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.

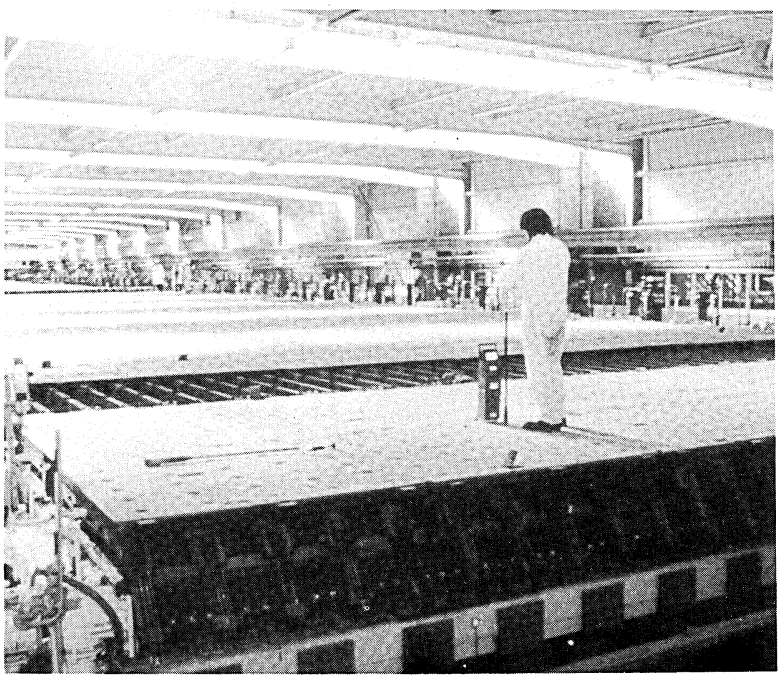

Figure 1 A modern electrolysis plant

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:

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

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

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

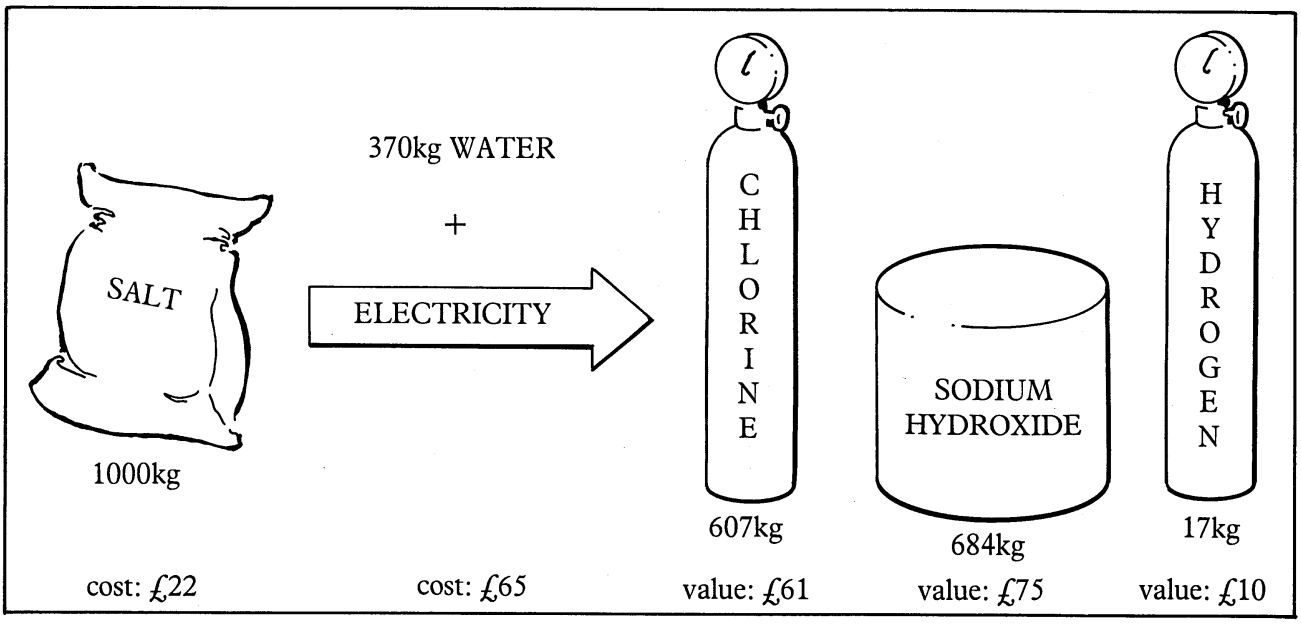

Figure 2 Amounts of products made by electrolysis of 1000kg of salt

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.

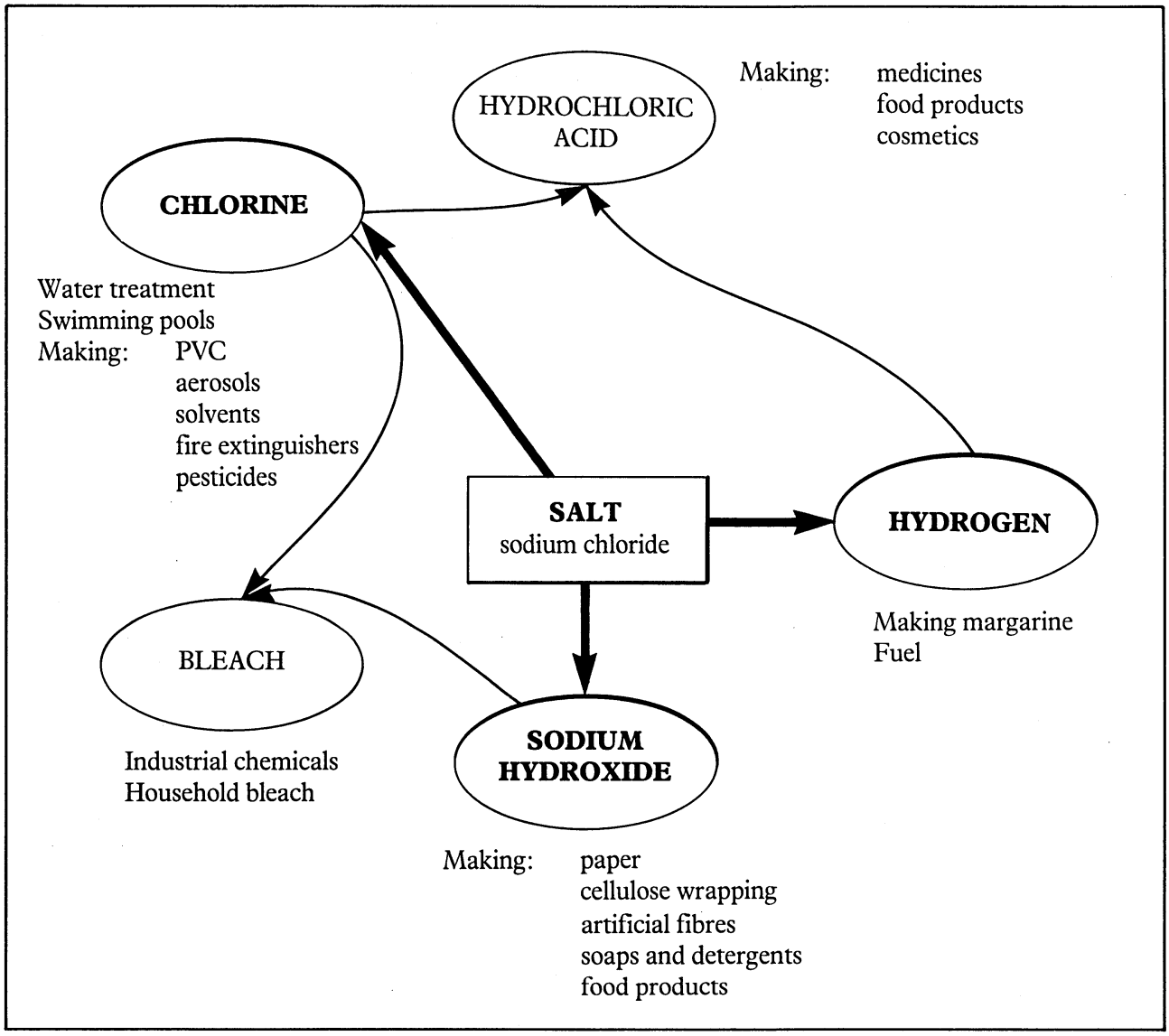

Figure 4 Uses of some of the chemicals made from salt

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.

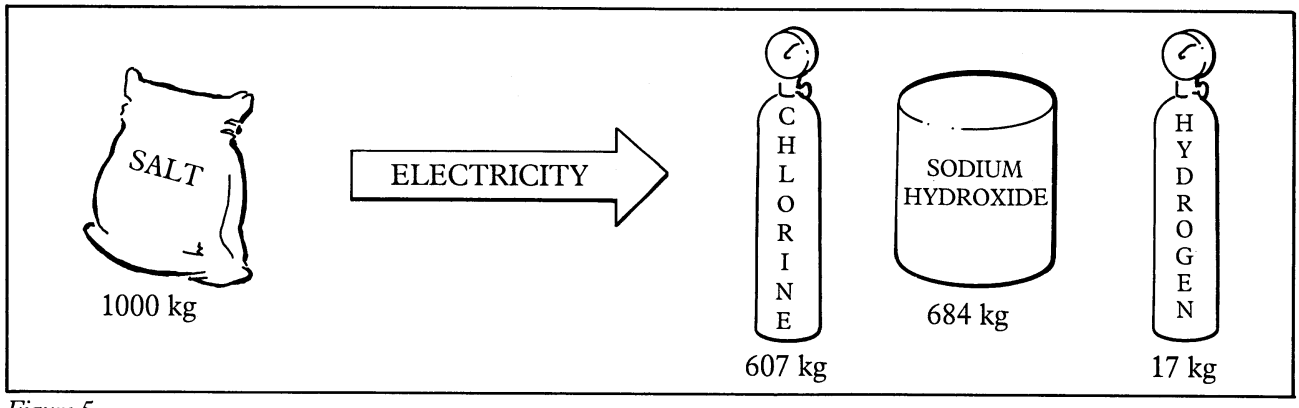

Figure 5

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).

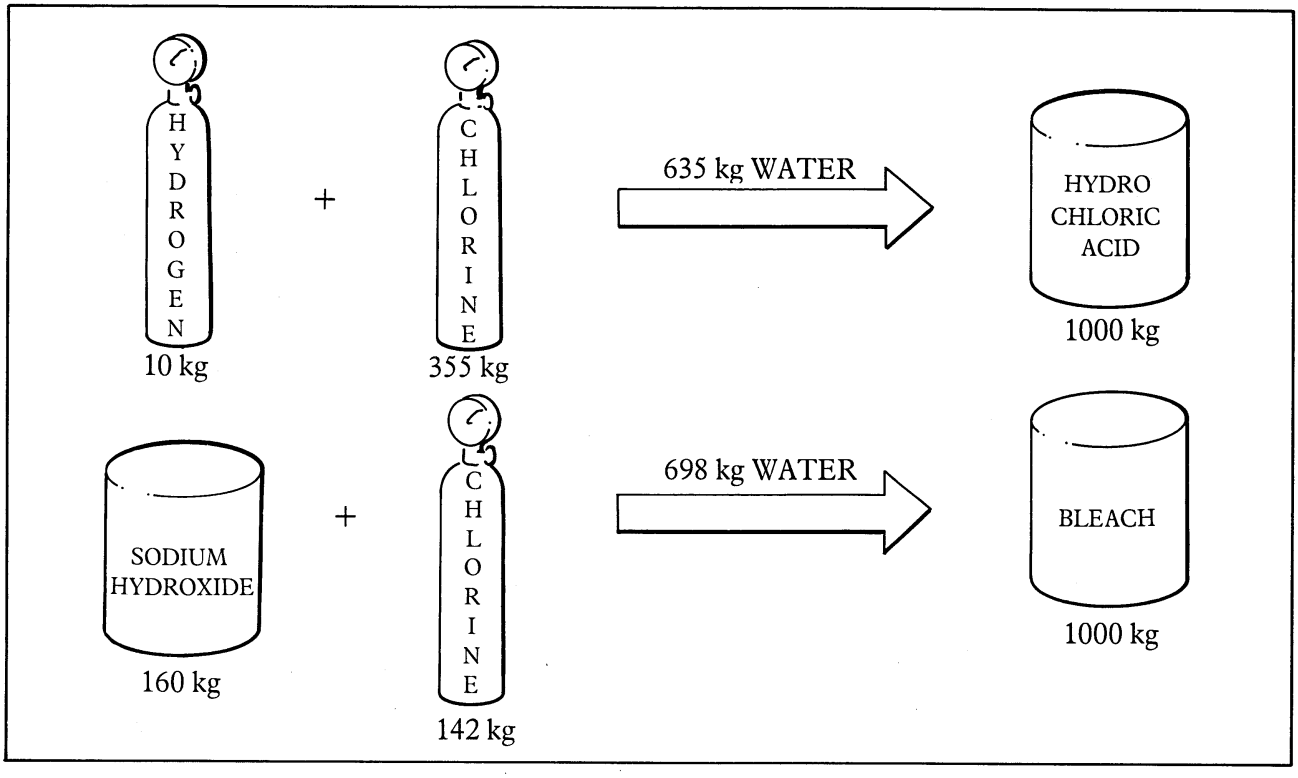

Figure 6 The quantities involved in making hydrochloric acid and bleach

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.

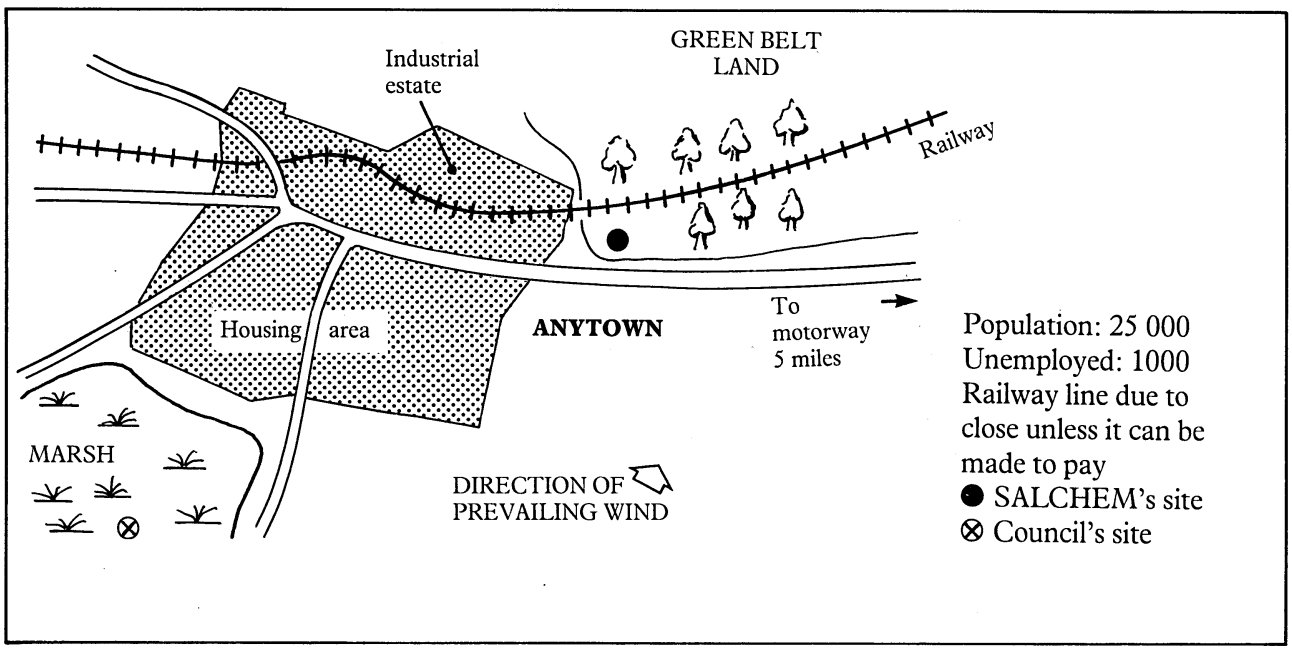

Figure 7 Anytown

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:

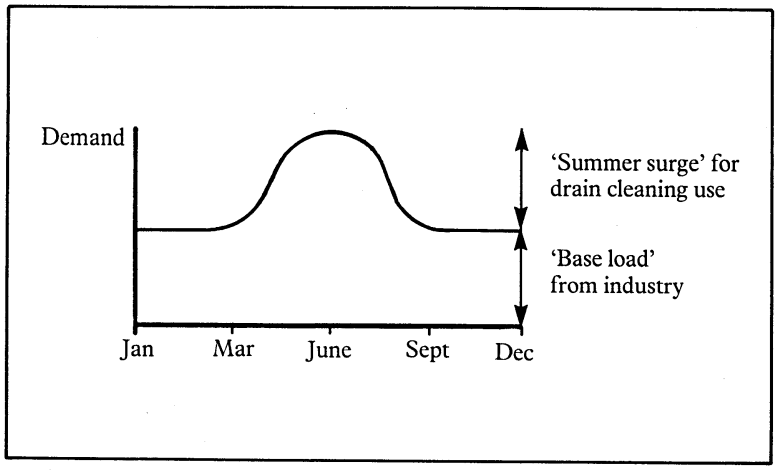

Figure 8

(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?