

## Applied Chemistry

To succeed with this topic you need to understand that the chemistry studied in the Factsheets has an impact on industry, everyday life and global issues

After working through this Factsheet, you will be able to

- Discuss the advantages of both liquid and gaseous fuels
- Understand how simple polymers are formed and be aware of their uses
- Discuss the use of halogens in pesticides, polymers and refrigerants and their impact upon the environment
- Recall the use of ammonia, nitric acid and sulphuric acid in the manufacture of fertiliser
- Discuss the extraction of aluminium from bauxite
- Recall the production of chlorine and sodium chlorate (I) by the electrolysis of sodium chloride solution

### Liquid and gaseous fuels

 A fuel is a substance which releases useful energy when combusted

An ideal fuel would

- Be abundant
- Be easy to store and transport
- Produce a large amount of energy per unit mass
- Be non-toxic
- Release harmless combustion products

### Abundance

- The majority of industrial fuel is fractionally distilled from crude oil (e.g. methane, butane, octane) and there are limited resources.
- Ethanol is a viable liquid fuel formed by fermentation of plant sugars.
- Hydrogen is plentiful, but too much energy is required for the electrolysis of water to separate it from oxygen.

### Transport and storage

Different fuels are obviously chosen for different purposes. Household fuel for cooking and heating is often gaseous due to the ease with which gaseous fuel can be piped into the home. Cars, however, tend to run on liquid fuel due to the ease of handling the fuel at filling stations. Whilst the transport of liquid fuel is dangerous, the transport of gaseous fuel is potentially more dangerous as practically it must be pressurised.

### Energy per unit mass

Where mass of fuel is important (prime example being aeroplanes) it is necessary for a great deal of energy to be generated from a relatively low mass of fuel.

### Toxicity

It is an advantage for fuels to be non-toxic if you consider how much they need to be handled, and the possible impact on the environment of a fuel leak.

### Combustion products

The extent and type of pollution produced needs to be considered.

- The quantity of greenhouse gases – specifically CO<sub>2</sub> – produced
- The emission of oxides of nitrogen and sulphur, which can lead to acid rain
- The emission of particles

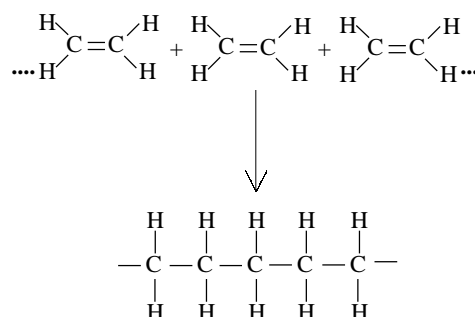
### Polymers

Polymers are long chain molecules made by joining together many small molecules (monomers).

Polymers have a wide and varied array of properties such as strength, flexibility and softening temperature.

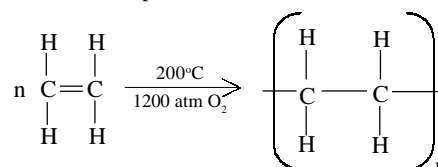
### Addition polymers

#### Polyethene



The name is due to the **addition** across the double bond.

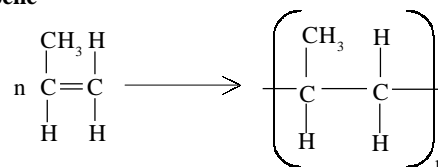
This reaction is better represented as follows



Properties of polyethene:

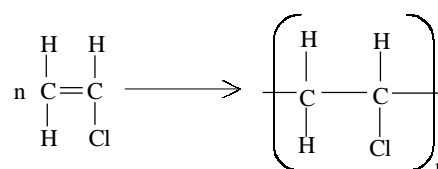
- Branched chains, will not pack closely, so readily melted and deformed. Used for bags and squeeze bottles
- If produced using catalysts at low temperatures, a harder form is produced with higher melting point and strength. High density polyethene is used for crates

### Polypropene

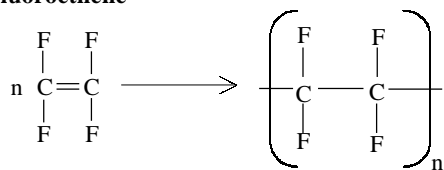


Well packed, similar properties to high density polyethene. Can be made into fibres and used for ropes – it does not rot away.

### Polychloroethene (or polyvinylchloride PVC)



Used for coating fabrics, electrical insulation and vinyl records.

**Polytetrafluoroethene**

“Teflon” is a very stable, low friction (“non-stick”) polymer used on kitchenware

**Problems with polymers – the environmental issue**

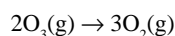
Simple polymers such as those given above are not broken down in normal environmental conditions – they are “non-biodegradable” due to the strength of the bonds within the compounds. Consequently, discarded polymers will not naturally disappear.

**Practical uses of organic halogen compounds, and their impact on the environment**

1. Polymers, as discussed above. PVC and Teflon are commonly used chemicals, but strong carbon-halogen and carbon-carbon bonds mean they are non-biodegradable
2. Pesticides and herbicides. DDT (dichlorodiphenyltrichloroethane) has been widely used as an insecticide, for instance eliminating malaria from several areas in the world. DDT has two major drawbacks:
  - i. Insects reproduce quickly, and resistant strains are now found
  - ii. DDT breaks down very slowly in the environment as it is very stable due to strong bonding

Complicated chlorine compounds such as 2,4 – D and 2,4,5-T are herbicides (or chemical weedkillers). They are also very stable compounds so persist in the environment, the problem being that, like pesticides, they may enter the water cycle and food chain, producing adverse effects on wildlife

3. CFCs – refrigerants and propellants. Chlorofluorocarbons (CFCs) have been widely used as aerosol propellants and as the cooling medium in refrigerators. They are so stable in air and water that when released they diffuse all the way up to the stratosphere, and only then will they be broken down by ultraviolet light. When decomposed by light, chlorine radicals are produced which catalyse the destruction of ozone.

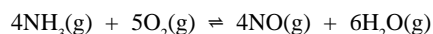


Consequently alternatives to CFCs are now being used.

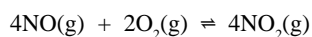
For the Contact process (manufacture of sulphuric acid) and the Haber process (manufacture of ammonia) see Factsheet 09 – Equilibrium and LeChatelier’s principle

**Oxidation of ammonia to nitric acid**

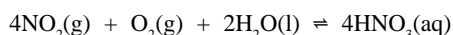
Ammonia and oxygen (from air) are heated to 900°C in the presence of a platinum/rhodium catalyst:



The nitrogen (II) oxide reacts with more oxygen on cooling



Nitrogen (IV) oxide and oxygen then react with water

**Ammonia, nitric acid and sulphuric acid in the manufacture of fertiliser**

Nitrogen is a vital element in fertilisers – ammonium nitrate (“nitram”) is widely used as it has a high nitrogen content and is water soluble. It is produced by reacting ammonia with nitric acid

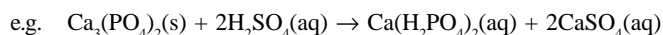


There are 3 types of nitrogen based fertiliser

- (i) quick release (eg  $\text{NH}_4\text{NO}_3$ )
- (ii) slow release (eg  $\text{NH}_2\text{CONH}_2$ , urea)
- (iii) natural (eg manure, compost)

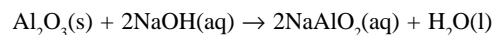
The first two are water soluble, so rapid leaching from soils can occur. Natural fertilisers are difficult and unpleasant to apply, and have low nitrogen contents.

Sulphuric acid is used in the manufacture of nitrogenous fertiliser (ammonium sulphate,  $(\text{NH}_4)_2\text{SO}_4$  and phosphate fertilisers. Phosphates are commonly too insoluble to be used, so sulphuric acid is used to produce the more soluble dihydrogen phosphates.

**The extraction of aluminium from bauxite**

Aluminium is manufactured by the electrolysis of molten aluminium oxide. This is obtained from bauxite – hydrated aluminium oxide containing impurities like iron (III) oxide and silicon (IV) oxide.

The bauxite is first treated to produce pure aluminium oxide. The ore is treated with a hot 10% solution of sodium hydroxide which reacts with the amphoteric aluminium oxide.



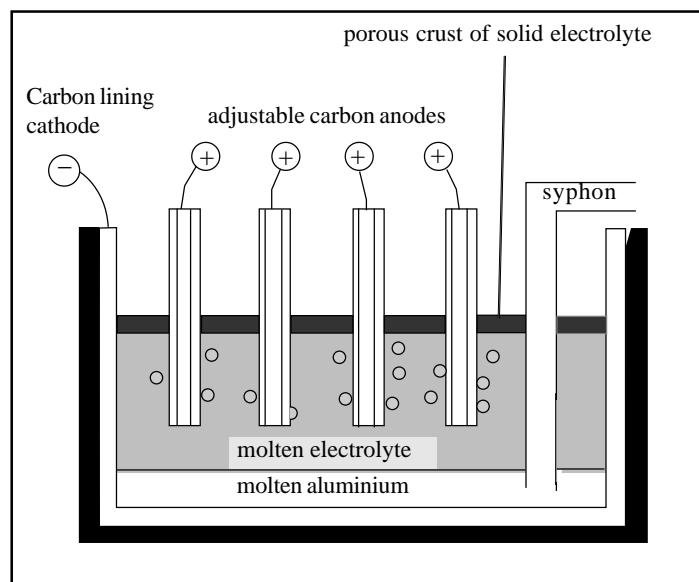
The basic  $\text{Fe}_2\text{O}_3$  does not react, and only small quantities of  $\text{SiO}_2$  react due to its giant atomic structure. These solid impurities are filtered off.

Carbon dioxide gas is blown through the sodium aluminate solution and aluminium hydroxide is precipitated – this is filtered and heated to make pure aluminium oxide.

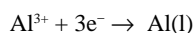
**The electrolysis of pure aluminium oxide**

Pure aluminium oxide is an unsuitable electrolyte due to its high melting point (2040 °C). To reduce costs, it is dissolved in **cryolite** ( $\text{Na}_3\text{AlF}_6$ ) at 900 °C, and then electrolysed (Fig 1).

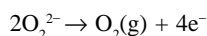
**Fig 1. Electrolytic cell for aluminium extraction**



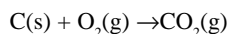
At the cathode, aluminium ions are reduced



At the anode, oxygen ions are oxidised



and react with the carbon anodes



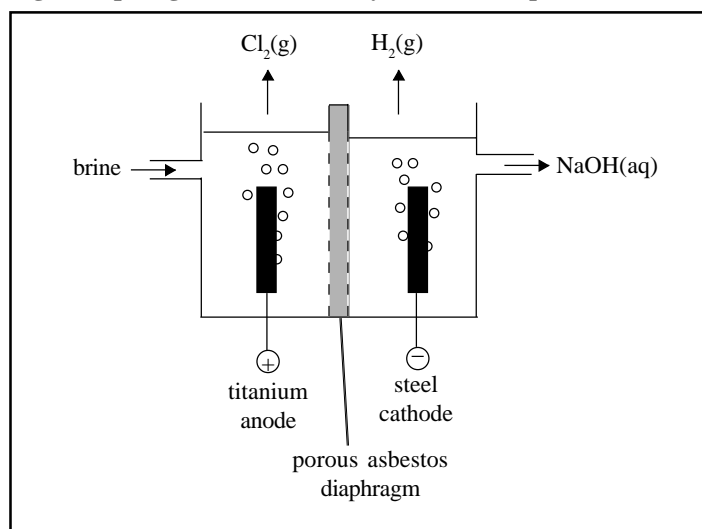
So the anodes gradually wear away and need moving and replacing regularly.

Aluminium is an expensive metal to manufacture, so the recycling of aluminium makes economic sense. It is a commonly used metal, e.g. for drinks cans, kitchenware, window frames and foil.

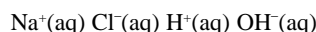
### The manufacture of chlorine and sodium chlorate (I)

This is done by the electrolysis of an aqueous solution of sodium chloride (brine) (Fig 2).

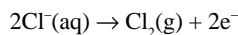
Fig 2. Diaphragm cell for electrolysis of NaCl(aq)



The solution contains the following ions:

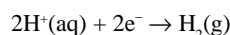


At the titanium anode (+) it is the chloride ions which are oxidised



so chlorine gas is produced

At the steel cathode (-), hydrogen ions are reduced



so hydrogen gas is produced.

The remaining solution still contains the  $\text{Na}^+(\text{aq})$  and  $\text{OH}^-(\text{aq})$  ions – hence sodium hydroxide solution is produced.

The porous asbestos diaphragm is necessary to keep the sodium hydroxide from the chlorine gas formed in the anode compartment.

Uses of chlorine gas (see also Factsheet 14)

- Water treatment
- Bromine manufacture
- Organochlorine compound manufacture
- PVC manufacture
- Hydrochloric acid manufacture

### Sodium chlorate (I) manufacture

If the chlorine gas and sodium hydroxide solution, as products of the electrolysis of brine, are allowed to mix, they react to form sodium chlorate (I).



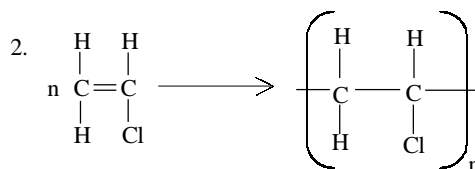
Note: recognise this as the disproportionation of chlorine - see Factsheet 14  
Sodium chlorate I is used as a bleach and a disinfectant

### Practice Questions

1. Briefly explain why there are concerns about the use of petrol as the main fuel for cars in the future
2. Write the equation showing the formation of polychloroethene (PVC) from its monomer
3. Explain how the use of chlorofluorocarbons as aerosol propellants has contributed to "the hole in the ozone layer"
4. Show how ammonia and nitric acid can be used in the formation of fertiliser
5. Explain why pure aluminium oxide cannot be used as an electrolyte in the industrial manufacture of aluminium.
6. Give the reactions at the anode and cathode during the electrolysis of brine.
7. Show how bleach (sodium chlorate) is produced from the products of the electrolysis of brine.

### Answers

1. Points to be mentioned
  - Petrol is fractionally distilled from crude oil, a fossil fuel of which there is a diminishing supply
  - Combustion products include carbon dioxide – increasing levels in the atmosphere contribute to global warming
  - Pollutants from the engine include nitrous oxides, which contribute to the formation of acid rain



3. The strong carbon-halogen and carbon-carbon bonds mean that CFCs are very stable compounds and when released into the atmosphere they stay intact until they reach the stratosphere, where they are broken down when irradiated by UV light and chlorine free radicals are produced. These free radicals catalyse the decomposition of ozone to oxygen in the stratosphere, decreasing the levels of ozone unnaturally.
4.  $\text{NH}_3 + \text{HNO}_3 \rightarrow \text{NH}_4\text{NO}_3$
5. Pure aluminium oxide has a very high melting point (2040 °C) and this would be a very expensive temperature to maintain, so a suitable solvent was found – cryolite ( $\text{Na}_3\text{AlF}_6$ ) which dissolves the aluminium oxide, and electrolysis can be carried out at the lower (and cheaper) temperature of 900 °C
6. Anode:  $2\text{Cl}^-(\text{aq}) \rightarrow \text{Cl}_2(\text{g}) + 2\text{e}^{-}$   
cathode:  $2\text{H}^+(\text{aq}) + 2\text{e}^{-} \rightarrow \text{H}_2(\text{g})$
7.  $\text{Cl}_2(\text{g}) + 2\text{NaOH}(\text{aq}) \rightarrow \text{NaOCl}(\text{aq}) + \text{NaCl}(\text{aq}) + \text{H}_2\text{O}(\text{l})$

### Acknowledgements:

This Factsheet was researched and written by Sam Goodman & Kieron Heath  
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