Cambridge OL

Chemistry

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Chapter 11

Chemistry of the environment

11.1 Water

Water, the most common compound on Earth, is essential for our survival and existence. It covers over 70% of Earth's surface and is found in bones, kidneys, and blood.

a Millions of tonnes of water pass over this waterfall every day

b Your blood contains a lot of water

▲ **Figure 11.1**

Water has many other important uses besides sustaining life. These include in the home:

» Cooking
» Cleaning
» Drinking.

In industry:

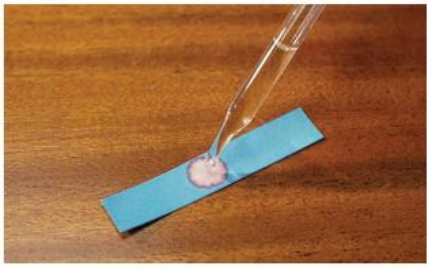
» As a solvent
» As a coolant
» For cleaning
» As a chemical reactant.

▲ **Figure 11.2** Liquid water boils at 100°C and freezes to form ice at 0°C

The unique properties of water

Water is a unique substance. Not only is it an excellent solvent for many ionic substances, such as sodium chloride, but it also has some unusual properties.

a Anhydrous copper(II) sulfate goes blue when water is added to it



b Cobalt(II) chloride paper turns pink when water is dropped on to it

▲ **Figure 11.3** Tests for the presence of water

▲ **Figure 11.4** When water freezes, its density falls; this is why icebergs float

Water pollution and treatment

Fresh water is crucial for global health and well-being, but pollution affects its quality, leading to waterborne diseases like cholera and typhoid. Agriculture requires water for crop irrigation, especially in hot climates, to meet the growing population.

Key definition

Pollution is a modification that takes place to the environment, water or air, caused by human influence such as releasing substances into our water or air.

As water falls through the atmosphere, on to and then through the surface of the Earth, it dissolves a tremendous variety of substances including:

▲ **Figure 11.6** A badly polluted river

»Carbon dioxide and oxygen, released by vehicles and industry, contribute to increasing water acidity, benefiting aquatic life but causing a decrease in oxygen levels in rivers and oceans.

»Chemical fertilisers and detergents from agricultural waste and industrial use add nitrate and phosphate ions to water, leading to deoxygenation and disrupting sensitive ecosystems. These ions encourage algae growth and degrade water.

»Metal compounds in industrial wastewater, including harmful chemicals like cadmium and mercury, can be toxic, but some are beneficial, particularly calcium-containing compounds, essential for bone and tooth growth.

▲ **Figure 11.7** This lake is used as a source of drinking water

»Human waste from sewage. Sewage contains harmful microbes which cause disease.

»Plastic waste, containing insoluble impurities like oil, is polluting our streams, rivers, and oceans, causing harm to aquatic and human life.

A lot of drinking water is obtained from lakes and rivers where the **pollution** levels are low (Figure 11.7). Undesirable materials are removed from water by the process of water treatment, which involves both filtration and chlorination and is summarised in Figure 11.8.

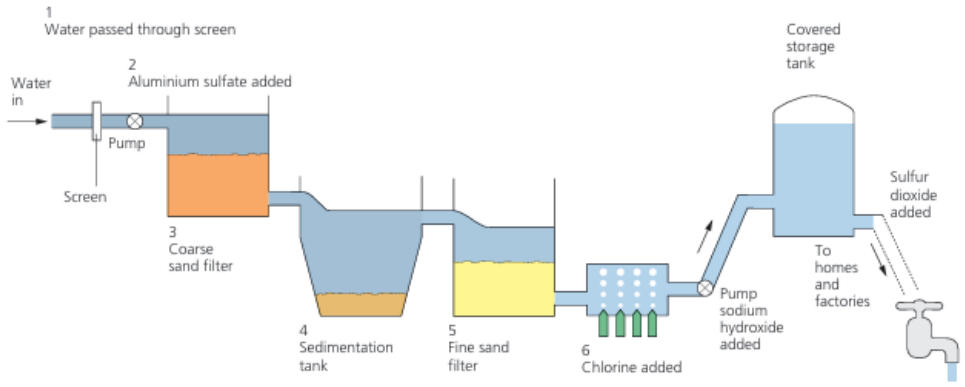
1. Impure water is passed through screens to filter out floating debris.

2. Aluminium sulfate is added to coagulate small particles of clay so that they form larger clumps, which settle more rapidly

3 Filtration through coarse sand traps larger, insoluble particles. The sand also contains specially grown microbes which remove some of the bacteria.

4. A sedimentation tank has chemicals known as flocculants,

5. These particles are removed by further filtration through fine sand.



▲ **Figure 11.8** The processes involved in water treatment

11.2 Artificial fertilizers

If ammonia is then reacted with the nitric acid, ammonium nitrate is produced. This gives us the basic reaction to produce many artificial **fertilizers**.

$$\text{ammonia} + \text{nitric acid} \rightarrow \text{ammonium nitrate}$$
$$NH_3(g) + HNO_3(aq) \rightarrow NH_4NO_3(aq)$$

Ammonium nitrate (Nitram®) is a widely used nitrogenous fertiliser, essential for farmers to produce enough crops to feed the growing world population. It replaces nutrients like nitrogen, phosphorus, potassium, calcium, magnesium, sodium, sulfur, copper, and iron.

Key definition

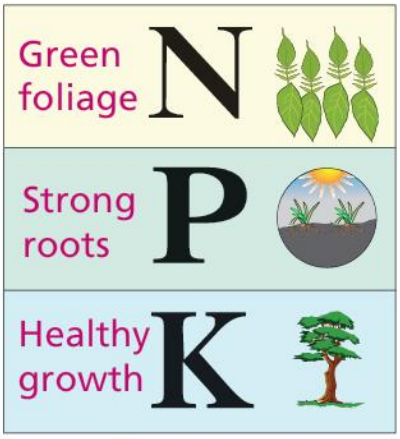
Fertiliser is a chemical put onto soil to replace lost mineral salts and so make plants grow more healthily. These include ammonium salts, such as ammonium nitrate, which is one of the most commonly used fertilisers.

▼ **Table 11.1** Some nitrogenous fertilisers

Fertiliser	Formula
Ammonium nitrate	NH_4NO_3
Ammonium phosphate	$(NH_4)_3PO_4$
Ammonium sulfate	$(NH_4)_2SO_4$
Urea	$CO(NH_2)_2$

▲ **Figure 11.10** Fertilisers have been used to help create some of the best fruit and vegetables on sale

a Different fertilisers contain differing amounts of the elements nitrogen, phosphorus and potassium.



b The different NPK elements are responsible for the healthy growth of plants in different ways.

▲ **Figure 11.9**

Problems with fertilisers

Artificial fertilisers can cause problems if not used correctly, leading to leaching and eutrophication. This process causes algae to multiply rapidly, turning water green and removing oxygen, causing insufficient oxygen for fish and other organisms. Concerns also arise about the impact of agricultural fertilizers, particularly nitrates, on public water supply.

11.3 The air

The composition of the atmosphere

If a sample of dry, unpolluted air was taken from any location in the atmosphere close to the Earth and analysed, the composition by volume of the sample would be similar to that shown in Table 11.2.

▼ **Table 11.2** Composition of the atmosphere

Component	%
Nitrogen	78.08
Oxygen	20.95
Argon	0.93
Carbon dioxide	0.04
Neon	0.002
Helium	0.000 5
Krypton	0.000 1
Xenon plus tiny amounts of other gases	0.000 01

Key definition

Clean, dry air is approximately 78% nitrogen, 21% oxygen and the remainder is a mixture of noble gases and carbon dioxide.

Plants produce oxygen in the atmosphere through **photosynthesis**, which uses carbon dioxide and water to synthesize glucose and oxygen in green leaves, which contain chlorophyll.

$$\text{carbon dioxide} + \text{water} \xrightarrow[\text{chlorophyll}]{\text{sunlight}} \text{glucose} + \text{oxygen}$$

$$6CO_2 + 6H_2O \rightarrow C_6H_{12}O_6 + 6O_2$$

Scientists have recently detected an increase in atmospheric carbon dioxide to around 0.04%, affecting Earth's climate. The **greenhouse effect**, which causes **global warming**, is believed to be the cause. If carbon dioxide levels build up, the Earth's average temperature will rise.

11.4 Atmospheric pollution

This chapter discusses the importance of water and air resources in our environment, which are constantly polluted by humans. Air pollution, primarily from fossil fuel combustion and smoking, is increasing due to the growing population and increased demand for energy, industries, and motor vehicles. The effects of air pollution and methods to control or eliminate it are discussed.

▼ **Table 11.3** Pollution caused by motor vehicles

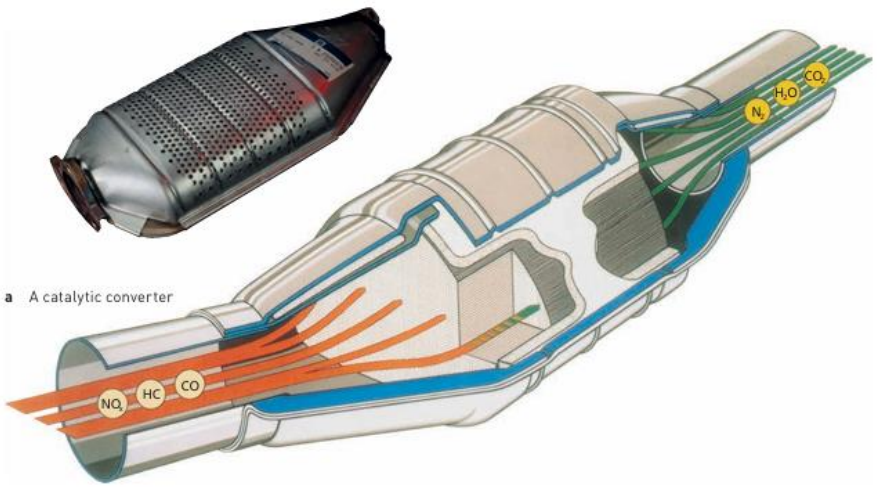
Pollutant	Caused by	Problems caused	Can be reduced by
Carbon monoxide, CO	The incomplete combustion of carbon-containing fuels	Toxic gas	Fitting catalytic converters to remove CO, but more CO_2 is produced. It should be noted that lean-burn engines also produce less CO
Particulates, C	The incomplete combustion of carbon-containing fuels	Increased risk of respiratory problems and cancer	Adding oxygenates such as ethanol to petrol to reduce the particulates produced
Methane, CH_4	The decomposition of vegetation and waste gases from digestion in animals	Higher levels of methane lead to increased global warming, which leads to climate change	Encouraging composting or incineration. Capturing the methane produced and using it as a fuel or to generate electricity when burned. Reducing the number of farm animals by encouraging people to eat less meat
Nitrogen oxides, NO_x	Car engines	Acid rain, photochemical smog and respiratory problems	Fitting catalytic converters to remove nitrogen oxides. However, in doing so more carbon dioxide is produced
Sulfur dioxide, SO_2	The combustion of fossil fuels which contain sulfur compounds	Acid rain	Removing sulfur from petrol to produce low-sulfur petrol. Using flue gas desulfurisation units (see p. 175) at coal-burning power stations

Catalytic converters

Many countries require new petrol cars to have **catalytic converters** in their exhaust systems to reduce pollution. Car exhaust fumes contain pollutants like carbon monoxide and nitrogen oxides. The catalytic converter speeds up the reaction by lowering activation energy, converting pollutants into carbon dioxide and nitrogen. The removal of nitrogen oxides is crucial as they cause respiratory disease and contribute to the production of photochemical **smog**, a major air pollutant. The catalyst is made from transition metals like platinum or rhodium.

nitrogen(II) oxide + carbon monoxide → nitrogen + carbon dioxide

$2NO(g) + 2CO(g) \rightarrow N_2(g) + 2CO_2(g)$



a A catalytic converter

b A section through a catalytic converter

▲ **Figure 11.15** A catalytic converter removes hydrocarbons, carbon monoxide and oxides of nitrogen from vehicle exhausts

Particulates

Global concern over rising particulates in the air, including smoke from diesel engines and dust, is heightened due to incomplete combustion of fuels like wood or coal.

▲ **Figure 11.17** Particulates produced by diesel engines are a real health problem worldwide

Acid rain

Acid rain is caused by sulfur dioxide emissions from motor vehicles, heavy industry, and power stations. Rainwater, naturally acidic, dissolves carbon dioxide gas from the atmosphere, resulting in sulfurous acid (H2SO3) and sulfuric acid (H2SO4). Nitrogen dioxide (NO2), produced in vehicle engines, also contributes to acid rain. Acid rain is a growing concern in Asia, with China and India having the highest sulfur dioxide emissions. It can damage buildings, soils, and ecosystems.

▲ **Figure 11.19** This forest has been devastated by acid rain

▲ **Figure 11.20** This plasterboard is made using calcium sulfate from an FGD plant

Acid rain is reduced by catalytic converters removing nitrogen oxides from engine hot gases. Flue gas desulfurisation (FGD) units prevent sulfur dioxide emissions by passing sulfur dioxide through calcium oxide in water. Calcium sulfite is created, oxidized to sulfate, which can be sold for plasterboard production.

▲ **Figure 11.18** Sulfur dioxide is a major pollutant produced by industry

Global warming

The greenhouse effect occurs when certain gases in the Earth's atmosphere trap the Sun's heat, causing the Earth's temperature to rise. High levels of carbon dioxide, for example, contribute to climate change. The Earth absorbs some Sun energy, while the rest is reflected back into space. Greenhouse gases, like carbon dioxide, prevent heat from escaping, similar to a greenhouse effect. Other greenhouse gases, like methane, also contribute to this effect.

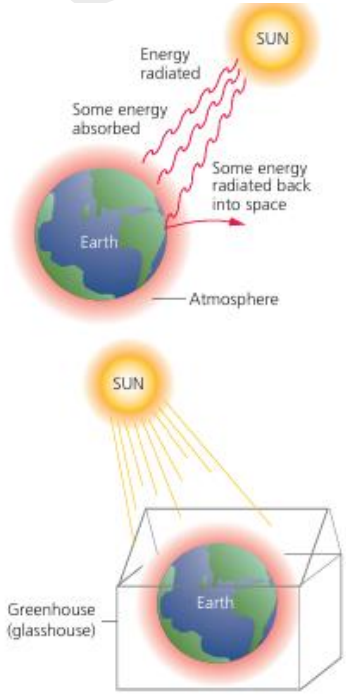
The amount of carbon dioxide in the atmosphere is increasing for three reasons:

» Major deforestation taking place in several countries of the world. Trees act as the lungs of the planet. During photosynthesis they absorb carbon dioxide and release oxygen.

» Pollution of our rivers and oceans. The more pollutants that are dissolving in these systems, the less carbon dioxide that can dissolve in the water.

» Large increase in the amounts of carbon dioxide released by the continued burning of large quantities of fossil fuels by industry and transport.

The greenhouse effect's higher temperatures will cause ice caps to melt, flooding low-lying areas, and alter weather patterns, impacting agriculture worldwide. Incomplete combustion of diesel produces carbon particles, which reduce snow reflectivity, increasing melting in mountainous and northern and southern pole areas.



▲ **Figure 11.21** The greenhouse effect

How can we reduce the effects of global warming?

There are several actions that can be taken to reduce the effects of global warming:

» Plant more trees and reduce the amount of deforestation taking place worldwide. This will cause more carbon dioxide to be absorbed from the atmosphere through photosynthesis.

» Alternative fuels can help reduce carbon dioxide emissions by burning fewer fossil fuels. However, sustainability is crucial, as fossil fuels are not renewable or sustainable. Table 11.4 outlines the advantages and disadvantages of these alternatives, as well as their perceived advantages and disadvantages.

» To combat global warming, increase energy efficiency in homes, consider insulating homes, turning off lights when not needed, and consider essential travel options to reduce carbon dioxide emissions.

» Increase the use of renewable energy sources such as solar, wind and tidal.

» Significantly reduce livestock farming to cut down the amount of methane released into the atmosphere.

▲ **Figure 11.22** A hydrogen-powered vehicle

▼ **Table 11.4** Alternative fuels to fossil fuels

Alternative fuel	Is the alternative sustainable?	Advantages	Disadvantages
Biodiesel	Yes it is! It is made from waste plant material and animal oils and fats.	Produces less CO, C_xH_y, SO_2 and particulates than diesel fuel.	NO emissions are higher than from standard diesel fuel.
Ethanol	This is open to debate since large amounts of energy and land are needed to cultivate sugar cane for fermentation.	Less CO, SO_2 and NO_x are produced than from petrol. Replanting sugar cane creates a cycle as it absorbs CO_2 from the atmosphere.	Very flammable.
Hydrogen	Hydrogen is sustainable only if the electricity needed to produce it, from the electrolysis of acidified water, is from a renewable resource such as solar power or wind. The car shown in Figure 11.22 is powered by hydrogen.	Water is the only product of production. Hence there is no pollution.	It is very, very flammable. Also a high-pressure fuel tank is needed to store it as a liquid.

Revision questions

3. Nov/2021/Paper_21/No.2

Dry air contains nitrogen, oxygen, noble gases and carbon dioxide.

(a) State the percentage of oxygen present in dry air.

..... [1]

(b) Carbon dioxide is removed from a sample of air by passing the air through aqueous sodium hydroxide.

Explain why aqueous sodium hydroxide removes carbon dioxide from air.

.....

.....

..... [2]

(c) Describe how oxygen, nitrogen and the noble gases are separated from each other after carbon dioxide has been removed.

.....

..... [2]

(d) Describe the test for oxygen.

test .....

observation .....
[2]

(e) Ozone, O_3, is formed in the atmosphere by the reaction of nitrogen dioxide with oxygen in the presence of ultraviolet light.

(i) State the type of chemical reaction that takes place when ozone is formed in this way.

(ii) Nitrogen dioxide is formed in internal combustion engines.

State one other source of nitrogen dioxide in the atmosphere.

..... [1]

(f) A layer of ozone is present high in the atmosphere.

State one problem for humans that can arise if the ozone layer is depleted by CFCs.

..... [1]

4. Nov/2021/Paper_22/No.2

This question is about pollutant gases.

(a) Hydrocarbons such as octane are used as fuels for cars.

The list shows the gases present in a car exhaust.

carbon dioxide
carbon monoxide
nitrogen
nitrogen dioxide
octane
water vapour

State which two gases in the list show that incomplete combustion has taken place in this car engine.

(b) Describe a test for carbon dioxide.

test .....

observation .....
[2]

(c) Two natural sources of methane in the atmosphere are from leaks of natural gas and waste gases from animals.

Give one other natural source of methane in the atmosphere.

..... [1]

(d) Complete this sentence about the effect of an increase in the concentration of methane in the atmosphere.

Methane is a ..... gas because it absorbs and then re-emits infrared radiation. This contributes to an increase in temperature of the atmosphere which is called ....
[2]

(e) Cars are fitted with catalytic converters to reduce the amount of harmful pollutant gases from car exhausts.

Describe how catalytic converters remove pollutant gases from car exhausts.

7. Jun/2021/Paper_21/No.6

Carbon dioxide and water vapour are greenhouse gases found in air.

(a) (i) Name one **other** greenhouse gas.

..... [1]

(ii) State **one** environmental problem that may be caused by an increase in the percentage of carbon dioxide in the air.

..... [1]

(b) Draw the dot-and-cross diagram to show the bonding in a molecule of carbon dioxide.

Only show the outer shell electrons.

(c) Some power stations burn methane, CH_4.

Construct the equation to show the complete combustion of methane.

(d) The carbon dioxide made in power stations can be removed by a reversible reaction with water.

$$CO_2(g) + H_2O(l) \rightleftharpoons H_2CO_3(aq)$$

The forward reaction is exothermic.

(i) The concentration of carbon dioxide is increased.

The temperature is kept constant.

Predict and explain how the position of equilibrium changes.

(ii) The temperature of the water is increased.

All other conditions are kept constant.

Predict and explain how the position of equilibrium changes.

(e) Carbonic acid, $H_2CO_3(aq)$, is a weak acid.

(i) What is the meaning of the term *weak* in weak acid?

(ii) Carbonic acid contains a small concentration of carbonate ions, $CO_3^{2-}(aq)$.

If carbonic acid is pumped deep underground, the $CO_3^{2-}(aq)$ will react with metal ions to form insoluble carbonates.

Write the ionic equation for the reaction of magnesium ions with $CO_3^{2-}(aq)$.

8. Jun/2021/Paper_22/No.6

Sulfur dioxide and oxides of nitrogen are pollutants found in air.

(a) State one environmental problem caused by the presence of sulfur dioxide in the air.

..... [1]

(b) Coal-fired power stations produce sulfur dioxide as a pollutant.

The sulfur dioxide produced is prevented from entering the air by a process called flue gas desulfurisation, FGD.

Name the compound used in FGD that reacts with the sulfur dioxide.

..... [1]

(c) Coal-fired power stations also produce oxides of nitrogen such as NO.

NO is produced when nitrogen, N_2, reacts with oxygen.

(i) Construct the equation for this reaction.

..... [1]

(ii) Draw a dot-and-cross diagram to show the bonding in a molecule of nitrogen.

Only include the outer shell electrons.

(iii) Explain why the rate of reaction between nitrogen and oxygen increases as the temperature increases.

(d) Nitrogen dioxide, NO_2, reacts with water to form a mixture of dilute nitric acid, HNO_3, and dilute nitrous acid, HNO_2.

$$2NO_2 + H_2O \longrightarrow HNO_2 + HNO_3$$

(i) Nitrogen dioxide reacts with aqueous sodium hydroxide to form two different salts and water.

Construct the equation for this reaction.

..... [2]

(ii) Nitric acid is a strong acid.

Nitrous acid is a weak acid.

Describe the difference between a weak acid and a strong acid.

9. Nov/2021/Paper_2S2/No.4a

Water from natural sources contains dissolved substances which are not pollutants, such as mineral salts.

(a) Name another substance found naturally in water which is **not** a mineral salt or a pollutant.

18. Jun/2020/Paper_21/No.7
Carbon dioxide is a colourless gas found in air.

(a) The percentage of carbon dioxide in the air is increasing.

State one environmental problem caused by this increase.

..... [1]

(b) Carbon dioxide is a product of the complete combustion of octane, C_8H_{18}.

Construct the equation for this reaction.

..... [2]

(c) Fermentation of glucose produces carbon dioxide.

(i) Give the equation for the fermentation of glucose.

..... [1]

(ii) State **two** essential conditions needed for fermentation.

.....

..... [2]

(d) When warmed, solid carbon dioxide changes directly into a gas. It does **not** become a liquid.

Use the kinetic particle theory to describe the changes in **movement** and **arrangement** of the particles during this change of state.

(e) Explain why solid carbon dioxide does not conduct electricity.

19. Jun/2020/Paper_22/No.9
Sulfur dioxide is a colourless gas which can be found in air.

(a) State one environmental problem caused by the presence of sulfur dioxide in air.

..... [1]

(b) When heated in air iron pyrite, FeS_2, reacts with oxygen.

Sulfur dioxide and iron(III) oxide, Fe_2O_3, are the products of this reaction.

Construct the equation for this reaction.

..... [2]

(c) Give one use for sulfur dioxide.

..... [1]

(d) Liquid sulfur dioxide is stored in cylinders.

When the cylinder is opened the liquid quickly changes into a gas.

Use the kinetic particle theory to describe the changes in **movement** and **arrangement** of the particles when liquid sulfur dioxide becomes a gas.

(e) Sulfur dioxide has a low melting point.

Suggest, in terms of structure and bonding, why sulfur dioxide has a low melting point.