

RED: write syllabus dot point on other side in red. (with question that you make up in blue – for flash cards) and one word heading on this side in red.

Purple in Bold: Key information

Green: Equations and Scientists

9.4 Chemical Monitoring and Management

9.4.1 Much of the work of chemists involves monitoring the reactants and products of reactions and managing reaction conditions.

- Monitoring and managing is essential to make sure:
 - Raw materials meet specifications
 - Chemical reactions proceed efficiently
 - Products are pure & free from toxic contaminants
 - Wastes don't exceed allowable amounts of pollution
 - Workplace remains safe & healthy.

9.4.1.1 The variety of chemical occupations, & a detailed specific chemical occupation study.

9.4.1.2 Role of a chemist in a named industry, their branch of chemistry & explain a chemical principle that the chemist uses.

- **Broad Areas:** -Education, -Industry, -Research
- **Occupations:**
 - Analytical Chemist:** Investigate & understand the **chemical nature** & behaviour of substances.

-**Clinical biochemist:** analyses **patient** data to assist with diagnosis & treatment of diseases.

-**Forensic Scientist:** Provides scientific **evidence** to support prosecution/defence in courts of law investigations.

-**Research (physical) Scientist:** studies **non-living** systems to increase understanding of how the physical world works.

-**Science Writer:** researches, writes, & edits scientific news **articles**.

-**Toxicologist:** Identifies, monitors, evaluates impact of **toxic** materials.

-**Process Engineer:** develops economical **industrial processes** to make the huge range of products in modern society. (food, pharmaceuticals etc.)

-**Chemical development engineer:** development of **industrial processes** for the production of a diverse range of products, as well as in commodity and specialty **chemicals**.

- **Case Study:** Richard Hoggard is a **Chemical Engineer** at **Orica** (Newcastle)
- **Orica:** operates fertiliser manufacturing plants that produce ammonia and nitrogenous fertilisers via the **Haber Process**. (exothermic)



-data may need to be collected or analysed in **different** ways
-chemists can access a wider range of detailed knowledge, or work together to develop **new** techniques, or learn new skills.

-Saves **time** and **resources**: repetition of established information is avoided.

-improves **accuracy** (wider sampling range), **validity** (more verification).

- **Industrial Chemists:** monitor **conditions** to ensure optimum **yield** and **safety** of the plant.
- **Analytical Chemists:** Analyse products by testing for **purity**/quality, and collaborate with industrial chemists to **improve** and maintain standards.
- **Environmental Chemists:** Monitor **disposal** of wastes, and analyse impact of wastes on the environment. They collaborate with the industrial chemists to **reduce** amount of wastes, while the analytical

• **Chemical Engineer Role:**

- **design, operate** and **enhance** industrial chemical plant to maximise the **profitability** of the process.
- This is done through **manipulating** reaction **conditions** (temperature, pressure, catalysts, and concentrations of reactants and products.) in order to optimise yield and rate, and meet environmental guidelines.
- This is an application of **Le Chatelier's** principle.
- Increase **yield** of ammonia: increase concentration of reactants, reduce concentration of product, increase pressure or decrease temperature.*
- To increase **rate** of reaction: add a catalyst or increase temperature.*

*Conflicting temperature addressed in 9.4.2

9.4.1.3 Collaboration between Chemists as they collect and analyse data

- There are many **specialised** chemists who all are required to ensure production operates efficiently and safely. **Collaboration** through sharing knowledge, ideas and data to create coordinated effort is essential as:
-findings may **affect** other chemists and/or society.

9.4.1.4 Example of a chemical reaction (combustion), where reactants form different products under different conditions, thus need for monitoring.

- Different conditions may affect the **rate, yield** or **products** of reactions.
- For example, **fuel combustion's** (reaction of a fuel with oxygen to release energy) products are changed by the availability of oxygen.
- **Complete** combustion occurs where there is **sufficient** oxygen that allows the fuel to burn completely, producing CO₂ and water.
- **Incomplete** combustion occurs when there is **insufficient** oxygen to completely oxidise the carbon. This results in some/or all the carbon forming carbon monoxide, or soot, or a mixture of all the products.
- For example: Methane combustion:

chemist advises both industrial and environmental chemists suitable techniques to **analyse** and dispose of wastes produced.

- **COMPLETE COMBUSTION:** $\text{CH}_4 (\text{g}) + 2\text{O}_2 (\text{g}) \rightarrow \text{CO}_2 (\text{g}) + 2\text{H}_2\text{O} (\text{l})$
- **INCOMPLETE COMBUSTION:** $2\text{CH}_4 (\text{g}) + 3\text{O}_2 (\text{g}) \rightarrow 2\text{CO} (\text{g}) + 4\text{H}_2\text{O} (\text{l})$
- **INCOMPLETE COMBUSTION:** $\text{CH}_4 (\text{g}) + \text{O}_2 (\text{g}) \rightarrow \text{C} (\text{s}) + 2\text{H}_2\text{O} (\text{l})$
- **INCOMPLETE COMBUSTION:** $4\text{CH}_4 (\text{g}) + 6\text{O}_2 (\text{g}) \rightarrow \text{C} (\text{s}) + 2\text{CO} (\text{g}) + \text{CO}_2 (\text{g}) + 2\text{H}_2\text{O} (\text{l})$
- Incomplete combustion is undesirable as it reduces **efficiency**, **economical** operation, creates **toxic** substances, and adds **maintenance**.

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- Incomplete combustion produces **less** energy per unit of fuel used.
- The products of carbon monoxide and soot are very **toxic** as they are poisonous and cariogenic to human health.
- Soot can build up and **ruin** equipment.
- Thus, to reduce undesirable incomplete combustion, monitoring is needed. Monitoring would occur through:
- measuring the **flow**, and **mixing** of the fuel and air, measuring the **temperature** and **pressure** in the combustion area and measuring the **composition** of the exhaust gases.

9.4.2 Chemical processes in industry require monitoring and management to maximise production

9.4.2.1 Identify and describe the industrial uses of ammonia.

- Ammonia (**NH₃**) is a **colourless gas**, with a pungent odour. It's Uses:

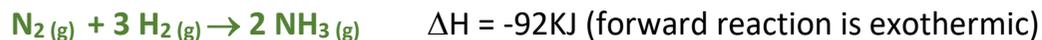
Industrial product derived from NH ₃	Use of Product
2NH₃(g) + H₂SO₄(aq) → (NH₄)₂SO₄(aq) ammonium sulphate, ammonium nitrate, urea	Fertiliser (80% of ammonia use)
Nitric acid	Explosives (TNT), plastics, fibres
Hydrazine (N ₂ H ₄)	Rocket Fuel
Ammonia	Refrigeration
Ammonium Hydroxide NH₃(g) + H₂O(l) → NH₄OH(aq)	Cleaning agent in factories, dry cleaning. (kills bacteria, dissolves grease)

9.4.2.2 Conditions and time period under which Haber developed the industrial synthesis of ammonia. (The Haber Process)

- German **Fritz Haber** developed the catalytic process in 1908 (pre-WW1).

- At this time Germany imported nitrates for fertilisers and explosives from **Chile**. During **WW1**, England **blocked** most of the South American imports to Germany. Thus the Haber Process allowed production of **fertilisers** (prevented some **starvation** in Germany), and **explosives** (extended length of **war**), to continue in Germany.

9.4.2.3 Ammonia is synthesised from nitrogen and hydrogen.



- N_2 – extracted from air in chemical reaction with natural gas.
- H_2 – extracted by electrolysis of salt water, or natural gas.

9.4.2.4 Haber Process is a reversible reaction that will reach equilibrium

- Reversible reaction**: once some ammonia is formed, some of it decomposes.
- To begin with, as the forward reaction proceeds, more NH_3 is produced, which increases the reverse reaction until **equilibrium** is reached.
- At ordinary pressures and temperatures, the equilibrium position lies well to the **left**, with very **little yield** of ammonia.

9.4.2.5 Reaction rate increased by higher temperatures

- Temperature rising increases particle **kinetic energy** (movement).
- This means that more particles will **collide** and collide with energy that exceeds the **activation energy**. Thus they can react. (increases reaction rate)

9.4.2.7 Yield of Haber process is reduced at Higher Temperatures

- Forward reaction is **exothermic**, thus Le Chatelier's principle indicates that high temperature providing more heat, will favour the **reverse reaction**, and reduce yield of ammonia.

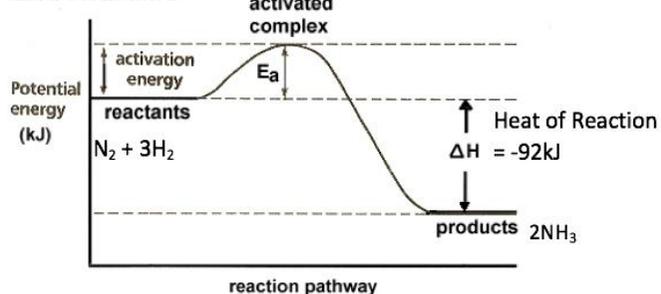
9.4.2.8 Balancing act involving reaction energy, reaction rate & equilibrium

- Increased temperature both increases reaction rate & decreases yield (above), thus a **compromise** of temperature needing satisfactory rate, & economic yield (30%) is achieved through **450°C**.

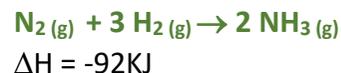
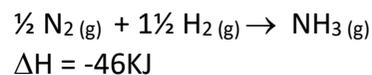
9.4.2.9 Haber process – Catalyst lowers reaction temperature

- Catalysts **lower** the **activation energy**, allowing a greater proportion of reactant molecules to have sufficient energy to react,
- Thus enabling a more rapid reaction at **lower temperatures**. (This favours the forward reaction; increasing yield)
- $\text{N}_2(\text{g})$ & $\text{H}_2(\text{g})$ are adsorbed onto **finely ground iron** (large surface area) to react.

EXOTHERMIC



9.4.2.6 Haber process – exothermic



Energy required to break the bonds **is less** than the

energy released when new bonds form in the products.

9.4.2.10 Increased pressure on system in Haber process

- Due to **Le Chatelier's** principle increased pressure increases the yield.
- Increased pressure by **adding more N₂ and H₂** (also increases reaction rate – closer and higher concentrations). But this is **expensive**.
- Economic yield of about 30%, a pressure of **20 000 kPa** is used.

9.4.2.11 Monitoring of reaction vessel is crucial

- Number of conditions need to maintained to achieve **safety** and **efficiency**. This is monitored automatically and by chemical/industrial engineers.

Monitor:

- **Concentration:** increase reactants, and reduce products (by condensing to liquid), to shift to right.
- **Temperature & Pressure:** Kept in range that provides optimum yield. (excessive temperature also can damage catalyst).
- **Contaminants:** Oxygen needs to kept absent to prevent explosion, Carbon monoxide & sulphur compounds can poison the catalyst, and the catalyst's surface needs to have maximum surface for adsorption.
- **Unreactive gases:** reduce efficiency in large quantities
- **Ratio:** of hydrogen to nitrogen gas needs to kept at 3:1 to avoid build up of one gas.

9.4.3 Manufactured products, including food, drugs and household chemicals, are analysed to determine or ensure their chemical composition

9.4.3.1 Carry out a range of tests, including flame tests to identify following ions: phosphate, sulphate, carbonate, chloride, barium, calcium, lead, copper, iron (III & II)

Note: Copper and Lead should not be disposed of in sink, but through collection for waste treatment/disposal.

Qualitative Analysis: (what substances are present)

Aim: Perform a range of tests to **identify** the **presence** of the following ions: PO_4^{3-} , SO_4^{2-} , CO_3^{2-} , Cl^- , Ba^{2+} , Ca^{2+} , Pb^{2+} , Cu^{2+} , Fe^{2+} , Fe^{3+}

Part A: Flame Tests

- When the metal is heated, it's **valence** electrons absorb energy and jump to higher orbits. As they cool off, the electron drops back to its electron shell & **emits** the **absorbed** energy as a distinctive colour of light.
- Each element emits a particular frequency, a unique "fingerprint" of **spectra lines** when viewed through a **spectroscope**.

Method:

1. Put Bunsen burner on blue flame. Using a **spray** bottle containing 1M barium chloride, or calcium chloride, or copper (II) sulphate, spray into flame
2. Record colour produced, and repeat with solutions on wood stick.

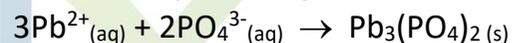
Part B: Spot Tests (identify ions through precipitation reactions)

Method:

1. Add 5 drops of a **cation** solution to a square on the **plastic overhead** sheet that lies on a white sheet of paper, with black stripes.
2. Add 5 drops of an anion solution. If a precipitate is produced, record its colour.
3. Test every anion solution with nitric acid, and look for bubbling.

Risks: -Nitric acid is **corrosive**. NaOH is **caustic**. Barium compounds are toxic. Lead(II) compounds are toxic.

Net Ionic Equation Eg:



Don't perform flame tests of Lead & Iron oxides = toxic.

9.4.3.2 Deduce the ions present in a sample from the results of tests.

- Flow charts are used to identify ions present in an aqueous sample.

Cation	Flame Colour	Remember	Key Test
Ba ²⁺	Apple Green	An apple a day keeps the doctor away, so you won't have to barium .	BaSO ₄ , BaCO ₃ , Ba ₃ (PO ₄) ₂ insoluble white ppt
Ca ²⁺	Brick red	Calcium is in bones which produces brick red blood cells.	CaSO ₄ , CaCO ₃ , Ca ₃ (PO ₄) ₂ , Ca(OH) ₂ insoluble white ppt
Cu ²⁺	Blue/ green	Copper copies barium green	CuCO ₃ , Cu ₃ (PO ₄) ₂ , Cu(OH) ₂ , Blue ppt CuI ₂ Brown ppt
Fe ²⁺ / Fe ³⁺	No Specific colour	Iron Man's suit is red and yellow , but red is already taken .	2+ : FeCO ₃ , Fe(OH) ₂ , (green ppt) Fe ₃ (PO ₄) ₂ (grey ppt) 3+ : Fe ₂ (CO ₃) ₃ , Fe(OH) ₃ Orange ppt FePO ₄ , (Beige ppt), FeI ₃ (Yellow ppt)
Pb ²⁺	Colour-less	If you use lead pencil , you won't need white out .	PbCl ₂ , PbSO ₄ , PbCO ₃ , Pb ₃ (PO ₄) ₂ , Pb(OH) ₂ , PbCl ₂ (white ppt) PbI ₂ (yellow ppt)

from dried **lead paint**, **solder**, from **smelting**, **battery** manufacturing or other lead industries. Lead pollution from the exhaust of **leaded petrol**.

9.4.3.4 Atomic Absorption Spectroscopy (AAS) in detecting concentrations of metal ions in solutions and assess its impact on scientific understanding.

- Flame/spot tests are adequate for qualitative analysis of samples containing more than 10mg/L (10ppm) of the element.
- Thus **Atomic Absorption Spectroscopy (AAS)** is essential in concentrations of metal ions in the **ppm** & sometimes **ppb** range.

First Use – AAS **Qualitative Analysis**

- Electrons exist in specific shells, & when in gaseous state if strongly energised one or more of the electrons **go into higher energy levels**.

9.4.3.3 Evidence for the need to monitor levels of one of the above ions in substances used in society.

- Instead of monitoring qualitatively we need to measure **quantitatively** as amounts of ions can be harmless at low concentrations but harmful at higher concentrations.
- PO₄²⁻ & NO₃⁻ are essential at **low concentrations** for aquatic plant growth, but can set off eutrophication if the concentration is too high.
- Trace elements** (Zn & Cu) are desirable in small concentrations, but in high concentrations are harmful.
- Lead**: is a poison & when it **accumulates** in the body, from intake by inhalation, ingestion, or absorption the lead particles interfere with **red blood cells** production. It can result in anaemia, fatigue, abdominal pain, vomiting, convulsions and even death. It can be detected through blood or urine samples, or x-rays of the bones. Although many lead poisoning cases can be **reduced** by restricting the **content** of lead in the **environment**. (eg. industries, paint, unleaded petrol etc).

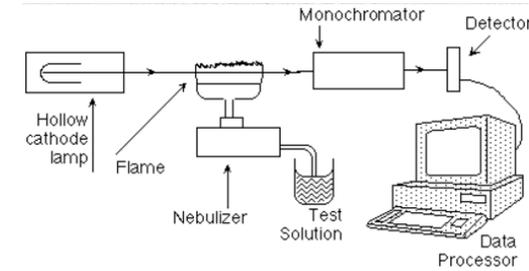
- Thus **monitoring** of the presence is essential. Lead exposure can come

Second Use – AAS **Quantitative Analysis**

- Once the elements present are known.
- The lamp contains the particular **element** that is being analysed, thus **emitting** is emission spectrum.
- The flame contains the **vaporised test solution**. The atoms of that element are exposed with light of a wavelength from the elements emission spectrum, the sample elements will **absorb** some of this light.
- The intensity of light passing through the flame thus drops sharply at the wavelengths of light absorbed thus producing an **absorption spectrum**.
- The **monochromater** selects one of the wavelengths.

- As they almost immediately fall back to ground state each electron **emits** energy in the form of a specific **wavelength** of **light** (energy released = energy absorbed to excite the electron)
- Each element thus has its own characteristic **emission spectrum**.
- By analysing the emission spectrum of a sample, elements are identified.

- The detector records the **intensity** of light passed through the flame, and compares/matches this against the **calibration graph** of the standard solutions. As the **decrease** in intensity is proportional to the **concentration** of the element.



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Scientific Impact of AAS:

- **Trace elements** (micronutrients) are essential in minute amounts (1 to 100 ppm) for helping enzyme function. Thus before the AAS, analytical methods could not detect these low concentrations & were unnoticed.
- AAS on organism/soil samples showed the **existence & necessity** of these trace elements.
- AAS can be used to detect whether essential trace elements are **present** in **sufficient** quantities in the organism and its environment. (eg. **molybdenum** needed in soil for legume crops, Magnesium = good muscle condition, Cobalt = immune functions). Thus AAS has had a great **impact** on scientific understanding of the effects of trace elements.

9.4.3.5 AAS measurements & effectiveness of this in pollution control.

- AAS was developed by the **CSIRO** scientist **Alan Walsh**, in the 1950s. It has allowed a more accurate & reliable detection of the concentrations of elements of **heavy-metal pollutants** in the **air, soil, and water** ways.
- **Advantages:** great **accuracy** (ppm/ppb), **reliability**, & **quick** results, thus allowing control mechanisms to be put in place immediately.

9.4.3.6/7 Measure the sulphate content of lawn fertiliser and explain the chemistry involved. Evaluate the reliability of the results & propose solutions

- Sulfate in ammonium sulphate fertiliser can be determined by **precipitation** of barium sulphate. The nitrogen is a vital soil **nutrient**, and the sulphur is a **trace element** for plant growth.

Aim: determine the **SO₄%** of lawn fertiliser (ammonium sulphate)

Reaction Equation: $(\text{NH}_4)_2\text{SO}_4 (\text{aq}) + \text{BaCl}_2 (\text{aq}) \rightarrow \text{BaSO}_4 (\text{s}) + 2\text{NH}_4\text{Cl} (\text{aq})$
(BaSO₄ is very insoluble thus **almost all** sulphate will precipitate.)

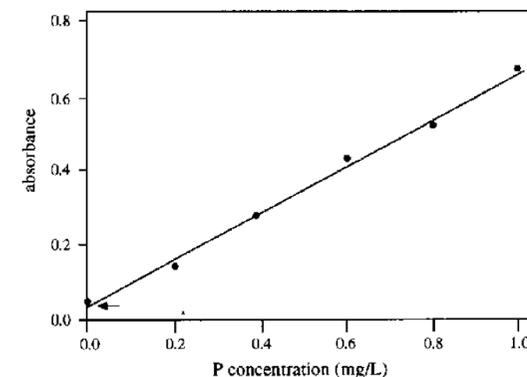
- Method:**
1. Weigh 0.5g of lawn fertiliser in a 250mL beaker. Record mass.
 2. Add 80mL of heated distilled water to the (NH₄)₂SO₄. Stir & **dissolve**
 3. Add approx. 20mL of 0.1 mol/L **HCl**. Boil to coagulate the precipitate.
 4. Stir & dissolve. **Filter** & collect the filtrate in a 250mL conical flask.

- **Disadvantages:** **expensive** machine, and **destroys** the test sample.

Eg. Monitoring Arsenic:

- Arsenic-rich ground water is a serious threat to people in Bangladesh. The **SORAS** method, has been proven by **AAS measurement** to reduce the pollution of arsenic in water. The SORAS method involves forming an iron(III) hydroxide precipitate where the As (V) adsorbs onto. Thus the AAS is effective as it measured the levels of arsenic in drinking water allowing changes to be made in pollution control.

Eg. if the AAS revealed an absorbance of 0.2 in the drinking water, the concentration from this standard calibration graph would be 0.22mg/L.



Note: concentration in ppm is the mass of solute in mg in one kilogram of solution.

Reliability: (look at Q27: 2003)

- Reliability can be increased by changing experimental design to create to be able to create consistent results. Then by doing it **multiple times & averaging** the results, the experiment will be more reliable and consistent.
- **Validity:**

Problems	Solutions
Insoluble impurities in fertiliser	Filter fertiliser solution before adding Ba ²⁺
CO ₃ ²⁻ impurities in fertiliser that would precipitate with Ba ²⁺	Dissolve fertiliser in dilute acid (HCl) to remove CO ₃ ²⁻
Not all SO ₄ ²⁻ precipitated	Add excess Ba ²⁺
BaSO ₄ precipitate is very fine, so much of it passes through ordinary filter paper.	Use of finer filter, or a sintered glass filter .

5. **Discard** the filter paper + residue.
6. Add 25mL of 0.2mol/L **BaCl₂** solution to the filtrate, whilst stirring.
7. **Filter** the mixture using a dried **pre-weighed** filter paper. **Wash** the residue in the filter paper three times using a wash bottle of distilled water.
8. **Dry** the filter paper & residue to **constant** weight. Record the final weight.

The precipitate cant be removed from the filter, so weight can't be determined directly.	Weigh filter paper before hand.
Residue contains dissolved ions.	Wash with distilled water before drying
Filter + residue contains water	Dry before weighing
Drying length to ensure all water is removed	Dry until weight remains constant .

- **Our experiment:** Improve by using a **sintered** glass filter, & **purser** chemicals.

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9.4.4 Human activity has caused changes in the composition and the structure of the atmosphere. Chemists monitor these changes so that further damage can be limited.

- Atmosphere chemical composition depends on gases released & absorbed at Earth's surface, & the chemical reactions that take place.

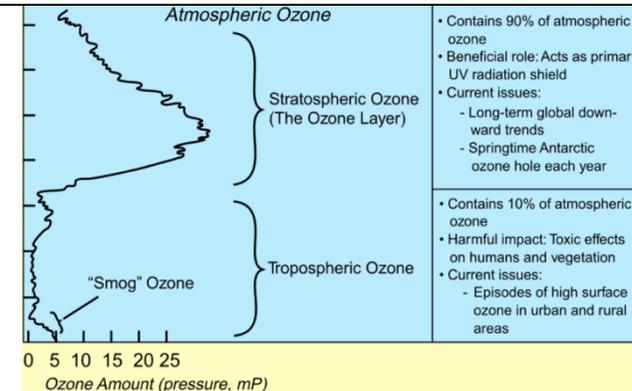
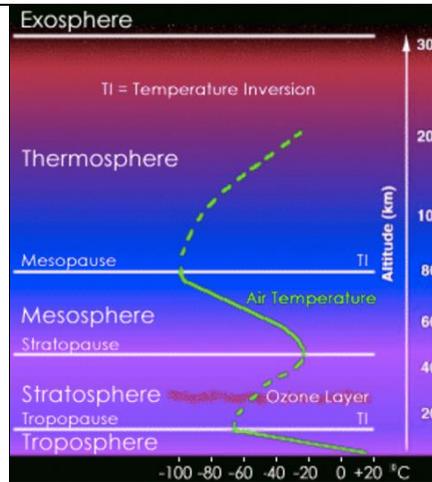
9.4.4.1 Composition and layered structure of the atmosphere.

- Boundaries ("pauses") of the layers are defined by changes in the rate of change in temperature.

Ionosphere -lower Exo + thermo, + upper meso (contains free ions, atoms & electrons)	Layer	Features
	Exosphere	Particles escape to space. Most satellites orbit
	Thermosphere	Temp increases . Absorbs high-energy UV & X-rays
	Mesosphere	Temp decreases . Most Meteors burn up.
	Stratosphere	Temp increases . Contains ozone layer.
	Troposphere	Temp decreases . Most water & weather here.

- Water vapour varies lots. So in dry air the atmosphere is composed of **Nitrogen** (78%), **Oxygen** (20%), Argon (0.93%), CO₂ (0.036%).
- Although in small concentrations many other gases cause concern due to the reactions they undergo. (**ozone**)

Volatile organic compounds (hydrocarbons)	Solvents Unburnt Fossil Fuels	Photochemical smog
Sulphur dioxide	Roasting of sulphide ores Combustion of fuels containing sulphur impurities	Acid rain Smog Respiratory issues
Lead	Combustion of leaded fuels Metal extraction leaded paints	Direct poison
Particulates	Incomplete combustion (soot) Earthmoving, Dust storms Agricultural/industrial practises	Damage to surfaces & materials Respiratory issues
Methane	Anaerobic decomposition of organic matter Natural gas seepage Ruminants & termites	Enhanced Greenhouse Effect

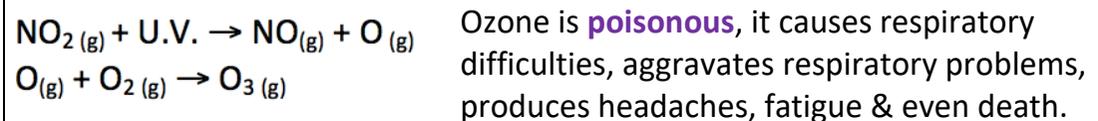


9.4.4.2 Main pollutants found in the lower atmosphere & their sources

Main Pollutants	Main Sources	Negative Effect(s)
Carbon Monoxide	Incomplete combustion of fuels	Direct poison
Nitrogen oxides	High temperature combustion in vehicles & power stations	Photochemical smog Acid rain

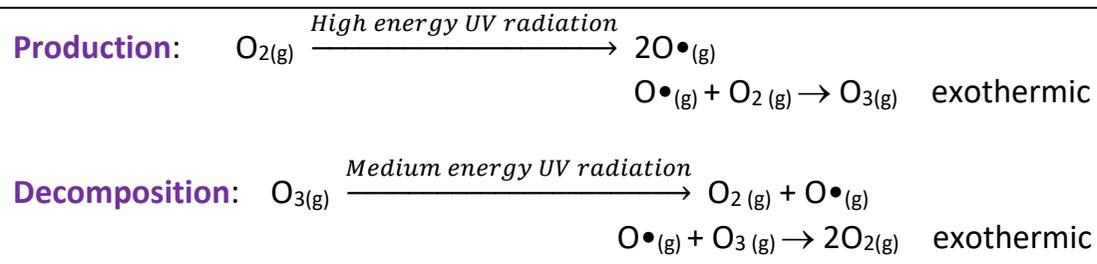
9.4.4.3 Ozone as a molecule able to act both as an upper atmosphere UV radiation shield & lower atmosphere pollutant

- Troposphere:** **pollutant** (even at low concentrations). It is a very reactive molecule capable of **oxidising** many substances. It forms in the lower atmosphere when sunlight is very intense & NO₂ levels are high.



- Stratosphere:** **Most** occurs in the stratosphere, and form a thin layer that acts as a **UV radiation shield**, protecting living tissue. In the stratosphere ozone is produced & broken down by:

Carbon Dioxide	Burning fossil fuels, Deforestation, Internal combustion in cars.	Enhanced Greenhouse Effect
Ozone	$\text{NO}_2(g) + \text{U.V.} \rightarrow \text{NO}(g) + \text{O}^\bullet(g)$ $\text{O}^\bullet(g) + \text{O}_2(g) \rightarrow \text{O}_3(g)$	Photochemical smog Direct poison Respiratory problems



- The **exothermic** reactions accounts for the **increasing** temperature in the stratosphere. Various substances such as NO molecules and Cl atoms, (free **radicals**), **catalyse** the decomposition reaction.

- Free radicals** are species with one or more lone or unpaired electrons

9.4.4.4 Describe the formation of a coordinate covalent bond

- Non-metal** elements & compounds contain covalent bonds (shared pair of electrons that keeps two atoms together)

- A **coordinate covalent bond** forms when one atom in a molecule or ion containing non-metal atoms, **provides both electrons** in the covalent bond. Once formed this is indistinguishable from other covalent bonds.

9.4.4.6 Properties of oxygen allotropes O₂ & O₃ & account for them on the basis of molecular structure and bonding.

- Allotropes: **different** physical forms of the same **element**. E.g diamond & graphite are allotropes of carbon.

- Molecular **O₂** (diatomic oxygen) & ozone **O₃** (triatomic oxygen) are **allotropes of oxygen**.

Properties	Gaseous Oxygen O ₂	Gaseous Ozone O ₃	Explanation
Colour	Colourless	Blue	
MP	-219°C	-193°C	Ozone has a higher molecular mass + more electrons. Hence stronger dispersion forces .
BP	-183°C	-111°C	
Density at SLC	1.3g/L	1.9g/L	Ozone has greater molecular mass.
Solubility in water at 25°C	Sparingly soluble 8mg/L	More soluble than oxygen 109mg/L	Non-polar O ₂ , whereas Ozone is slightly polar .
Chemical reactivity	Far less reactive than ozone	Far more reactive than oxygen molecule	Coordinate covalent bond in O ₃ is much more easily broken down than the covalent bond in O ₂ .
Oxidation ability	Moderately strong oxidant	Very powerful oxidant	O ₃ is less stable (above) so more reactive, oxidising.

- Ozone = 3 oxygen atoms held together by a **double** covalent bond and a **single coordinate** covalent bond.
- Oxygen = **Diatomic** molecule – 2 oxygen atoms held together with a **double** covalent bond.

9.4.4.7 Properties of gaseous forms of oxygen & the oxygen free radical

Free-radical: is a species containing at least **one unpaired electron** in outer shell. The Oxygen atom has 2 unpaired electrons. The presence of unpaired electrons means the **oxygen free-radical** is **unstable** & needs to gain two electrons to become stable.

Similarities: Oxygen molecules, Ozone & Oxygen free radicals are all **allotropes** of Oxygen.

Differences: Ozone and Oxygen have **full outer** shells, whereas free radicals (short life span) don't.

Reactivity: Oxygen Molecule < Ozone < Free Radical

9.4.4.8 Isomers (excluding geometrical & optical) of haloalkanes up to 8 carbon atoms.

- **Haloalkanes** are alkanes in which one or more hydrogen atoms have been replaced by **halogen** atoms.
 - **Isomers:** molecules with the same **molecular formula** but different **structural** formulas (arrangements of atoms)
- Naming (same as alkanes) plus:
1. **Prefixes:** Bromine=bromo, Chlorine=chloro, Fluorine=fluoro, Iodine=iodo
 2. If more than possible possible **position** for functional group, then its position is identified by a number. (from end that has the **smallest sum**)
 3. **Prefixes** di(2), tri(3), tetra(4) are used, with all positions shown.
 4. Halogens go in **alphabetical** order.
 5. The element with lowest numbers is given to the most electronegative halogen (F>Cl>Br>I) (?)

9.4.4.10 Origins of Chlorofluorocarbons (CFCs) & halons in the atmosphere

- **ChloroFluroCarbons**: haloalkanes that contain **both chlorine** and **fluorine** atoms with **no hydrogen** atoms.
- CFCs were developed to replace ammonia as a **refrigerant**, as due to being inert, low BP they were thought to be “safer”. Also used as **solvents** in dry cleaning, **propellants** in spray cans.
- **Halons**: haloalkanes with **bromine** & other **halogens** but **no hydrogen**.
- They were used in **fire extinguishers** for electrical fires, or to **protect** computer & electrical systems. (fortunately not used as much as CFCs).
- The gases from CFC & halon released **aren't destroyed** by sunlight & oxygen, & aren't soluble. Thus have a long life where they eventually drift to the **stratosphere**. **UV** breaks C-Cl & C-Br bonds that are on the surface of **ice crystals** releasing Cl & Br free **radicals**.
- These radicals are **catalysts** in the **decomposition** of **ozone**. The cold winter adsorbs these radicals onto ice crystals, then the summer UV rays increases the concentration of free-radicals. Thus leading to the '**ozone hole**'.

9.4.4.11 Changes in atmospheric ozone concentrations observed, & how this information was obtained.

- Ozone measurements have been recorded since **1957**.
- **Ground-based ultraviolet spectrophotometers**: measures the **intensity** of radiation in UV. They are directed **vertically upwards** through the atmosphere to measure the intensity of UV that **ozone absorbs**, and the intensity of UV wavelengths on either side of this range.
- Can also be **directed downwards** from helium balloons and aircraft.
- In **1970s** it was clear that the ozone was depleting. It was discovered that **nitrous oxide** could destroy ozone, and in the **mid-1970s CFCs** were known to be significant decomposers.
- **Total Ozone Mapping Spectrophotometers (TOMS)**: On board **satellites** scan the atmosphere, measuring ozone **concentration** as a function of **altitude** & **geographical** position.
- **1980s** used TOMs & UV spectrophotometers, to determine the ozone holes especially occurred over the entire Antarctic.
- **1985**, ozone concentrations declined by **30%**.

- Now the decline in Antarctic during springtime exceeds **50%**, or some places is completely **destroyed**.
- Decrease in the rate of release of CFCs & halons today, is expected to **fully repair** the ozone hole by **2050**.

9.4.4.11 Problems associated with use of CFCs & effectiveness of solutions

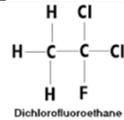
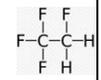
Problems with CFCs:

- Inert in the troposphere thus move up into stratosphere where they **destruct ozone**, especially at the poles.
- Cl free radicals can destroy **thousands** of O₃ molecules (lives for around **150 years**) until it is neutralised by a reaction with methane gas.
- As the ozone formation/decomposition cycle absorbs UV radiation, a decrease in O₃ allows **more radiation** reaching the earth's surface.
- Resulting in **skin cancers**, eye **cataracts**, **plant** damage, decreased **immune** response, **polymer** decomposition.
- Is a **greenhouse gas** (absorbs heat rays) adding to global climate change.

Steps Taken: (reducing CFCs released)

- 1987 the **Montreal Protocol** on Substances which deplete the O₃ layer:
 - **freezing** CFC production at 1986 levels
 - & **reducing** CFC production by 50% by 2000
- **London** (1990), **Copenhagen** (1992) further developed agreements to phase out CFCs & Halons. & provided financial **aid** for developing nations.
- CFCs have been replaced by **alternative** chemicals HCFCs & HFCs.
- These agreements have been **successful**, but due to being **unable** to remove CFCs already in the stratosphere:
 - New sunscreens & UV stabilisers in polymers are used to reduce effects.

9.4.4.12 Identify alternative chemicals to replace CDCs & effectiveness

	HCFC (Hydrochlorofluorocarbons)	HFC (Hydrofluorocarbons)	Hydro-carbons
Description	Haloalkanes with H, Cl & F atoms (1 st replacement) 	Haloalkanes with H, F atoms (1,1,1,2-tetrafluoroethane is mainly used) 	- Same as HFC but only H & C atoms & used in spray cans instead.
Positives	<ul style="list-style-type: none"> C-H bonds are susceptible to attack by reactive radicals in the troposphere. (more likely to breakdown in troposphere) Shorter lifespan 	<ul style="list-style-type: none"> C-H bonds cause some decomposition, & no C-Cl bonds means zero capacity to destroy ozone. 	
Negatives	<ul style="list-style-type: none"> Reactions are slow, so many still diffuse into stratosphere & cause ozone destruction. More expensive & unknown toxicity Greenhouse gas. 	<ul style="list-style-type: none"> More expensive & less efficient than CFCs. Less effective in uses (air conditioning, refrigeration.) Greenhouse gas 	

Turbidity	Undissolved (suspended) solids (eg. algae & sediment). Water with high turbidity reduces penetration of light (scattered more), decreasing photosynthesis.	- Turbidity tube (in NTU) or less subjective nephelometer
Acidity (pH)	pH affects aquatic life & biochemistry . -below 7 = acid sulphate soils or decomposition of organic matter -Above 7 = limestone soils.	- pH meter -Test with universal pH paper
Dissolved Oxygen (DO)	Concentration of O ₂ in ppm. -DO is increased by photosynthesis & atmospheric O ₂ dissolving. -DO decreased by respiration decomposition, & warmer temperature	- Oxygen-sensitive electrode . -Back titration involving manganese ions (Winkler titration)

9.4.5 Human Activity also impacts on waterways. Chemical monitoring & management assists in providing safe water for human use & to protect the habitats of other organisms.

9.4.5.1 Identify that water quality can be determined by considering:

Property	Details	Testing
Concentration of common ions:	(Na ⁺ , K ⁺ , Ca ²⁺ , Mg ²⁺ , Cl ⁻ , HCO ₃ ⁻ , SO ₄ ²⁻) Presence of certain ions affects aquatic organisms. Nitrates & phosphates must be monitored (eutrophication)	- AAS for metal ions -Precipitation & gravimetric analysis
Total dissolved Solids (TDS)	(salinity) aquatic organisms prefer a particular range.	- TDS or conductivity meter or evaporation & gravimetric analysis.
Hardness	- Ca²⁺ & Mg²⁺ in water easily precipitate with soap ions (won't bubble with soap). Leaving scum . -Ca ²⁺ can also precipitate with SO ₄ ²⁻ & CO ₃ ²⁻ at high temps to form ' scale '	- Titred against EDTA & expressed as mg/L of CaCO ₃ -Precipitation with CO ₃ ²⁻ & gravimetric analysis. -Qualitatively by adding soap (doesn't lather)

9.4.5.2 Qualitative & Quantitative tests to analyse & compare quality of water samples.

- TDS (quantitative)**: Weigh flask. Filter large sample into flask. Re-weigh flask + water. Evaporate water gently. Re-weigh flask when completely dry. Determine mass of dried residue in ppm.
(**ppm=mass of dried residue (in mg) ÷ mass of filtered water sample (in kg)**)
- Hardness (qualitative)**: Stir **soap** solution into water sample. Observe how much lathers. (the less lather, the harder the water)
- Turbidity (quantitative)**: Use a **turbidity tube**, by adding water until the base can't be seen through the water. (measure in NTUs)

Biochemical Oxygen Demand (BOD)	<p>-Microbial activity in water (deplete oxygen needed for aquatic organism's.)</p> <p>-Aerobic micro-organisms need oxygen for respiration while decomposing organic matter. Thus high DO removed indicates high decomposition by microbes = high presence of organic matter & nutrients.</p>	<p>-2 samples taken. One measured for DO, the other left in a dark place for 5 days & then tested for DO.</p> <p>-Calculate difference</p>	<ul style="list-style-type: none"> • Acidity (quantitative): Use a pH meter. (complete at site so that dissolved gases don't change due to temperature.) • DO (quantitative): Using oxygen selective electrode (OSE) – test water samples under water. (complete at site) • BOD (quantitative): Collect 2 water samples (seal under water). <p>-Measure 1 DO reading (DO_0) immediately. & Incubate other sealed sample in dark for 5 days at 20°C before measuring DO_5. BOD (ppm) = $DO_0 - DO_5$</p>
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9.4.5.3 Factors affecting concentrations of a range of ions in solution in natural bodies of water such as rivers & oceans

Natural Sources:

- **Acidic rain** can increase concentrations of H⁺ ions. It can also increase water's ability to leach ions (Mg²⁺, & Ca²⁺) from the soil.
- **Quantity** of water (frequency & rate) & the soils porosity & permeability to absorb this water can determine the concentration (eg. dilute water).
- **Soil type**, minerals & their solubilities present in pathway to water body.
- **Temperature**: increase dissolved ions & evaporation (leaves ions behind).

Agriculture:

- Animal **faeces** & **fertilisers** can run-off into water bodies, leading to possible eutrophication. (increase in NO₃⁻, PO₄³⁻, turbidity & TDS)

Industrial waste (depends on type of Industry) & Sewage:

- Industrial **discharge** of waste (eg. heavy metals) can increase metallic cations & pH in water, leaching from **rubbish dumps** & **effluent** discharge

Land Clearing:

- **Earth moving**: sediments flow into water increasing turbidity & can expose

layers containing sulphide to air, & **deforestation** decreases soil stability.

- **Removal** of native vegetation or irrigation with salt water can increase salinity.

9.4.5.4 The Chemistry of & the range of tests used to:

Identity heavy metal pollution of water (metals such as mercury & lead)

- Heavy metal pollution is **toxic**, as they have large atomic masses.

Heavy Metal	Effect	Tests
Mercury (leads to bio-accumulation & bio-magnification)	Brain damage, birth deformities.	- Qualitatively : flame testing (although discouraged due to toxic gaseous atoms), & precipitation . (can't measure amount, due to low amount) - Quantitatively : colourimetry (below), chromatography, & spectroscopy (especially AAS).
Lead	Brain, Kidney damage.	

Monitor possible eutrophication of waterways

- **Eutrophication**: significant rise in **nutrients** (excess phosphates & nitrates) resulting in excessive growth of plants (**algae bloom**) & cyanobacteria.

- These deplete the levels of **DO** (Block air O₂ dissolving, use up O₂, & cut off the sunlight photosynthesis.) This results in **death** of organisms which sink to the bottom & **decompose** thus depleting more DO.
- Decomposer microorganisms increase, releasing more **toxins** that cause death. Eventually plant & animal life die, leaving an **anaerobic** water body.
- **Qualitative Tests (Observing):**
 - **Stagnation**, algal blooms, dead organisms, smell of H₂S & NH₃
- **Quantitative Tests:** ratio should be 10:1 (N:P)
 - Measure the effect (**DO levels** would be **less** & **BOD levels** would be **more**)
 - Measure the cause (Nitrate & phosphate concentration):
 - **Colourimetry:** (reactions producing strongly-coloured products)
 - NO₃⁻ react with **sulphanilamide** to produce a **red** colour.
 - PO₄³⁻ react with sodium **molybdate** to produce a **blue** colour.
 - The samples are put into a **colorimeter** that measures the transmittance of light through the sample (implies concentration). A calibration curve then determines the concentration.

9.4.5.5 Effectiveness of methods used to purify/sanitise mass water supplies

- **Screening:** Removes **large** particles/debri. (leaves, twigs etc.)
- **Coagulation:** Chemicals (eg. **Liquid aluminium sulphate - Alum**) are added to help fine particles clump together (coagulate) to form floc (heavier, larger particles).
- **Flocculation:** These flocs continue to **flocculate** together removing small suspended particles, making the following steps easier.
- **Sedimentation:** Water is moved slowly to let the floc/particles settle out to the bottom to be removed by **sludge processing**.
- **Filtration:** Removes smaller particles such as viruses & protozoans, by passing water through one or more of the following:
 - **Sand-pebble filtration:** layers of sand.
 - **Activated Carbon Filtration:** layers of charcoal
 - **Synthetic Membrane Filtration:** through tiny synthetic pores (used for particles too fine, although very expensive)

The filters are continually cleaned by backwashing, & the solids collected are settled out by sedimentation again & removed by sludge processing.

- **pH adjustment** with Lime (CaOH_2) & **caustic soda**:
The water should be between 6.5-8.5 pH, to minimise corrosion in pipes.

- **Inactivation of Microbes**:
 - **Disinfection**: Disinfectant chemicals are added to **kill/inactivate** any remaining microbes/pathogens & stop further growth/contamination. Possible disinfections include **chlorine**, and/or ozone or irradiation (through UV-radiation).
 - **Fluoridation**: Fluorine is added to prevent **tooth decay**.

Effectiveness:

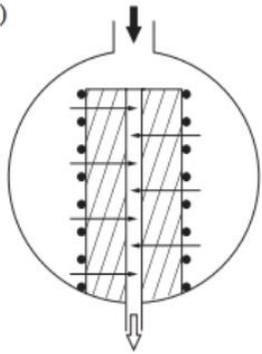
- **Compromise** between cost, speed & quality. (Main focus is **cost-effective**)
- Flocculation, sand filters & chlorination are relatively cheap, & fast in producing large volumes of treated water.
- Although not all organisms are **adequately removed**. (eg. **Giardia** & **Cryptosporidium**). Which need expensive **membrane** filters.
- Hence water supplies are **monitored daily**, & in each catchment during storms. (cheaper than using membrane filters daily).

9.4.5.6 Design & composition of microscopic membrane filters & how they purify contaminated water.

- Microscopic membrane filters are more effective due to their **very small pore size**, but are more **expensive**, thus used in specific areas (**hospitals**)
- Microscopic membrane filters utilise synthetic polymers which have tiny pores which can **remove** solutes & **microorganisms**.
- The polymers are wound around a central rigid core where the clean water flows through.
- Hollow fibres around around the central channel, where purified water passes into & flows lengthwise. The particles are retained on the outer surface of the hollow fibres.
- Water flows **along not through** the membrane (reduces blockage)

Process	Removes	Use In Aus
Microfiltration	Suspended solids, protozoa & bacteria	Rural areas
Ultrafiltration	Most viruses & most organic matter	Minimal
Nanofiltration	All viruses, most organic matter, insecticides	None (kidney dialysis)

(B)



KEY

 Clean water

 Contaminated water

 Microscopic membrane

 Movement of water

 Trapped contamination

9.4.5.7 Features of the local town water supply in terms of:

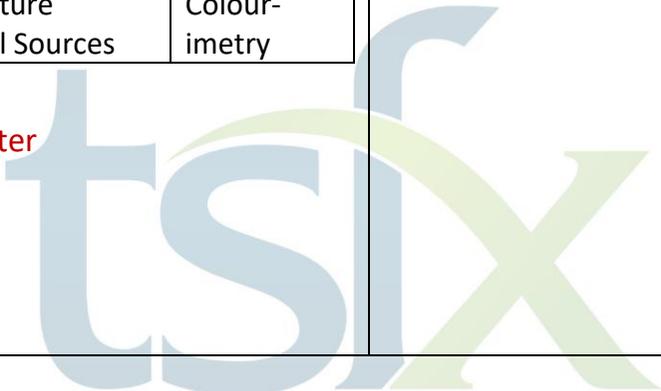
- **Catchment area**
 - **Catchments** collect water from natural landscape by run-off & ground water to form a river, dam or groundwater system.
 - Eg. **Grahamstown dam catchment**. (processed in a Water Filtration plant, due to naturally present impurities.)
- **Possible sources of contamination in this catchment & Chemical tests**
 - **Little** or no **human habitation**, & restricted access to reduce adverse affects from urban development, farming, industry or animal waste.

Contaminants	Effects	Sources	Tests
Metals	-taste, odour, aesthetic problems -Toxicity -Water hardness	-Industry (metal purification) -Mining	Precipitation Flame Tests AAS
Silt	-Turbidity -Particles can shield micro-organisms	-Mining -Agriculture -Urban Stormwater	Turbidity tube Filtration + gravimetric analysis

Organic Matter	-Taste/odour -Turbidity -Eutrophication	-Agriculture -Urban stormwater -Sewage/landfill -Natural sources	BOD Turbidity tube
Acids/Bases	-Taste/odour -Corrosion -Ineffective disinfection (neutralisation)	-Industry -Mining -Natural sources	pH meter & indicator
Micro-organisms (cryptosporidium, giardia, E.coli)	-Pathogens cause water-borne illness	-Agriculture -Sewage -Urban Stormwater	BOD Agar plates DO
NO₃⁻ & PO₄³⁻	-Eutrophication	-Agriculture -Natural Sources	Colour- imetry

- **Chemical additives in the water & reasons for their presence**
 - **Alum:** Aluminium sulphate is used to flocculate particles to remove **turbidity & colour**. Alum is filtered from the water but a small fraction dissolves & is not removed. (concentrations can be reduced by additional treatments)
 - **Chlorine: Disinfectant** that destroys disease-causing bacteria, viruses, & parasites.
 - **Fluoride:** Helps prevent **tooth decay**.
 - **Water Stabilisation:** Prevents **corrosion** of pipes by added lime (calcium carbonate) which makes the water harder, or carbon dioxide.

• **Physical & chemical processes used to purify water**
 Previous Dot Point



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