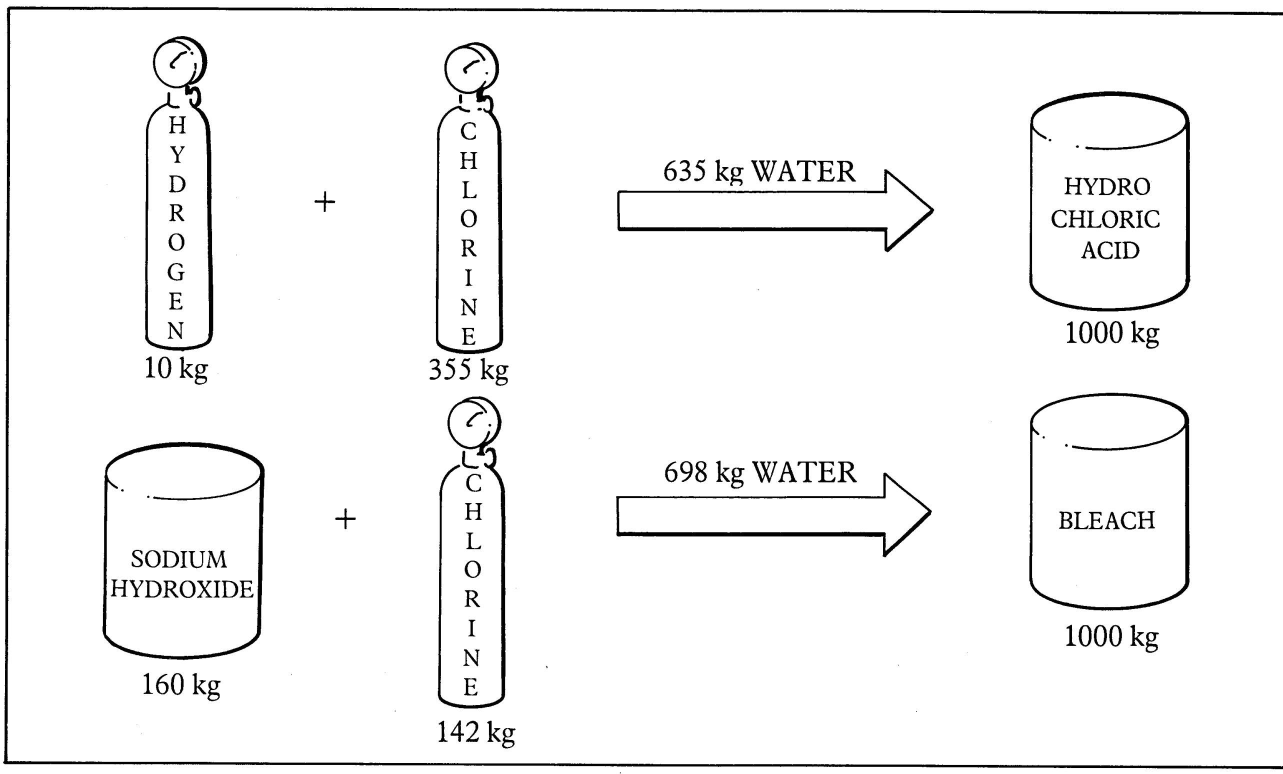

Figure 6 The quantities involved in making hydrochloric acid and bleach

Whether a particular factory makes bleach or hydrochloric acid at a particular time will depend on demand.

Transporting the products

Transport is expensive, and can add a lot to the cost of the products. To cut transport costs, large users of sodium hydroxide, chlorine and hydrogen sometimes build their factories next door to where these chemicals are made.

Chlorine is distributed as a liquid under pressure, in cylinders, drums and road and rail tankers. It is a very poisonous gas and must be handled very carefully.

Hydrogen cannot be made into a liquid under pressure. It is sold as a gas under very high pressure.

Sodium hydroxide is usually sold as a very concentrated solution. 1000kg of the solution usually contains about 500kg of sodium hydroxide.

Bleach and **hydrochloric acid** are also sold as solutions.

Figure 3 A road tanker carrying chlorine

Problems to solve

The problems here are all of the kind that might crop up from time to time in a company making chemicals from salt. In these problems we have invented an imaginary company called SALCHEM. Your teacher will tell you which problems to work on.

Tackle the problems in groups of four. Give yourselves roles.

Examples of roles:

Chairman — responsible for the running of the plant
Commercial Director — responsible for buying and selling
Technical Director — responsible for the running of the plant
Trade Union Representative — responsible for the interests of the workers.

Bear in mind that the company must:

(a) Make money
(b) Look after its employees
(c) Remember its responsibility to the local community.

Problem 1

A national power strike is threatened and SALCHEM are worried.

(a) What problems would a power strike cause?
(b) What plans can you make in case the strike happens?

Problem 2

SALCHEM is considering building a new factory near Anytown. A map of part of Anytown is shown in Figure 7, together with some facts about it.

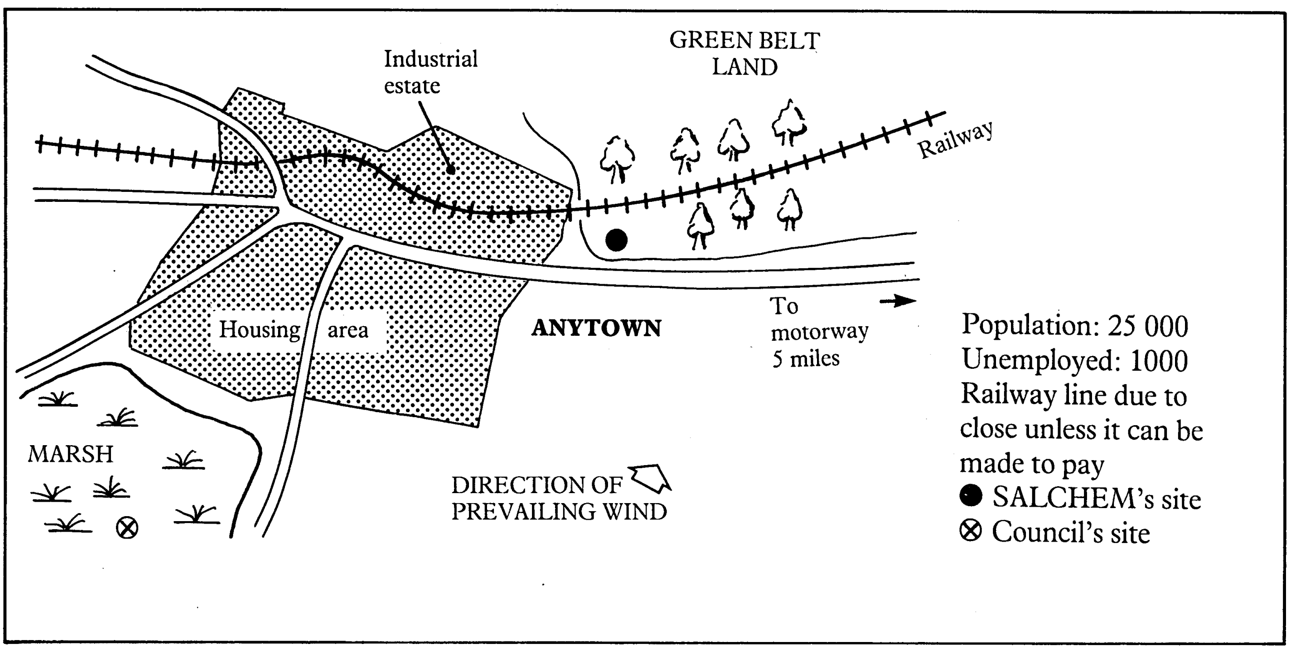

Figure 7 Anytown

You prefer to build your new factory at the site shown on the map. However the local council is against this site. This is because it lies inside Green Belt land, which they want to protect from building. They have offered to pay you to reclaim a piece of marshland in order to build your plant at the site shown on the map.

Write your reply to the council, explaining why you believe your preferred site is more suitable than their suggested one. Explain what benefit you can bring to the town.

Problem 3

SALCHEM normally makes PVC from the chlorine produced in its main electrolysis plant.

Another company has offered SALCHEM enough PVC to supply all your customers for six months at a cost 10 per cent less than you can make it yourself. What factors would you need to consider before deciding to close your PVC plant for six months in order to sell the PVC you have been offered?

Problem 4

There has recently been a big increase in fuel prices, and SALCHEM are worried about transport costs.

A PVC manufacturer and a margarine manufacturer are both planning new factories, using your products.

(a) What product will each use?

(b) Compare the costs of transporting 10 tonnes of each of these two products from SALCHEM to the manufacturers.

(c) What would be the advantages and disadvantages of supplying each manufacturer by pipeline?

(d) What suggestions would you make to each manufacturer concerning the siting of their factory?

Problem 5

SALCHEM uses a lot of sodium hydroxide and chlorine to manufacture bleach.

Bleach is used in industry to make water treatment additives for use in power stations. Its biggest household use is in treating smelly drains. A graph showing approximate bleach demand throughout the year looks like this:

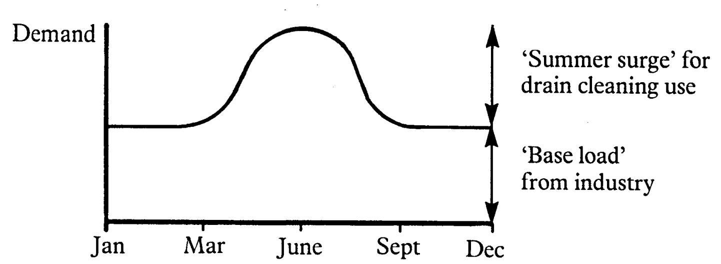

Figure 8

(a) Assuming your plant can produce enough bleach to satisfy the peak demand, what *extra* equipment will you need to cope with the surge in summer demand?

(b) If you use your sodium hydroxide and chlorine to make bleach, will you have a 'quantity problem'? Will sodium hydroxide or chlorine be left over? What will you do with the left-over hydrogen?

The Second Law of — What?

Contents: Reading and questions explaining very simply the ideas behind the Second Law of Thermodynamics and relating them to everyday problems such as pollution and the provision of energy.

Time: 2 periods. Could be used for homework.

Intended use: GCSE Chemistry, Physics, Biology and Integrated Science. Links with work on diffusion, fuels, energy sources, electricity generation and photosynthesis.

Aims:

- To complement work on energy supply
- To develop a simple understanding of the idea of the inevitable spreading out of matter and energy as the origin of all change
- To develop awareness of some of the fundamental problems involved in pollution control
- To develop awareness of the fundamental limiting problems of energy supply, the need for conservation of fossil fuels and the potential and limitations of alternative energy sources
- To provide opportunities to practise skills in reading and comprehension.

Requirements: Students' worksheets No. 308

The Second Law of Thermodynamics is not (yet) part of any GCSE science syllabus, but the principles it embodies are so relevant to the world and its problems that every citizen can benefit from an awareness of them. There is of course no intention here of formalizing the law, which is simply stated in terms of 'spreading out' of matter and energy.

The term 'entropy' is not used anywhere in the unit, though the teacher might want to introduce it, simply as a measure of how spread out energy is. Able students might be interested in exploring the idea of the 'energy crisis' further. How can there be an energy crisis, when the Law of Conservation of Energy says we can never use it up? Perhaps 'entropy crisis' might be a more appropriate term.

Further resources

The following SATIS units are relevant to this topic:

107 *Ashton Island — a problem in renewable energy*
201 *Energy from Biomass*
301 *Air Pollution — where does it come from?*
403 *Britain's Energy Sources.*

A range of resource materials and information relating to alternative energy sources is obtainable from Earthscan. Catalogue from: Earthscan, 3 Endsleigh Street, London WC1H ODD.

The major oil companies produce a wide range of resource materials relating to energy supply. A particularly useful film is 'Time for Energy' from Shell, which looks at the problem of future energy supply, conservation and alternative sources. Available as film or video, on free loan from: Shell Film Library, 25 The Burroughs, Hendon, London NW4 4AT.

Acknowledgement Figure 4 supplied by the Intermediate Technology Development Group.

THE SECOND LAW OF — WHAT?

Everything spreads out

Why does sugar dissolve in water? Why does a cup of tea cool — but never freeze? Why is pollution such a problem? Why do we have an energy problem? In this unit we will be looking for an answer to all these questions.

The answers can be traced to a simple rule:

Everything in nature tends to spread out

You are probably familiar with the idea of 'spreading out', or *diffusion*, as it is also called. Answer questions 1 and 2.

Gases spread out easily because their molecules move freely. Molecules do not care where they go. Moving around at random, they spread out to fill whatever space is available.

In a solid, on the other hand, the molecules cannot spread out. They are held back by bonds. But solids can spread out if they are turned to liquid or gas by heating. Solids also spread out when they dissolve in liquids. Drying washing is another example of spreading out (Figure 1).

Answer question 3.

Questions

1 *What are the three states of matter?*

2 *Which state spreads out most easily? Which spreads out least easily?*

Question

3 *Suppose you have a bottle of perfume. What would you do to allow the perfume to spread out through the air?*

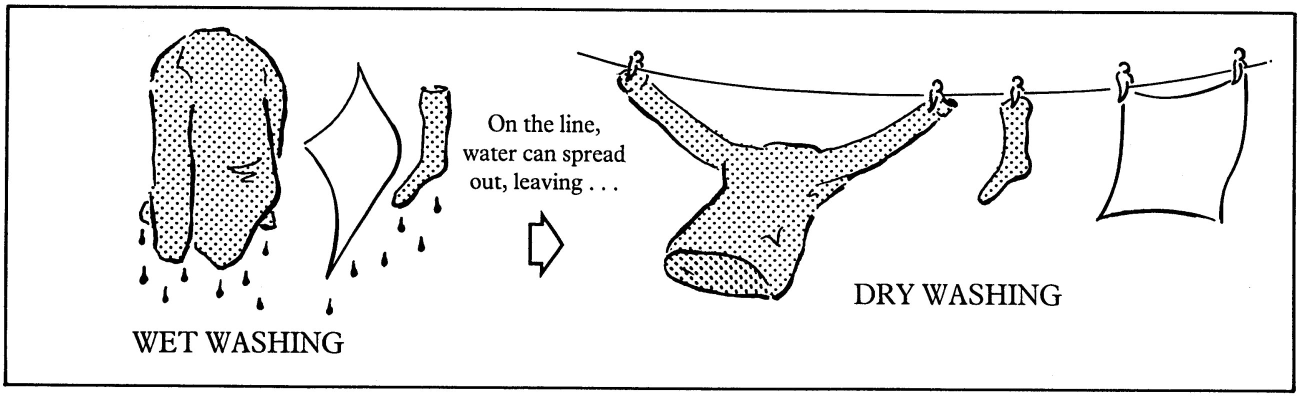

Figure 1 Drying washing depends on letting the water spread out into the air

Spreading out can be a nuisance

The tendency of things to spread out can cause a lot of problems. One of these problems is pollution.

Take a power station, for example. The fuels burned in power stations often contain sulphur. When sulphur burns, it forms sulphur dioxide, an acid gas.

Like all gases, sulphur dioxide spreads out, unless something is done to stop it (Figure 2 on the next page). It spreads out of the chimney and into the atmosphere, where it can cause acid rain. Removing the sulphur dioxide is possible, but can be expensive. Answer questions 4 and 5.

Questions

4 *Modern farmers use a lot of fertilizers. These can spread out away from the fields, and cause pollution problems. Where do they spread to, and what problems do they cause?*

5 *Give one more example of a pollutant that causes a nuisance by spreading out.*

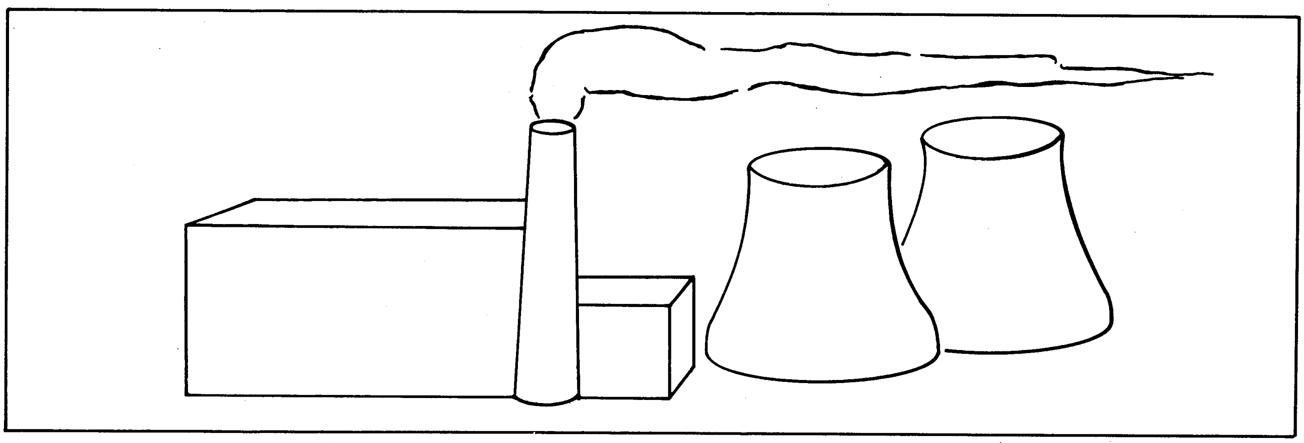

Figure 2 Pollution spreads out...

Spreading out can be useful

Spreading out is not always a nuisance. In fact, we depend on it. Imagine what life would be like if nasty smells did not spread out and disappear! And washing would never dry without the tendency of water to spread out into the air as water vapour. Answer question 6.

Question

6 *Why is it important to living things that gases like oxygen and carbon dioxide spread out?*

Energy spreads out too

A hot cup of tea always cools. When it is hot, the tea has more energy than when it is cool. But energy does not care where it is, and there are more ways it can be spread out through the air than locked up in the tea. So the energy spreads out, away from the tea, and the tea cools.

But the tea does not freeze. The energy spreads out as much as possible, but this leaves some energy in the tea. The tea cools until it is at the same temperature as the air around.

So, we can say:

Energy tends to spread out

Answer questions 7 and 8.

Questions

7 *In what ways is the spreading out of energy a nuisance to householders?*

8 *In what ways is the spreading out of energy useful to householders?*

To keep our houses warm we burn fuels and we use electricity to produce heat. Unfortunately, the heat always tends to spread out — out of the house through the roof, windows and walls. That is why people insulate their lofts, double-glaze their windows and put in cavity-wall insulation. Insulation helps lock up the energy inside the house. Eventually it will escape though — it always does.

The energy that leaks out of roofs and windows is not much use to anyone. It is too spread out to be useful. *Energy is at its most useful when it is concentrated.* Unfortunately, energy always tends to get *less* concentrated, by spreading out.

Answer question 9.

Question

9 *What sources of concentrated, locked-up energy do we use most commonly?*

Why are fuels so useful?

Fuels are energy stores. When the fuel burns in air, it combines with oxygen and the stored energy is released.

Fuels are useful because they are a way of locking up energy in a concentrated form until it is needed. Once the fuel is burnt, though, energy is released and tries to spread out. Some of this energy is bound to be wasted.

We can never turn all the energy stored in the fuel into useful work. Some is always lost. Power stations are a good example (Figure 3).

Answer question 10.

Question

10 In a car engine, fuel is burned to give useful energy but some energy is wasted.

(a) What form does the useful energy take?

(b) What form does the wasted energy take?

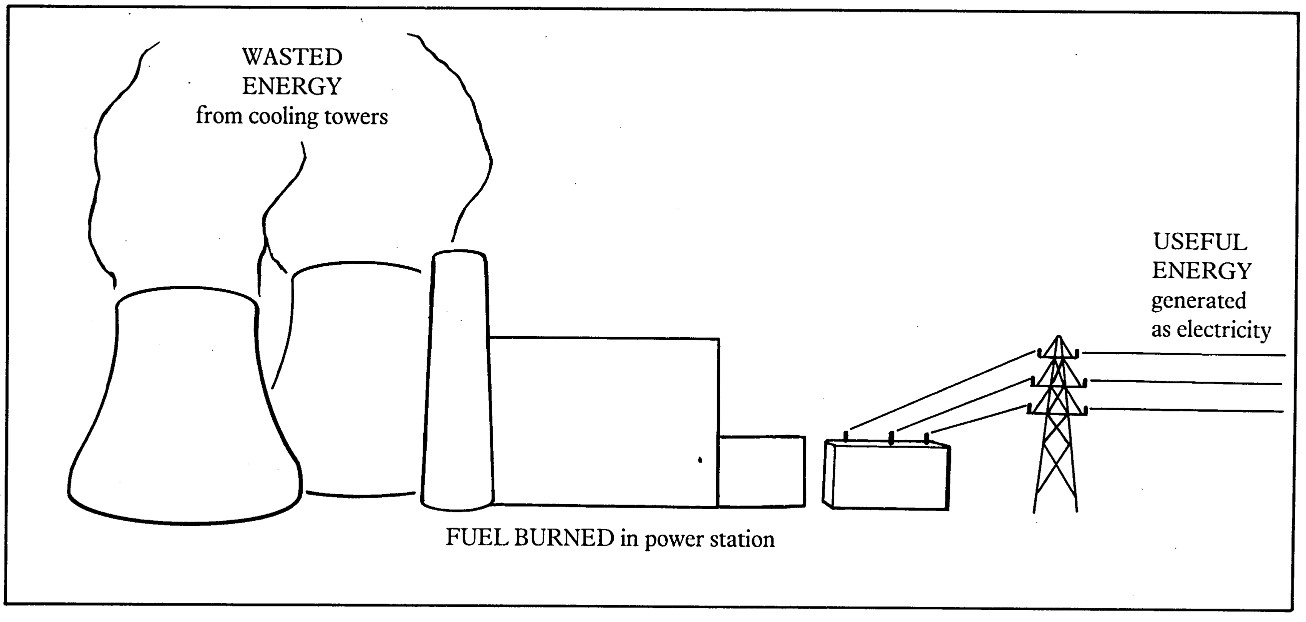

Figure 3 Using fuel to generate electricity in a power station

The energy problem

Fossil fuels such as coal and oil are in limited supply and cannot last forever. Once they are burned, their concentrated, locked-up energy gets spread out and becomes much less useful. This is why it is so important to save fuels whenever possible, and to look for alternative sources.

Alternative energy sources

Here are some of the alternative energy sources which might be used instead of fossil fuels:

Solar energy from the Sun
Hydroelectric energy from falling water
Wind energy
Wave energy from waves on the sea
Tidal energy from the rising and falling tides
Biomass — energy from plants
Geothermal energy from inside the Earth

Some of these alternative sources are quite concentrated. For example, water falling from a great height has concentrated energy that can easily be converted to electricity in a hydroelectric power station.

Unfortunately, some of the most attractive energy sources are not very concentrated. Solar energy is useful for warming houses, and scientists are finding ways to convert it to electricity. But solar power stations present more problems than ordinary oil- or coal-fired power stations, because they depend on a less concentrated energy source.

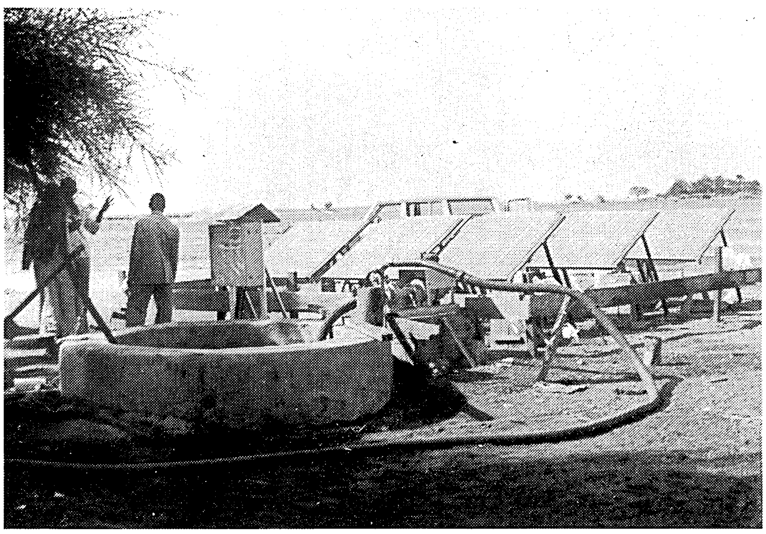

Figure 4 A solar powered pump in Mali, Africa

There are similar problems with wave energy and wind energy. Neither of them are very concentrated energy sources. Waves are normally quite small, so to get a lot of energy you need a lot of waves. The wind normally blows quite gently, so to get a lot of energy you need a big windmill, or lots of small ones.

However, these problems are not impossible to overcome. Alternative energy sources have many attractions. For one thing, they are *renewable*— they do not get used up. What is more, they cause far less environmental damage (pollution, etc.) than fossil fuels.

Answer questions 11 and 12.

Questions

11 Which alternative energy sources do you think have the greatest chance of success in Britain?

12 Alternative energy sources tend to be used more in tropical countries like India than in Britain. Why do you think this is?

Plants have the knack

Plants are an excellent energy source. Wood is a good fuel. Fossil fuels such as coal, oil and gas store the energy of plants that grew millions of years ago. We rely on plants for our own energy source — food.

Plants have a very clever knack. They can take energy from the Sun and lock it up. This is photosynthesis. The plants lock up energy in sugars, starch and cellulose, which they make during photosynthesis.

The word *biomass* is used for all the living things on Earth which depend on photosynthesis. This includes animals as well as plants, because animals depend on plants for their food.

Scientists are looking at ways of using the clever knack of photosynthesis to solve our energy problems. For example, in Brazil a lot of sugar cane is grown. This sugar can be fermented to give alcohol. Alcohol is an excellent liquid fuel which can be used in cars (Figure 5).

Answer question 13.

Question

13 Another important fuel made from plants is biogas. *Try to find out what biogas is.*

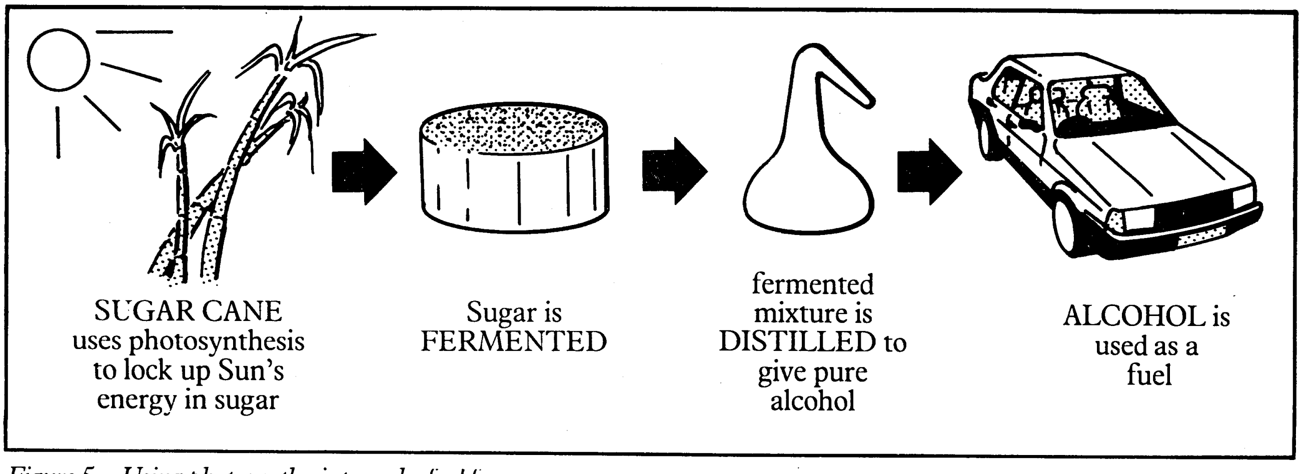

Figure 5 Using photosynthesis to make fuel for cars

Biomass fuels such as gasohol and biogas may be very important in the future. But even photosynthesis only locks up energy temporarily. Eventually all plants die and decay, or get eaten. Eventually all fuels get burned. When this happens, the locked-up energy is released and gets spread out again. In the end, we cannot stop it spreading out.

You might be interested to know that the rule 'Energy tends to spread out' is a simplified version of a scientific law called the Second Law of Thermodynamics. It is perhaps the most important of all the laws of science, because it applies to everything in the universe.