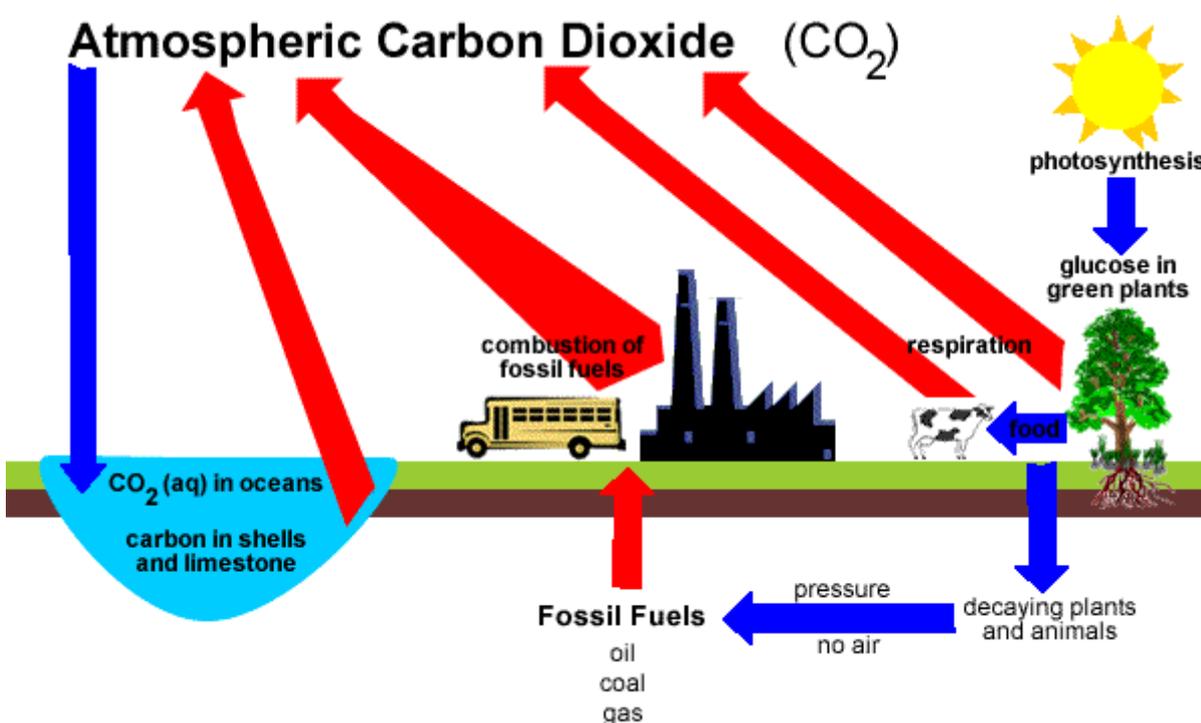


## Carbon Cycle

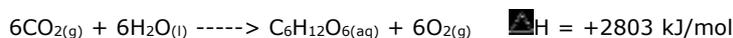
### Key Concepts

Carbon is constantly being used and reused by living things in a process known as the carbon cycle. The original energy source is the sun. Chlorophyll in green plants absorbs energy from the sun and converts it to chemical energy through photosynthesis. Photosynthesis converts atmospheric carbon dioxide (CO<sub>2</sub>) into glucose (C<sub>6</sub>H<sub>12</sub>O<sub>6</sub>). In the cells of living things energy is released during respiration. Respiration converts glucose (C<sub>6</sub>H<sub>12</sub>O<sub>6</sub>) into carbon dioxide (CO<sub>2</sub>).

### The Carbon Cycle



Green plants convert atmospheric carbon dioxide and water into glucose and oxygen in a process called photosynthesis.

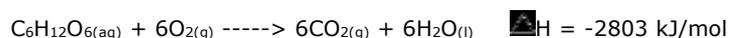


Photosynthesis is an endothermic reaction. Solar energy from the sun provides the necessary energy for the reaction to proceed.

Animals eat plants, or eat other animals that have eaten plants, and incorporate the carbon atoms into their cells.

Plants and animals both respire.

During respiration, glucose and oxygen are converted into carbon dioxide and water.



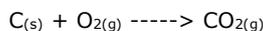
Respiration is an exothermic reaction, releasing 2803 kJ per mole of energy.

The process of decomposition also releases carbon dioxide back into the atmosphere.

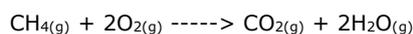
Dead organisms under particular conditions, such as under pressure and in the absence of air, may, over time, be converted into fossil fuels such as coal, oil and gas.

Humans combust these fossil fuels as an energy source which releases carbon dioxide back into the atmosphere.

The complete combustion of coal results in the formation of carbon dioxide gas:



The complete combustion of hydrocarbons, such as methane ( $\text{CH}_{4(g)}$ ), produces carbon dioxide and water:



The combustion of fossil fuels are exothermic reactions, they release energy.

The total number of carbon atoms is always constant by the Law of Mass Conservation, but there is growing concern over the number of carbon atoms that exist as carbon dioxide because carbon dioxide is a greenhouse gas and a main contributor to the greenhouse effect.

## Nitrogen Cycle

### Key Concepts

Nitrogen gas,  $\text{N}_{2(g)}$ , is the major constituent of air, ~78% by volume.

Inorganic (non-carbon) compounds of nitrogen are not commonly found as minerals because most of them are water soluble.

In dry climate locations there are beds of nitrates.

Nitrogen is found combined in organic (carbon) compounds in all living matter, both plant and animal.

Nitrogen in the atmosphere is the source of all nitrogen found in living matter.

The complex interrelationship between atmospheric nitrogen, nitrate, nitrite and ammonium ions found in soils, and organic nitrogen compounds found in living matter, is called the nitrogen cycle.

The nitrogen cycle keeps the nitrogen content of the atmosphere constant.

Nitrogen fixation refers to the conversion of nitrogen gas into nitrogen compounds.

Nitrification is the process of converting one nitrogen compound to another.

Denitrification is the process of releasing nitrogen gas back into the atmosphere.

### Nitrogen Cycle

$\text{N}_2$  gas in the atmosphere can be changed into soluble nitrogen compounds in the soil.

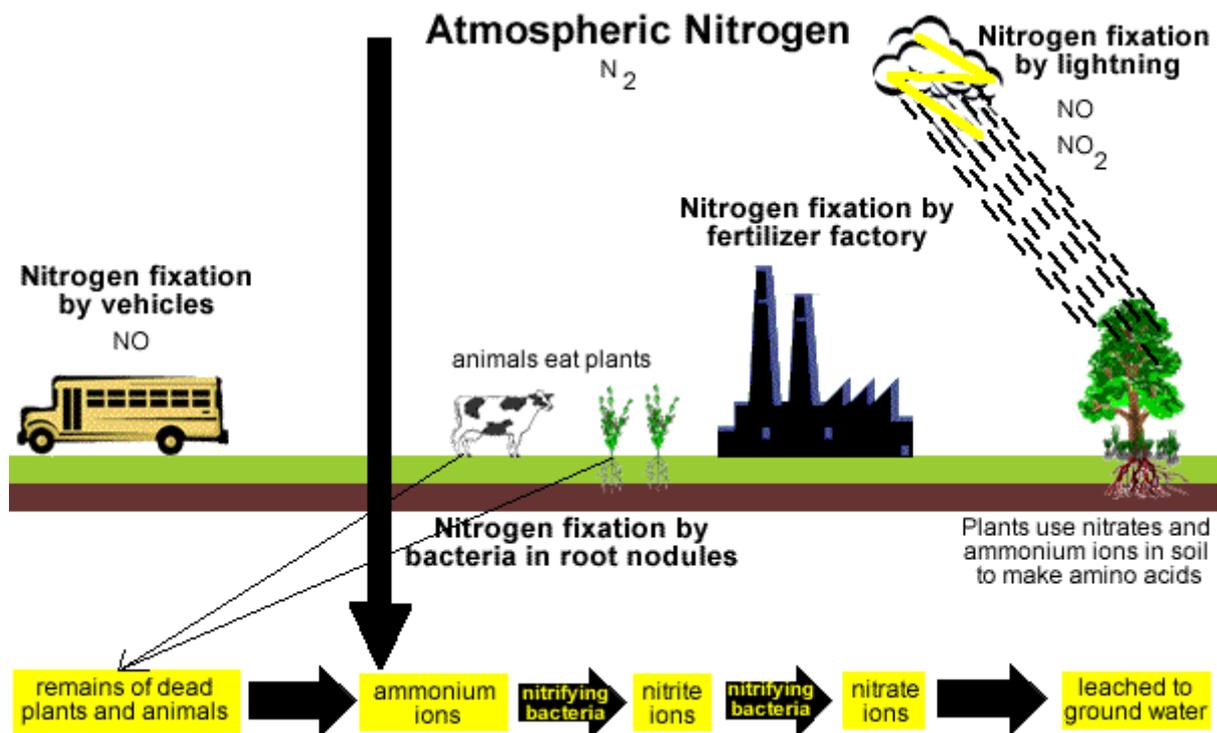
Electrical storms can produce small quantities of nitrites ( $\text{NO}_2^-$ ) and nitrates ( $\text{NO}_3^-$ ) which are carried to earth in rain.

Some plants, like legumes, can convert atmospheric  $\text{N}_2$  gas into nitrogen compounds which can be converted by bacteria into nitrates ( $\text{NO}_3^-$ ), which plants can use to make plant proteins.

Soluble nitrogen compounds in soil can be taken up by plants to make plant proteins.

Animals eat the plants and by the process of digestion convert the plant proteins to animal proteins.

Plants and animals die and their decomposing cells release  $\text{N}_2$  gas back into the atmosphere.



The nitrogen cycle involves oxidation and reduction of nitrogen.

<b>Nitrogen Cycle</b>	$N_{2(g)}$	----->	$NH_4^+_{(aq)}$	----->	$NO_2^-_{(aq)}$	----->	$NO_3^-_{(aq)}$
<b>Oxidation Number of N</b>	0	----->	-3	----->	+3	----->	+5
<b>Reaction Type</b>			reduction		oxidation		oxidation

## CFC's and Ozone Depletion

### Ozone in the Atmosphere

#### Ozone in the Lower Atmosphere (troposphere)

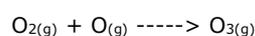
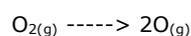
About 10% of all ozone ( $O_3$ ) in the atmosphere is found in the troposphere (up to 16km above the earth's surface).

Ozone in the troposphere has harmful effects on many living things because it is toxic.

In humans, ozone causes eye irritation, compromised lung functions, aggravation of respiratory conditions like asthma, and increases the susceptibility to infection.

Ozone pollution in the troposphere is often linked to photochemical smog.

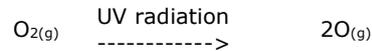
Ozone in the lower atmosphere is formed during electrical discharge from high voltage appliances as shown in the equations below:



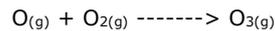
## Ozone in the Upper Atmosphere (stratosphere)

About 90% of all ozone (O<sub>3</sub>) in the atmosphere is found in the stratosphere (16 to 32 km above the earth's surface).

In the stratosphere ozone acts as the primary UV radiation shield, short wavelength UV radiation from the sun (<240nm) provides the energy to split oxygen molecules into oxygen atoms:



Oxygen atoms then react with oxygen molecules to form ozone:



Ozone can absorb harmful UV-B and UV-C radiation, preventing it from reaching the earth's surface:



The constant formation and destruction of ozone maintains a balance over time.

Human activities, such as the release of chlorofluorocarbons into the atmosphere, have disturbed this balance.

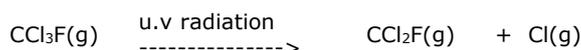
## Chlorofluorocarbons (CFCs) and Halons

- CFCs and halons belong to the haloalkanes.
- Chlorofluorocarbons (CFCs) are compounds containing only carbon, chlorine and fluorine (no hydrogen). Halons are compounds containing only carbon, bromine and other halogens (no hydrogen).
- Chlorofluorocarbons (CFCs) are sold under the trade name of Freons.
- CFCs are used as working fluids in refrigerators and air conditioners because they are gases at room temperature which can be easily liquified by compression and because they are stable and non-toxic
- CFCs are used as foaming agents in the production of polystyrene and polyurethane foam plastics used for insulation and packing materials
- CFCs are used as a propellant in spray cans for paint, insect repellants, deodorants
- Halons are used in fire extinguishers because they are dense, non-flammable liquids. Bromochlorodifluoromethane, CF<sub>2</sub>ClBr, is commonly used in halon fire extinguishers.

CFC Name	Formula	Code	Uses
trichlorofluoromethane freon-11	CCl <sub>3</sub> F	CFC-11	refrigeration, aerosols, foams
dichlorofluoromethane freon-12	CCl <sub>2</sub> F <sub>2</sub>	CFC-12	refrigeration, aerosols, foams, air conditioning
1,1,2-trichloro-1,2,2-trifluoroethane freon-13	CCl <sub>2</sub> FCF <sub>2</sub>	CFC-13	electronics, dry cleaning, fire extinguishers
1,2-dichloro-1,1,2,2-tetrafluoroethane freon-14	CClF <sub>2</sub> CCF <sub>2</sub>	CFC-14	aerosols
1,2,2-trichloro-1,1,2-trifluoroethane freon-113	CClF <sub>2</sub> CCl <sub>2</sub> F	CFC-113	degreasing and cleaning printed circuit boards

## Chemistry of Ozone Depletion by CFCs

- CFCs destroy the ozone in the stratosphere (15 - 20 km above the earth's surface) (Ozone concentrations are measured in Dobson units, 1 Dobson unit represents 1 molecule of O<sub>3</sub> for every 1 billion air molecules)  
Ozone loss is greatest over Antarctica where the ozone depletion has been recorded and is commonly referred to as the "ozone hole".
- Ozone (O<sub>3</sub>), an allotrope of oxygen, is poisonous to humans if breathed in, but is important to life in that it filters out or absorbs short wavelength ultraviolet radiation (u.v) in the 280 - 320nm range which can cause serious sunburn, skin cancer and eye disorders.
- The inertness and lack of water solubility of CFCs mean they are not destroyed nor are they dissolved in rain water so they stay in the atmosphere for a very long time and diffuse up to the stratosphere
- In the stratosphere, CFCs come into contact with short wavelength ultraviolet radiation which is able to split off chlorine atoms from the CFC molecules

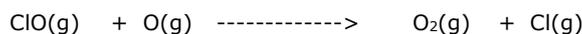


These chlorine atoms destroy the ozone layer



There are significant numbers of oxygen atoms in the stratosphere (since ozone undergoes a natural photochemical decomposition producing oxygen atoms and molecules) which leads to the regeneration of chlorine atoms in the stratosphere.

So, 1 CFC molecule can destroy many ozone molecules.



## Substitutes for CFCs

The only long term solution to solve the problem of depletion of the ozone layer is to phase out the use of CFCs

(Montreal Protocol of 1987 and subsequent modifications)

Some CFCs can be replaced by HCFCs (hydrochlorofluorocarbons), compounds containing at least 1 H atom.

The C-H bond makes these compounds more reactive in the atmosphere so they are destroyed more quickly and so are less able to diffuse into the stratosphere

Name	Formula	Code	Uses
chlorodifluoromethane	CHClF <sub>2</sub>	HCFC-22	air conditioning, refrigeration, foams
1-chloro-1,1-difluoroethane	CClF <sub>2</sub> CH <sub>3</sub>	HCFC-142b	aerosols
1,1-difluoroethane	CHF <sub>2</sub> CH <sub>3</sub>	HCFC-152a	aerosols, refrigeration

## The Chemistry of Photochemical Smog

### Key Concepts

Photochemical smog is a type of air pollution produced when sunlight acts upon motor vehicle exhaust gases to form harmful substances such as ozone (O<sub>3</sub>), aldehydes and peroxyacetyl nitrate (PAN).

Photochemical smog formation requires the following conditions:

a still, sunny day  
temperature inversion (pollutants accumulate in the lower inversion layer)

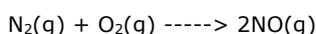
Ozone causes breathing difficulties, headaches, fatigue and can aggravate respiratory problems.

The peroxyacetylnitrate ( $\text{CH}_3\text{CO-OO-NO}_2$ ) in photochemical smog can irritate the eyes, causing them to water and sting.

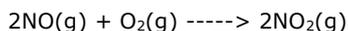
### Ozone Production

Motor vehicles produce exhaust gases containing oxides of nitrogen such as nitrogen dioxide ( $\text{NO}_2$ ) and nitric oxide ( $\text{NO}$ ).

At the high temperatures of the car's combustion chamber (cylinder), nitrogen and oxygen from the air react to form nitric oxide ( $\text{NO}$ ):

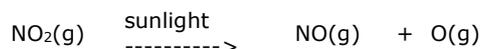


Some of the nitric oxide ( $\text{NO}$ ) reacts with oxygen to form nitrogen dioxide ( $\text{NO}_2$ ):

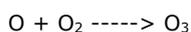


The mixture of nitric oxide ( $\text{NO}$ ) and nitrogen dioxide ( $\text{NO}_2$ ) is sometimes referred to as  $\text{NO}_x$ .

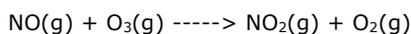
When the nitrogen dioxide ( $\text{NO}_2$ ) concentration is well above clean air levels and there is plenty of sunlight, then an oxygen atom splits off from the nitrogen dioxide molecule:



This oxygen atom ( $\text{O}$ ) can react with oxygen molecules ( $\text{O}_2$ ) in the air to form ozone ( $\text{O}_3$ ):



Nitric oxide can remove ozone by reacting with it to form nitrogen dioxide ( $\text{NO}_2$ ) and oxygen ( $\text{O}_2$ ):



When the ratio of  $\text{NO}_2$  to  $\text{NO}$  is greater than 3, the formation of ozone is the dominant reaction. If the ratio is less than 0.3, then the nitric oxide reaction destroys the ozone at about the same rate as it is formed, keeping the ozone concentration below harmful levels.

The reaction of hydrocarbons (unburnt petrol) with nitric oxide and oxygen produce nitrogen dioxide also in the presence of sunlight, increasing the ratio of nitrogen dioxide to nitric oxide.

### Peroxyacetylnitrate Production

Nitrogen dioxide ( $\text{NO}_2$ ), oxygen ( $\text{O}_2$ ) and hydrocarbons (unburnt petrol) react in the presence of sunlight to produce peroxyacetylnitrate ( $\text{CH}_3\text{CO-OO-NO}_2$ ):



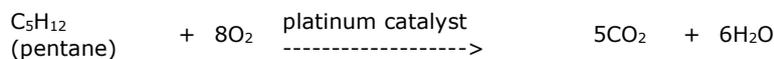
### Catalytic Converters

Catalytic converters on motor vehicle exhausts are a way of trying to reduce the carbon monoxide and nitrogen

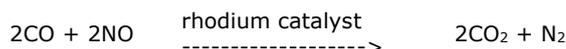
oxide emissions.

The catalyst used is either platinum or a combination of platinum and rhodium.

The platinum catalyses the reaction of unburnt hydrocarbon (such as pentane) and oxygen (O<sub>2</sub>) to produce carbon dioxide (CO<sub>2</sub>) and water vapour (H<sub>2</sub>O):



The rhodium catalyses the reaction of carbon monoxide (CO) and nitric oxide (NO) to form carbon dioxide (CO<sub>2</sub>) and nitrogen gas (N<sub>2</sub>):



The reduction of nitric oxide (NO) to nitrogen gas (N<sub>2</sub>) must proceed more quickly than the oxidation of carbon monoxide (CO) to carbon dioxide (CO<sub>2</sub>) or else all the carbon monoxide will be oxidised to carbon dioxide before it can be used to reduce the nitric oxide.

Motor vehicles can only use catalytic converters if they use unleaded petrol since the lead in petrol renders the catalyst inactive.

## Greenhouse Gases and the Greenhouse Effect

### Key Concepts

- The greenhouse effect is a natural process that produces a relatively warm environment near the earth's surface conducive to life on earth.
- The natural greenhouse effect is caused by greenhouse gases which occur naturally in the earth's atmosphere.
- The main natural greenhouse gases are carbon dioxide (CO<sub>2(g)</sub>), methane (CH<sub>4(g)</sub>), nitrous oxide (N<sub>2(g)O</sub>), and water (H<sub>2O(g)</sub>).
- The enhanced greenhouse effect is caused by human activities which release greenhouse gases into the atmosphere.
- The main anthropogenic, or human-induced, greenhouse gases are carbon dioxide (CO<sub>2(g)</sub>), nitrous oxide (N<sub>2O(g)</sub>), hydrofluorocarbons (HFCs), perfluorocarbons (PFCs), methane (CH<sub>4(g)</sub>) and sulfur hexafluoride (SF<sub>6(g)</sub>).
- The enhanced greenhouse effect is widely believed to be responsible for the increase in global temperatures seen in the 20<sup>th</sup> century (global warming).

### Greenhouse Gases

Sources of greenhouse gases, the length of time they exist in the atmosphere, and the percentage of emissions they represent are shown in the table below:

Gas Name	Gas Symbol	Common Sources	Sinks	Atmospheric Lifetime (years)	% Emissions
carbon dioxide	CO <sub>2</sub>	-combustion of fossil fuels -deforestation -gas flaring -cement production	-photosynthesis -ocean surface	5-200	60
methane	CH <sub>4</sub>	-landfills -production and distribution of natural gas and petroleum -fermentation from digestive system of livestock	-reaction with tropospheric hydroxyl (OH) -removal by soils	12	20

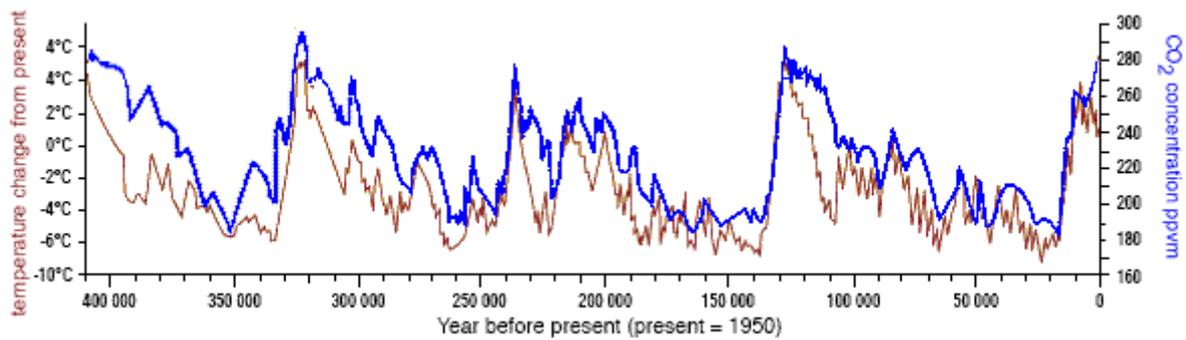
		-rice cultivation -natural wetlands -combustion of fossil fuels			
nitrous oxide	N <sub>2</sub> O	-combustion of fossil fuels -fertilizers -nylon production -biological sources in oceans and soils	-removal by soils -stratospheric photolysis	114	6
hydrofluorocarbons	HFCs	-aerosol propellants -refrigeration gases -foam-blowing agents -solvents -fire retardants -aluminium smelting -semiconductor production	-CFCs, HCFCs removal by stratospheric photolysis -HCFC, HFC reaction with tropospheric hydroxyl (OH)	2 - 50,000 (dependent on compound)	<14%
perfluorocarbons	PFCs	-aluminium production -semiconductor production		>10,000	<1%
sulfur hexafluoride	SF <sub>6</sub>	-electrical transmission and distribution systems -circuit breakers -magnesium production		3,200	<1%

**The Greenhouse Gas Effect**

Greenhouse gases in the earth's atmosphere absorb infrared radiation from the ground.

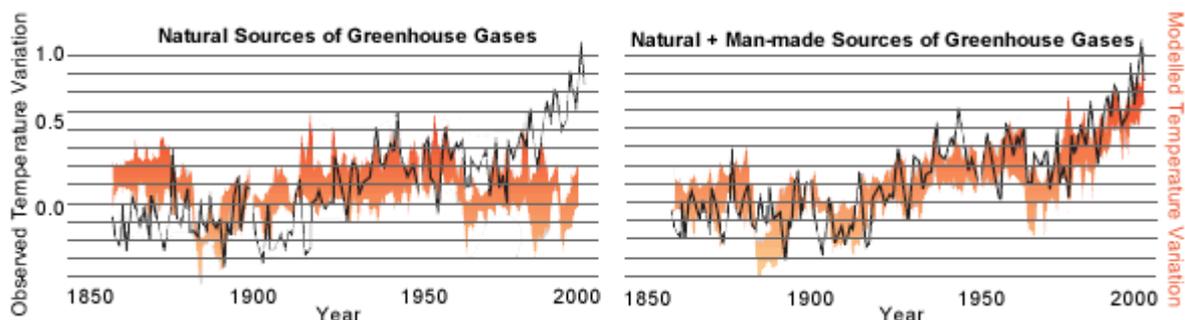
This radiation (heat) is re-emitted in all directions. Heat radiated back towards the earth's surface leads to the warming of the surface.

Using data from ice cores and other sources, scientists have been able to determine the temperature variation and carbon dioxide concentrations on earth over time:



Since 1950, temperature variations have been observed that can not be explained solely on the basis of the presence of natural greenhouse gases.

Scientists have modeled this unusual temperature variation to take into account man-made sources of greenhouse gases and have found that this may explain the temperature variations being observed.



During the 21<sup>st</sup> century, the earth is likely to experience:

- higher maximum temperatures and more hot days
- higher minimum temperatures and fewer cold days
- more intense precipitation events like rain over many areas
- melting of polar ice caps resulting in rising sea levels

Suggestions for combatting global warming have been:

- reduction in combustion of fossil fuels and sourcing new fuel alternatives
- reducing deforestation and replanting forests
- reducing and/or eliminating the use of HCFs, HCFCs, perfluorocarbons and sulfur hexafluoride.

Finding alternatives to these greenhouse gases in chemical and industrial processes has led to the development of a new branch of chemistry called Green Chemistry.

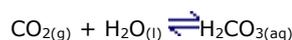
## The Chemistry of Acid Rain

### Key Concepts

Rain from an unpolluted atmosphere has a pH close to 6.0 (slightly acidic).

This acidity is due to the reaction of water vapour and non-metal oxides in the atmosphere, such as carbon dioxide and nitrogen oxide, forming dilute acids.

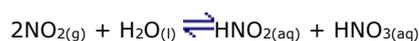
- carbon dioxide reacts with water to form carbonic acid:



Since carbonic acid is a weak acid it partially dissociates:

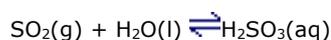


- nitrogen dioxide reacts with water to form a mixture of nitrous acid and nitric acid:

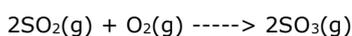


Acid rain has a pH below 5.6 due mainly to the reaction of water vapour with sulfur dioxide and the oxides of nitrogen.

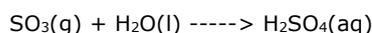
Sulfur dioxide reacts with water to form sulfurous acid ( $\text{H}_2\text{SO}_3$ ):



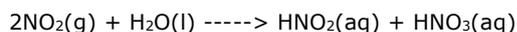
Sulfur dioxide ( $\text{SO}_2$ ) can be oxidised gradually to sulfur trioxide ( $\text{SO}_3$ ):



Sulfur trioxide ( $\text{SO}_3$ ) reacts with water to form sulfuric acid ( $\text{H}_2\text{SO}_4$ ):



Oxides of nitrogen, particularly nitrogen dioxide ( $\text{NO}_2$ ) react with water to form nitrous acid ( $\text{HNO}_2$ ) and nitric acid ( $\text{HNO}_3$ ):



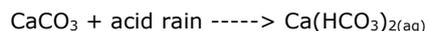
### Sources of the acids in clean and polluted air

Acid	Clean air	Polluted air
Carbonic acid ( $\text{H}_2\text{CO}_3$ )	natural carbon dioxide ( $\text{CO}_2$ ) produced during plant and animal respiration produced during decomposition of organic matter	Carbon dioxide ( $\text{CO}_2$ ) released from the combustion of fuels The complete combustion of coal: $\text{C}(\text{s}) + \text{O}_2(\text{g}) \rightarrow \text{CO}_2(\text{g})$ The complete combustion of petrol (for example octane, $\text{C}_8\text{H}_{18}(\text{l})$ ): $2\text{C}_8\text{H}_{18}(\text{l}) + 25\text{O}_2(\text{g}) \rightarrow 16\text{CO}_2(\text{g}) + 18\text{H}_2\text{O}(\text{g})$ Complete combustion of ethanol (ethyl alcohol): $\text{C}_2\text{H}_5\text{OH}(\text{l}) + 3\text{O}_2(\text{g}) \rightarrow 2\text{CO}_2(\text{g}) + 3\text{H}_2\text{O}(\text{g})$
Formic acid (Methanoic acid) ( $\text{HCOOH}$ )	Oxidation of natural methane ( $\text{CH}_4$ ) formed during the anaerobic decomposition of organic matter	Increased oxidation
Sulfuric acid (Sulphuric acid) ( $\text{H}_2\text{SO}_4$ )	Natural decay of organic matter releases hydrogen sulfide gas ( $\text{H}_2\text{S}$ ) which can be oxidised to sulfur dioxide ( $\text{SO}_2$ ): $2\text{H}_2\text{S}(\text{g}) + 3\text{O}_2(\text{g}) \rightarrow 2\text{SO}_2(\text{g}) + 2\text{H}_2\text{O}(\text{l})$ Sulfur dioxide can be oxidised to sulfur trioxide ( $\text{SO}_3$ ): $2\text{SO}_2(\text{g}) + \text{O}_2(\text{g}) \rightarrow 2\text{SO}_3(\text{g})$ Sulfur trioxide then reacts with water to form sulfuric acid: $\text{SO}_3(\text{g}) + \text{H}_2\text{O}(\text{l}) \rightarrow \text{H}_2\text{SO}_4(\text{aq})$ Volcanoes emit sulfur dioxide which can be oxidised to sulfur trioxide which then reacts with water forming sulfuric acid. Ocean algae release sulfur gases such as dimethyl sulfide which is oxidised to form sulfuric acid.	Combustion of coal and other fossil fuels account for about 80% of the man-made sulfur dioxide in the atmosphere (sulfur is present in the proteins of the original living matter that has been fossilised to produce the fossil fuel such as coal, oil or petroleum). Most of this is from coal-fired power stations, motor vehicle emissions account for only about 1% of the sulfur dioxide present. Sulfur dioxide is also produced when sulfur ores are roasted: $2\text{ZnS}(\text{s}) + 3\text{O}_2(\text{g}) \rightarrow 2\text{ZnO}(\text{s}) + 2\text{SO}_2(\text{g})$ Sulfur dioxide is also produced in the manufacture of sulfuric acid by the contact process, in petroleum refining and in the manufacture of coke from coal
Nitric acid ( $\text{HNO}_3$ )	Lightning flashes lead to a reaction between atmospheric nitrogen and oxygen in the presence of water vapour which forms nitric acid	Combustion of fossil fuels Nitric oxide (nitrogen monoxide, $\text{NO}$ ) is produced in internal combustion engines as a result of the reaction between oxygen and nitrogen at high temperatures: $\text{N}_2(\text{g}) + \text{O}_2(\text{g}) \rightarrow 2\text{NO}(\text{g})$ Nitrogen monoxide is readily oxidised to nitrogen dioxide ( $\text{NO}_2$ ): $2\text{NO}(\text{g}) + \text{O}_2(\text{g}) \rightarrow 2\text{NO}_2(\text{g})$ Nitrogen dioxide reacts with water to form nitrous acid ( $\text{HNO}_2$ ) and nitric acid ( $\text{HNO}_3$ ): $2\text{NO}_2(\text{g}) + \text{H}_2\text{O}(\text{l}) \rightarrow \text{HNO}_2(\text{aq}) + \text{HNO}_3(\text{aq})$

Methanesulfonic acid  (Methanesulphonic acid)	Ocean algae emit dimethyl sulfide which oxidises in air to produce methanesulfonic acid.	methanesulfonic acid is only produced naturally
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### Effects of Acid Rain

Acid rain is a form of environmental pollution that damages buildings and marble statues by reacting with the calcium carbonate to form soluble calcium hydrogen carbonate (calcium bicarbonate,  $\text{Ca}(\text{HCO}_3)_2$ )



Acid rain can leach aluminium from the soil into ground water, lakes and rivers, poisoning fish and plant roots.

The sulfates and hydrogen sulfates in acid rain can leach essential plant nutrients such as calcium and magnesium, from the soil.

Acid rain disrupts the process of photosynthesis resulting in damage to plant life.

At low concentrations it retards the production of chlorophyll and at high concentrations it forms sulfuric acid which kills the plant.

Some organisms are sensitive to changes of acidity in water which can affect their ability to reproduce and in some cases may kill them.

## 9.4 Chemical monitoring and management: 5. Monitoring and management in water

Extract from *Chemistry Stage 6 Syllabus (Amended October 2002)*. © Board of Studies, NSW.  
[Edit: 18 Jun10]

**Prior Learning:** Preliminary modules **8.2** (8.2.1, 8.2.2, 8.2.3) **8.3** (8.3.2, 8.3.3, 8.3.5), **8.4** (8.4.1, 8.4.3, 8.4.4), **8.5** (8.5.1, 8.5.3); HSC modules **9.2** (9.2.4), **9.3** (9.3.1, 9.3.3, 9.3.4).

**Background:** Many environmental problems have been generated by humans and their activities. One problem is excess salinity, especially of the Murray Darling Basin. Primary production in this basin makes a major contribution to the economies of both NSW and Victoria. The chemical problems caused by excess salinity will need to have chemical solutions and will require the cooperation of all parties including farmers, the public, state and federal governments and industries that rely on water, either directly or indirectly. Management practices that ensure the sustainability of the environment and long-term viability for all parties using the environment will need to be developed and implemented.

**gather, process and present information on the range and chemistry of the tests used to:**

**identify heavy metal pollution of water**

**monitor possible eutrophication of waterways**

**Heavy metals**

Heavy metal pollution of water may be caused by the presence of unacceptable levels of the ions of arsenic, cadmium, copper, chromium, mercury, nickel, lead and zinc.

[Heavy metal pollution in aquatic sediments](#) ▶ A transcript of an interview with Stuart Taylor URS Australia Pty Ltd North Sydney NSW, speaking with Robyn Williams on The Science Show, ABC Radio National, March 2007.

[Fish Eaters Poisoned](#) ▶ by Lisa Pryor, Sydney Morning Herald, April 20, 2006

## Eutrophication

The process of eutrophication involves the increase in nutrient content of a body of water resulting in excessive growth of plants, which when they die, causes oxygen depletion during the decay process. The oxygen depletion threatens the survival of fish.

- Simple techniques to identify the presence of heavy metals include precipitation and flame testing. Techniques to quantitatively determine heavy metals include volumetric and gravimetric analyses, colorimetry, chromatography and spectroscopy, particularly atomic absorption spectroscopy (AAS) and mass spectroscopy.
- Tests to determine the extent of eutrophication of a waterway involve measurement of dissolved oxygen and nutrients, such as nitrates and phosphates. **Gather information** on the range and chemistry of tests by looking in encyclopaedia, scientific and popular journals and magazines and chemistry textbooks as well as searching the Internet under specific techniques. If you have access to CD ROMs, such as Encarta or Encyclopaedia Britannica, also search in them under specific techniques.
- **Process** your information making sure you assess its reliability by comparing information from various sources.
- When you **present** information, make sure you select and use appropriate methods to acknowledge sources of information. If a reference is from a book, provide *Author(s), year, book title and publisher*. If a reference is from the Internet, provide *Author (if relevant), Title of item, web site owner, online (date last modified) Available at (provide URL)*.

[Water Quality: HSC Chemistry](#) Sydney Catchment Authority

[Water Quality](#) ▶ Department of Primary Industry, Victoria

[Animation of the process of artificial eutrophication](#) ▶ Degradation of water quality in a lake is shown in a seven-slide presentation. Mike Docker, The Sixth Form College, Farnborough, UK.

**[perform first-hand investigations](#) to use qualitative and quantitative tests to [analyse](#) and compare the quality of water samples.**

- A qualitative test shows what (element, compound or ion) is present.
- A quantitative test shows how much (element, compound or ion) is present.
- **Perform** some investigations to determine the quality of water samples by selecting and modifying procedures like those described under the next syllabus point (below) and carrying them out carefully. Be alert to recognise where and when modifications are needed and analyse the effect of any adjustments that you make. Write descriptions of the tests used.

**identify that water quality can be determined by considering:**

**concentrations of common ions**

**total dissolved solids**

**hardness**

**turbidity**

**acidity**

**dissolved oxygen and biochemical oxygen demand**

**Water quality**

*Water quality is commonly defined by its physical, chemical, biological and aesthetic (appearance and smell) characteristics. A healthy environment is one in which the water quality supports a rich and varied community of organisms and protects public health.*

[Water Quality: HSC Chemistry](#) Sydney Catchment Authority , 2007

[NSW State of the Environment 2009](#) ▶ , Department of Environment, Climate Change and Water, NSW, January 2010.

The following tests determine water quality according to a given set of criteria supported by World Health Organisation information.

- The **concentration of common ions**.
- **Atomic Absorption Spectrometry (AAS)** is a common technique used to identify the concentration of metal ions. In testing water quality the concentration of the following cations are usually determined: sodium, magnesium, calcium and potassium.
- **Gravimetric analysis** can be used to determine the quantities of both cations and anions, e.g. for chloride ions precipitated and weighed as silver chloride.

Common anion concentrations measured include chloride, sulfate, bicarbonate and fluoride ions.

Refer also to subsection 9.4.3 of this module, where a method for the precipitation of barium sulfate from ammonium sulfate fertilizer is described.

## Total dissolved solids (TDS)

Total dissolved solids (TDS) are determined by evaporation to dryness of a known volume of a filtered sample. The value is converted to parts per million (ppm) and expressed in mass per volume units, ppm (m/v).

Since most of the dissolved solids are ionic, their presence can be determined by data loggers that have the electrical conductivity probe attached. They can be set up to record continuously if needed.

## Hardness

Hardness is due to the presence of calcium and magnesium ions in the water. These form insoluble compounds with soap ions, resulting in a scum on the water surface and around sink basins. This removal of soap ions from solution reduces the ability of soap to lather.

The test for hardness involves precipitating the calcium and magnesium ions from a known volume of the water sample with a solution of sodium carbonate (of known concentration), followed by filtering and drying of the precipitate. Most of the insoluble salt is assumed to be calcium and the concentration of calcium ions is calculated and reported in parts per million (ppm).

## Turbidity

This can be one measure of the ability of the water to support life. Turbidity results from the presence of suspended solids in the water. Water with a high turbidity reduces penetration of light and decreases photosynthesis, which in turn reduces the oxygen concentration.

The test for turbidity is conducted using a turbidity tube standing on a white tile. The tube has a black cross marked on the base. The water sample is poured into the tube until the cross just disappears when looking from above.

The use of a turbidity tube is less reliable than a transmittance of light test done with a colorimeter. The lower reliability is due to variations in human eyesight and the intensity of background light during testing.

## Acidity (pH)

A pH reading below 7 would be expected where there are acid sulfate soils or where there is acid produced by decomposition of organic matter in stagnant situations. The test can be conducted with a data logger and pH probe, universal indicator solution or paper, or a pH meter. If using the universal indicator,

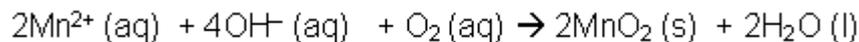
comparison with a coloured pH scale provides the pH value. If it is less than 7, the solution is acidic.

## Dissolved oxygen (DO)

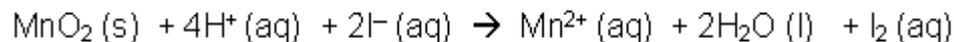
There are several tests for determining the DO in a water sample. The Winkler method *fixes* the amount of dissolved oxygen, which is later determined by titration.

The amount of manganese dioxide produced by adding manganese(II) ions and hydroxide ions is a measure of the DO. Acidified iodide ions are added to cause the manganese dioxide to produce a yellow iodine solution. This is then titrated against a standard sodium thiosulfate solution using starch as the indicator. The indicator turns a blue colour with the iodine and the blue disappears at the endpoint. To conduct the test, no air is to be trapped with the sample and it is to be kept in the dark to reduce algae photosynthesis increasing the DO.

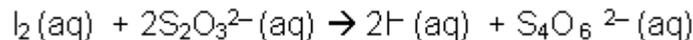
reaction 1:



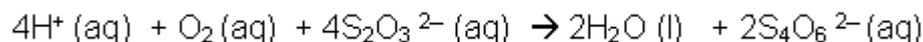
reaction 2:



reaction 3:



The overall reaction can be represented by the equation:



This shows that, for each mole of thiosulfate ( $\text{S}_2\text{O}_3^{2-}$ ) used in the titration, there was 0.25 moles of dissolved oxygen in the original sample.

## Biochemical oxygen demand (BOD)

BOD measures the amount of oxygen used by bacteria and other micro-organisms during a five-day period. The sample bottles are held below the water surface and away from the bank. One sample is measured for DO as soon as possible while the other sample is kept in a dark place for 5 days and then tested for DO. The BOD is calculated by subtracting the DO value after 5 days from the initial DO value. The reading is given as milligrams per litre ( $\text{mg L}^{-1}$ ).

**identify factors that affect the concentrations of a range of ions in solution in natural bodies of water such as rivers and oceans.**

- Factors include:
  - the frequency of rainfall (floods and droughts),
  - water temperature
  - evaporation rates
  - soil type
  - pollution sources, such as the presence of animal faeces and fertiliser usage (leading to eutrophication)
  - land use.
- Farming practices such as the removal of native vegetation or irrigation can increase the salt (NaCl) concentration in rivers.

Earthmoving associated with waterfront developments can expose layers containing sulfide to air. The sulfides are oxidised by oxygen to form sulfates and sulfuric acid, which can kill fish and other living things.

High evaporation rates in the Dead Sea have increased the dissolved salt concentration.

Run-off of water from agricultural land in Queensland, near the Great Barrier Reef, contains ions, such as phosphate, which can affect the growth of organisms.

**gather, process and present information on the features of the local town water supply in terms of:**

**catchment area**

**possible sources of contamination in this catchment**

**chemical tests available to determine levels and types of contaminants**

**physical and chemical processes used to purify**

**chemical additives in the water and the reasons for the presence of these additives**

- This syllabus point could efficiently be addressed by you working with other students in a group. Assign each member of the group to **gather** data about a part of the syllabus requirement. As a whole group, you may need to decide on the structure and components of the final group report so that relevant information is gathered. Many local regional councils and Sydney Water have web sites and some have project officers who can provide information to you on the issues listed above. Before contacting an organisation, you should conduct as much research as you can using

published information from the organisation, from books in the school or local library and from the Internet. This will ensure that you are well prepared to discuss relevant chemistry and catchment issues without using an officer's time inappropriately.

- **Process** the information gathered by comparing the information from interviews and your secondary sources. This will assist you to evaluate the validity of all information gathered.
- **Present** your information to other students. Consider using visual aids such as maps, photographs, diagrams, overhead transparencies, graphics or an extract from a video interview. A *Powerpoint* presentation allows each group member to develop materials individually then contribute to the final report. Keep the presentation precise, by only focusing on the information asked for in the syllabus point.

Some useful local NSW web sites:

[Your water](#) ▶ Sydney Water, Typical Drinking Water Analysis

[Water quality monitoring](#) Sydney Catchment Authority

[Country towns water supply and sewerage program](#) ▶ Local Government and Shires Association of NSW. The Country Towns Water Supply and Sewerage Program (CTWSSP) is a long standing program which supports councils in country NSW in their provision of water supply and sewerage services.

### **describe and assess the effectiveness of methods used to purify and sanitise mass water supplies.**

- There are several methods used to purify mass water supplies. Most are variations on the following process:

*flocculation and sedimentation → filtration → sanitisation → pH adjustment*

- Water is collected in dams and pumped to a treatment site where the larger solids such as pieces of plastic are removed by screens.
- Fine particles suspended in water have electric charges on their surface that keep the particles from joining together. This stops particles from becoming large enough to settle as sediment. Separation of fine particulate matter suspended in water involves the addition of coagulants, such as iron(III) chloride,  $\text{FeCl}_3$ , to the water. The added  $\text{FeCl}_3$  neutralises these surface charges so the particles come together. Iron(III) hydroxide is formed by reaction of  $\text{FeCl}_3$  with water and precipitates out as a *floc* (flocculant). The floc collects the neutralised particles into large masses that are more easily filtered.

- The chloride ions added with the  $\text{FeCl}_3$  remain in the water. They do not have a harmful impact on the water quality as determined by the *Drinking water quality guidelines* (1996), National Health and Medical Research Council (NHMRC).
- In some instances, after flocculation the particle size of suspended solids is too fine for filtration through sand beds and so membrane filters are used. They are more effective than sand filters as they can have a very small pore size. However membrane filtration is more costly than sand bed filtration.
- Sanitising mass water supplies involves disinfecting with chlorine gas,  $\text{Cl}_2$ , liquid sodium hypochlorite solution,  $\text{NaOCl}$  (aq), or solid calcium hypochlorite,  $\text{Ca}(\text{OCl})_2$ . Sedimentation and filtration removes some harmful organisms, such as bacteria, viruses, cryptosporidium and giardia, but disinfection is needed to ensure concentrations are acceptably low. In some parts of the water distribution system, ammonia,  $\text{NH}_3$ , is added to form monochloramine,  $\text{ClNH}_2$ , by reaction with chlorine. This is a less reactive disinfectant, but lasts much longer in the distribution system.
- Assessment of the effectiveness of sanitisation methods should involve:
  - microbiological testing of water samples throughout the distribution system, in particular before and after sanitisation processes.
  - public health surveys and reporting by medical doctors of incidences of illnesses that are possibly transmitted through water supplies.
- A few years ago, some water supplies in NSW were contaminated by the micro-organisms, cryptosporidium and giardia. As a result, water supplies are monitored daily at water treatment plants and throughout each catchment during storms or other events that cause a rise in stream water levels and could influence water quality. This is considered effective, as the cost of treatment of all water supplies with membrane filters would make treatment very expensive.

[Managing Drinking Water Quality](#) ▶ Sydney Water, 2009

**describe the design and composition of microscopic membrane filters and explain how they purify contaminated water.**

- Microscopic membrane filters have microscopic pores and the use of appropriate sized filters can avoid the need to chemically treat the water. The filters can be classified as microfiltration, ultrafiltration, nanofiltration or reverse osmosis membranes depending on the size of the pore.
- The membrane is made from synthetic polymers dissolved in a mixture of solvents. Water-soluble powders of a particular size are added. The mixture is spread out over a plate and left for the solvent to dry. The polymer membrane formed, containing particles of water-soluble powder, is then placed in water. Remaining solvent and the powder particles dissolve, leaving a very thin polymer sheet with definite sized microscopic pores where the water-soluble particles were located.

- Semi-permeable membranes used in reverse osmosis are either made of cellulose acetate or a layer of polyamide attached to another polymer. Under pressure these polymers allow the passage of water molecules but not that of most atoms, ions or other molecules.
- Water is made to flow across the membrane not through it. This reduces the blockage factor. Microfiltration removes protozoans, bacteria, colloids, some colouration and some viruses. The size of the pore determines which sized particle or organism may pass through the membrane. The finer the pore size the smaller the particles trapped and the more expensive the membrane.

## Water Analysis

### Key Concepts

Water is an essential resource for living systems, industrial processes, agricultural production and domestic use.

The principal factors that are taken into consideration when determining water quality are:

turbidity  
 acidity & alkalinity  
 trace elements and nutrients such as nitrogen, phosphorus, halogens (chloride and fluoride ions), alkali metals (sodium and potassium ions), calcium and magnesium ions.  
 microorganisms  
 dissolved oxygen content (DO)

Saturated Dissolved Oxygen (DO) Levels		
Temperature (°C)	Saturated level of DO (ppm)	
	Freshwater	Sea water
10	10.9	9.0
20	8.8	7.4
30	7.5	6.1
40	6.6	5.0

### Example: Water Quality of a Typical Natural Aquatic System

Substance or Quality	River Water	Sea Water
pH	6.8	8.0
Dissolved Oxygen	6-8 ppm	6-8 ppm
Na <sup>+</sup>	6.7 ppm	1.1 × 10 <sup>4</sup> ppm
K <sup>+</sup>	1.5 ppm	380 ppm

	Ca <sup>2+</sup>	17.5 ppm	400 ppm
	Mg <sup>2+</sup>	4.8 ppm	1.3 x 10 <sup>3</sup> ppm
	Cl <sup>-</sup>	4.2 ppm	1.9 x 10 <sup>4</sup> ppm
	SO <sub>4</sub> <sup>2-</sup> /HSO <sub>4</sub> <sup>-</sup>	17.5 ppm	2.6 x 10 <sup>3</sup>
	CO <sub>3</sub> <sup>2-</sup> /HCO <sub>3</sub> <sup>-</sup>	33.0 ppm	142 ppm
	Hg <sup>2+</sup>	< 1 ppb	0.03 ppb
	Cd <sup>2+</sup>	< 1 ppb	0.1 ppb
	Pb <sup>2+</sup>	< 1 ppb	4-5 ppb

### Tests for Water Quality

Test	Method	Reason for testing
<b>Temperature</b>	Use an alcohol thermometer in a hard plastic cover	Temperature influences the amount of dissolved oxygen in water which in turn influences the survival of aquatic organisms (raising the temperature of a freshwater stream from 20 to 30°C will decrease the dissolved oxygen saturation level from about 9.2 ppm to 7.6 ppm.). Increasing temperature also increases the rates of chemical reactions taking place in the water. Increases in temperature are often associated with hot water discharge from power stations and industries that use water as a coolant.
<b>pH</b>	Use a pH meter in a hard plastic cover, pH paper or Universal Indicator solution.	pH measures the acidity or alkalinity of water. pH of rain water is about 5.5-6.0. Typically, natural water has pH 6.5-8.5. A pH<5 (acidic water) is most damaging to eggs and larvae of aquatic organisms. Most aquatic life (except for some bacteria and algae) cannot survive pH<4. Natural alkalinity is due to CO <sub>2</sub> (g), HCO <sub>3</sub> <sup>-</sup> , CO <sub>3</sub> <sup>2-</sup> and OH <sup>-</sup> , carbonate rocks such as limestone and dolomite increase alkalinity. Alkalinity is increased by caustic substances from industry (KOH, NaOH), soil additives in agriculture such as lime Ca(OH) <sub>2</sub> , superphosphate which is mixture of Ca(H <sub>2</sub> PO <sub>4</sub> ) <sub>2</sub> and CaSO <sub>4</sub> , and soaps and detergents.

Natural acidity is due to  $\text{CO}_2(\text{g})$ ,  $\text{HPO}_4^{2-}$ ,  $\text{H}_2\text{PO}_4^-$ ,  $\text{H}_2\text{S}$ ,  $\text{Fe}^{3+}$ , other acidic metal ions, proteins & organic acids. Increases in acidity can be due to acids used in industry, acid mine drainage, acid rain.

### **Turbidity**

Use a Secchi disc or 500mL of water in a measuring cylinder standing on paper marked with a black cross.

Turbidity is a measure of water clarity. Suspended solids in water can stop light reaching submerged plants and can raise water temperature. Suspended solids often present in water are mud, clay, algae, bacteria and minerals such as silica, calcium carbonate and ochre (iron oxide). Suspended solids can be increased by the discharge of wastes (domestic sewage, industrial and agricultural effluents), leaching of wastes (from mines), and agitation (dredging or shipping).

### **Total Dissolved Solids (TDS)**

Use an appropriate TDS meter. Freshwater meters: 0-1990 ppm (parts per million). Dual range brackish water meters: 0-19,900 ppm. Salt-water meters: to above 35,000 ppm.

This is a conductivity test of available ions in the water, including  $\text{Ca}^{2+}$ ,  $\text{Na}^+$ ,  $\text{K}^+$ ,  $\text{Fe}^{2+}$ ,  $\text{Fe}^{3+}$ ,  $\text{HCO}_3^-$  and ions containing P, S & N. High levels of  $\text{Na}^+$  is associated with excessive salinity and is found in many minerals. Potassium is incorporated into plant material and is released into water systems when plant matter is decayed or burnt.

### **Dissolved Oxygen (DO)**

#### Winkler Titration Method

-Halve the water sample. Place one sample in the dark (for BOD analysis).

-To the other sample add 2mL  $\text{MnCl}_2(\text{aq})$  (4g  $\text{MnCl}_2$  dissolved in 10mL distilled water) + 2mL alkaline iodide solution (3.3g  $\text{NaOH}$  + 2.0g  $\text{KI}$  dissolved in 10mL distilled water). Shake sample.

-Add 2 mL concentrated  $\text{HCl}$ . Shake. The iodine formed is directly proportional to the dissolved oxygen.

-Titrate 50.0mL of the above solution with 0.0125M sodium thiosulfate solution using starch as an indicator. The end-point is reached when the blue-black colour disappears.

Colorimetric Method (A field kit is available using a 'Smart' colorimeter)

The Dissolved Oxygen test measures the current oxygen levels in the water. The DO level varies with temperature. DO levels are highest in the afternoon due to photosynthesis and lowest just before dawn. DO is lowered by an increase in temperature (as from a discharge of hot water from a power station), increases in aerobic oxidation (due to increases in organic matter from sewage or due to inorganic fertilisers such as phosphates and nitrate with overstimulate algal growth). Water with  $\text{DO} < 1\text{ppm}$  is dead.

Collect 2 water samples, 1 for DO test, 1 for BOD test. Sample must be collected under water to ensure there are no trapped air bubbles.

### **Biochemical Oxygen Demand (BOD)**

The first water sample from above is kept in the dark for 5 days at the temperature at which the sample was collected. Then the dissolved oxygen is determined using the Winkler titration method as above. Subtract the mass of oxygen obtained on day 5 from mass of oxygen on day 1 to determine the BOD (mg/L). Unpolluted natural waters have  $\text{BOD} < 5\text{mg/L}$ . Treated sewage can have  $\text{BOD} 20\text{-}30\text{mg/L}$ .

BOD measures the rate of consumption of oxygen by organisms in the water over a 5 day period. Increases in BOD can be due to animal and crop wastes and domestic sewage. Untreated domestic sewage  $\text{BOD} \sim 350\text{ppm}$   
Waste water from breweries  $\text{BOD} \sim 550\text{ppm}$   
Waste water from petroleum refineries  $\text{BOD} \sim 850\text{ppm}$

Abattoir wastes BOD~2,600 ppm  
Pulpmill wastes BOD~25,000 ppm

### Salinity

Titrate a known volume of the water sample with silver nitrate solution (2.73g AgNO<sub>3</sub> per 100mL distilled water) using K<sub>2</sub>CrO<sub>4</sub> as indicator. The end-point of the titration is given by the reddening of the silver chloride precipitate (AgCl<sub>(s)</sub>). Volume of AgNO<sub>3</sub> used = chloride content in g/L.

Many aquatic organisms can only survive in a narrow range of salt concentrations since salt controls their osmotic pressure.

### Total Phosphate Test

-acid digestion using concentrated H<sub>2</sub>SO<sub>4</sub> and ammonium persulfate.  
-Titrate using NaOH and phenolphthalein as indicator  
-Use a few drops of H<sub>2</sub>SO<sub>4</sub> to turn the solution clear again.  
-Add ammonium molybdate solution then solid ascorbic acid.  
-An intense blue complex of molybdenum blue is formed which can be measured colorimetrically. Absorbency is measured at 882nm. (A field kit is available using a 'Smart' colorimeter)

Total Phosphate is used as an indicator of pollution from run-off in agricultural areas or domestic sewage. Concentrations of 0.2mg/L are common. Concentrations of 0.05mg/L indicate the possibility of eutrophication (increased nutrient concentrations) and algal blooms are likely. Natural phosphate is due to decayed organic matter and phosphate minerals.

### Total Nitrogen test

Kjeldahl digestion  
-digestion with concentrated sulfuric acid, converting the nitrogen into ammonia sulfate  
-Solution is then made alkaline  
-liberated ammonia is distilled, and the amount determined by titration with standard acid.  
distillation titration method for samples containing >1mg/L  
Add Nessler's reagent (100g mercuric iodide + 70g KI in 100mL distilled water, then add 160g NaOH in 700mL distilled water, then dilute to 1L) for samples containing <1mg/L and measure absorbency colorimetrically at 425nm.

Total Nitrogen is an important indicator of eutrophic waters, especially for those contaminated by animal wastes, fertiliser run-off and domestic sewage. Aquatic nitrogen is essential for the growth of organisms and is produced in natural processes including decay of proteins, the action of lightning, and the action of nitrogen-fixing bacteria on ammonia.

### Hardness

Calcium Ions, Ca<sup>2+</sup>  
-complexometric titration using EDTA (ethylenediaminetetraacetic acid) at a pH of 12-13 (at this pH Mg<sup>2+</sup> is precipitated and not complexed with EDTA)  
-OR potentiometric techniques using selective electrodes  
-OR Atomic Absorption Spectroscopy (AAS)  
-OR Gravimetric Method - measure the amount of CaCO<sub>3</sub>(s) precipitated by a known volume of 0.02M Na<sub>2</sub>CO<sub>3</sub>  
-OR by Flame Test - Ca<sup>2+</sup> flame test a brick-red colour in a non-luminous Bunsen flame Mg<sup>2+</sup>  
-complexometric titration using EDTA at pH=10 (both Ca<sup>2+</sup> and Mg<sup>2+</sup> will complex with EDTA at this pH, [Mg<sup>2+</sup>] can be found by subtracting the results of this titration from the results of the first titration.)  
-OR potentiometric techniques using selective electrodes  
-OR Atomic Absorption Spectroscopy (AAS)

Calcium ions are a major contributor to water hardness and are due to water running through rocks containing minerals such as gypsum (CaSO<sub>4</sub>.2H<sub>2</sub>O), calcite (CaCO<sub>3</sub>), dolomite (CaMg(CO<sub>3</sub>)<sub>2</sub>). Hard water has a noticeable taste, produces precipitates with soaps which inhibits lathering and forms precipitates (scale) in boilers, hot water systems and kettles. Temporary hardness (or 'bicarbonate hardness') is due to Ca(HCO<sub>3</sub>)<sub>2</sub> which deposits CaCO<sub>3</sub>(s) as scale on boiling the water. Magnesium ion levels are often high in irrigation water and can cause scouring in stock. Ca<sup>2+</sup> and Mg<sup>2+</sup> can combine with Cl<sup>-</sup> and/or SO<sub>4</sub><sup>2-</sup> causing permanent hardness which can't be removed by boiling. Water can be softened by an ion exchange process using a solid material such as a resin or clay that is capable of exchanging Na<sup>+</sup> or H<sup>+</sup> for Ca<sup>2+</sup> and Mg<sup>2+</sup>.

### Microorganisms

microorganisms in a water sample are counted under a microscope

Many protozoa, bacteria, viruses, algae and fungi are found in natural

Method for finding the number of coliform organisms in a water sample:

Filter a known volume of water sample through a filter that retains microorganisms. Transfer the filter to a sterile petri dish containing appropriate agar and incubate at 35°C for 20-40 hours. Also incubate a control plate with agar only. Colonies will develop on the filter wherever bacteria are retained. Either visually, or using a microscope, count the number of coliform colonies. Express these values as CFU/100mL.

water systems. Some are pathogenic (typhoid, cholera and amoebic dysentery can result from water-borne pathogens). The excessive growth of algae (called 'algal bloom') can degrade water quality because it lowers dissolved oxygen levels thereby killing other living things. The level of bacterial contamination of water due to animal waste is measured by determining the number of coliform organisms such as E. coli

### Heavy Metals

$\text{Ni}^{2+}$  + dimethylglyoxime in ethanol turns pink-red  
 $\text{Fe}^{3+}$  + ammonium thiocyanate turns blood-red  
 $\text{Cu}^{2+}$  + dithizone in 1,1,1-trichloroethane turns yellow-brown  
 $\text{Cd}^{2+}$  + dithizone in 1,1,1-trichloroethane turns blue-violet  
 $\text{Pb}^{2+}$  + dithizone in 1,1,1-trichloroethane turns brick-red  
 $\text{Pb}^{2+}$  + 2KI(aq) -----> yellow precipitate of  $\text{PbI}_2(\text{s})$   
 $\text{Zn}^{2+}$  + dithizone in 1,1,1-trichloroethane turns pink

Heavy metals in concentrations above trace amounts are generally toxic to living things. Trace amounts (<0.05 mg/L) of Zn, Cu and Mn are present in most natural waters. Zn and Cu may be present in higher levels in irrigation areas due to the use of galvanised iron, copper and brass in plumbing fixtures and for water storage. In irrigation areas, acceptable levels are 0.2 mg/L for  $\text{Cu}^{2+}$ , and 2.0 mg/L for  $\text{Zn}^{2+}$  and  $\text{Mn}^{2+}$ .

### Other Ions

$\text{Al}^{3+}$  + aluminon -----> pink-red  
 $\text{Mg}^{2+}$  + magneson I -----> light blue  
 $\text{Na}^+$  flame test -----> yellow flame  
 $\text{K}^+$  flame test -----> lilac flame  
 $\text{NH}_4^+$  &  $\text{NH}_3$  + Nessler's reagent (100g mercuric iodide + 70g KI in 100mL distilled water, then add 160g NaOH in 700mL distilled water, then dilute to 1L) -----> yellow-brown  
 $\text{NO}_3^-$  + conc  $\text{H}_2\text{SO}_4$  +  $\text{FeSO}_4$  -----> brown ring forms at junction  
 $\text{S}^{2-}$  + lead acetate solution -----> black deposit of  $\text{PbS}$   
 $\text{SO}_4^{2-}$  +  $\text{BaCl}_2(\text{aq})$  -----> white precipitate of  $\text{BaSO}_4(\text{s})$

## identify natural and industrial sources of sulfur dioxide and oxides of nitrogen

- Some coal or oil reserves contain considerable quantities of sulfur compounds. Most sulfur dioxide ( $\text{SO}_2$ ) released into the atmosphere comes from the burning of such coal or oil in electric power stations.  $\text{SO}_2$  is the major contributor to acid rain that can affect places thousands of kilometres from the source. The low sulfur content of Australian coal is one reason why Australia is the world's largest exporter of coal.
- Smelters where metal sulfides are heated in air to remove the sulfur as  $\text{SO}_2$  are becoming a smaller source of atmospheric  $\text{SO}_2$ . Most of the  $\text{SO}_2$  released is now used to make sulfuric acid. The huge amount of  $\text{SO}_2$  that used to be released from Mt Isa

mine's smelter in Queensland is now changed to sulfuric acid and transported by rail 150 km away to make ammonium sulfate and superphosphate fertilisers at Phosphate Hill.

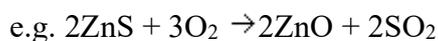
- Volcanoes are an unpredictable source of SO<sub>2</sub>. After Mt Pinatubo erupted in the Philippines in 1991, oxidation of the emitted SO<sub>2</sub> and reaction with water formed an aerosol of sulfuric acid droplets. This aerosol reduced global temperatures by about 0.5°C.

[National Pollutant Inventory Database for Australia](#) ▶ 2008/2009 data within Australia - Sulfur dioxide from All Sources, Department of Environment, Water, Heritage and the Arts, Australia.

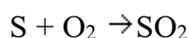
[The figures for Oxides of Nitrogen](#) Department of Environment, Water, Heritage and the Arts, Australia.

### **describe using equations, examples of chemical reactions which release sulfur dioxide and chemical reactions which release oxides of nitrogen**

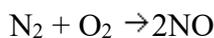
- In a metal sulfide smelter, the ore is heated in air and converts to a metal oxide, releasing sulfur dioxide.



- When coal, petroleum or natural gas are burnt, sulfur in sulfur compounds is converted to sulfur dioxide.



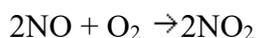
- Lightning strikes cause reaction between the two most common gases in the atmosphere.



- High temperature combustion reactions in furnaces and internal combustion engines produce significant amounts of NO [called nitrogen monoxide, nitric oxide or nitrogen(II) oxide] above 1300°C.



- Colourless, neutral nitrogen monoxide reacts with oxygen in the air to form brown, acidic nitrogen dioxide [nitrogen(IV) oxide].



**analyse information from secondary sources to summarise the industrial origins of sulfur dioxide and oxides of nitrogen and evaluate reasons for concern about their release into the environment**

- Information about sources of acid rain, mostly produced by SO<sub>2</sub> emissions and to a lesser extent by NO<sub>x</sub> emissions, can be found by using Internet search engines or by going to sites for scientific magazines and journals and using site search engines. In **choosing equipment**, determine the suitability and effectiveness of your browser search facilities to locate the relevant information.
- Some suitable starting points from which to **gather** information include:
  - search engines, such as [Google](#) ▶
  - popular scientific journals, such as [Nature](#) ▶ [New Scientist](#) ▶
  - science specific Internet sites, such as [Nova](#) ▶ and [Science Daily](#) ▶

Specific information on industrial origins of pollutants in Australia can be found in the [National Pollutant Inventory Database](#). ▶ Reasons for concern about release of these gases into the environment can be found by:

- searching the Internet using a search engine
- accessing material safety data sheets (MSDS) for these gases using CD-ROMs, such as the one supplied to schools with the *Chemical Safety In Schools* (CSIS) package.
- **analyse** the information you access to evaluate the reasons for concern about the release of sulfur dioxide and the oxides of nitrogen into the environment. Your evaluation might describe cause and effect relationships and could be based on criteria such as economic, social cost, health effects, environmental, political and energy benefit. List the criteria or values you use in your evaluation.

**assess the evidence which indicates increases in atmospheric concentration of oxides of sulfur and nitrogen**

- There is extensive evidence for an increase of over 25% in atmospheric carbon dioxide levels over the last two hundred years. The evidence comes from quantitative analysis of trapped air bubbles in Antarctic ice and measurement of carbon isotopes in old trees, grass seeds in museum collections and calcium carbonate in coral.
- Finding evidence for increases in atmospheric sulfur oxides and nitrogen oxides is more difficult for the following reasons:
  1. Whereas atmospheric CO<sub>2</sub> concentrations are about 360 parts per million (ppm), the levels for SO<sub>2</sub> and NO<sub>x</sub> are only about 0.001 ppm in populated parts of the Earth.
  2. The chemical instruments able to measure very low concentrations, like those for SO<sub>2</sub>, have only been commercially available since the 1970s.

3. CO<sub>2</sub> changes to carbonate ions when it dissolves in water and most carbonates are insoluble. Seashells and coral are made up of carbonates that came from atmospheric CO<sub>2</sub>. Isotope ratio measurements using mass spectrometers on shells and corals of different ages give clues as to past atmospheric CO<sub>2</sub> concentrations.

On the other hand, SO<sub>2</sub> eventually forms sulfate ions and NO<sub>2</sub> forms nitrate ions. Most sulfates and all nitrates are water-soluble. Soluble sulfates and nitrates circulate in the hydrosphere and biosphere and are chemically changed while insoluble carbonates tend to stay in inert forms such as shells or coral.

### explain the formation and effects of acid rain

- Distilled water in contact with the atmosphere is not neutral. It has a pH of 5.5 to 6, due to absorption of the acidic gas CO<sub>2</sub> from the atmosphere.
- In Australia, unpolluted rainwater has a pH between 5 and 6. If the pH is below 5, an acidic substance, such as SO<sub>2</sub> or NO<sub>2</sub>, has dissolved in the water, which is sometimes called *acid rain*. In the Northern Hemisphere, pHs as low as 2 have been recorded in acid rain. The source of the SO<sub>2</sub> or NO<sub>2</sub> could be hundreds or thousands of kilometres from where the acid rain falls.
- SO<sub>2</sub> sources, such as fossil fuel burning power stations and metal sulfide smelters, are larger but fewer in number than NO<sub>2</sub> sources, like internal combustion engines in vehicles.
- If the quantity of acid rain is greater than the capacity of an environment to neutralise it then the following can occur:
  1. Soil pH can drop, making it difficult for plants to absorb sufficient calcium or potassium.
  2. Soil chemistry can change, leading to the death of important micro-organisms and release of normally insoluble aluminium and mercury into soil water.
  3. Protective waxes can be lost from leaves, causing leaf damage.
  4. Buildings made of carbonates, such as concrete, mortar, limestone and marble, can be gradually dissolved away.
  5. Aquatic animals can die as water acidity drops below pH 5.
  6. Smog and acid rain can combine to form *killer fog*, as happened after the Second World War in London, when many homes burnt sulfur dioxide-releasing coal.

[Acid rain effects described](#) ▶ United States Environmental Protection Agency, US

(These web sites last checked 27 June 2008)