# DP IB Environmental Systems & Societies (ESS): HL

Your notes

## 6.4 Stratospheric Ozone

### Contents

## UV Radiation

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# UV Radiation Effects

- The Sun emits electromagnetic radiation in a range of wavelengths, from low-frequency radio waves to high-frequency gamma radiation
- **Shorter wavelengths** of radiation have higher frequencies
  - **More energy damages living organisms**
  - E.g. ultraviolet (UV) radiation

# Effects on human health

- Ultraviolet radiation from the Sun can have damaging effects on **human living tissues**
  - When excessive UV radiation reaches the surface of the Earth, it can lead to various health issues by damaging cells and tissues

**UV Radiation Effects on Humans**

| Health issues caused by UV radiation | Explanation |
|---|---|
| Cataracts | Prolonged exposure to UV radiation can contribute to the development of cataracts<br><br>Cataracts cause **clouding** of the **lens** in the eye, leading to blurry vision and eventual vision loss if left untreated |
| UV radiation affects cells | UV radiation has the potential to induce **mutations** in **DNA** during cell division<br><br>When cells are exposed to UV radiation, it can lead to genetic alterations and mutations<br><br>This can disrupt normal cell growth and increase the risk of developing **cancer** |

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|---|---|
| Skin cancer | UV radiation is a major risk factor for the development of **skin cancer**<br><br>UV rays can damage the DNA in skin cells, leading to uncontrolled cell growth and the formation of cancerous **tumours**<br><br>Prolonged or intense exposure to UV radiation, especially without proper **protection**, increases the risk of developing skin cancer |
| Sunburn | When the skin is exposed to excessive UV rays, it triggers an **inflammatory response** as a defence mechanism<br><br>Sunburned skin becomes red, painful and may blister, indicating damage to the skin cells |
| Premature skin ageing | Chronic exposure to UV radiation accelerates the **ageing** process of the skin<br><br>It can cause the breakdown of collagen and elastin fibres, leading to **wrinkles**, **sagging skin** and the development of **age spots** |


***Measures such as wearing sunscreen with a high sun protection factor (SPF), using sunglasses that block certain UV rays, seeking shade during peak sun hours and wearing protective clothing can help***

***reduce the risk of UV-related health issues (Photo by Dimitris Chapsoulas on Unsplash )***

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## Effects on biological productivity

- Harmful UV radiation reaching the Earth's surface affects plant growth and productivity
- Increased UV exposure can lead to:
  - Reduced photosynthesis rates
  - Altered plant metabolism
  - Decreased crop yields
- Exposure to increased UV radiation can affect other photosynthetic organisms, such as **phytoplankton**
  - Phytoplankton play a crucial role in **aquatic food webs**
  - They convert sunlight, carbon dioxide and nutrients into organic matter through **photosynthesis**
  - UV radiation damages phytoplankton by:
    - Causing DNA damage
    - Reducing photosynthetic activity and growth
  - This leads to a decrease in primary productivity in aquatic ecosystems
- Reduced phytoplankton productivity can have cascading effects on **higher trophic levels** in aquatic ecosystems
  - **Zooplankton**, which feed on phytoplankton, have less food available
    - This affects their growth and reproduction
  - This, in turn, can impact higher-level consumers, such as **fish** and **marine mammals**
    - Organisms in these higher trophic levels rely on phytoplankton and zooplankton as food source
    - This can significantly reduce the biodiversity of aquatic ecosystems

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## Stratospheric Ozone

# Stratospheric Ozone

- Ozone is a molecule composed of three oxygen atoms (**$O_3$**)
  - It is mainly found in the Earth's **stratosphere**
  - This is a layer of the atmosphere located approximately 10 to 50 kilometres above the Earth's surface
- Ozone plays a very important role in **protecting life** on Earth
  - This is because it **absorbs** a significant portion of the Sun's harmful UV radiation
  - This significantly reduces the amount of UV radiation that reaches the Earth's surface
- **Types of UV radiation:**
  - **UVA:**
    - Longest wavelength
    - Least harmful but can cause skin aging and contribute to skin cancer
  - **UVB:**
    - Medium wavelength
    - Can cause skin burns and direct DNA damage
    - Mostly absorbed by stratospheric ozone, but some reaches the Earth's surface
  - **UVC:**
    - Shortest wavelength
    - Most harmful
    - Completely absorbed by stratospheric ozone

# Ozone Equilibrium

- The amount of ozone in the stratosphere remains relatively constant over long periods
  - This is due to a **steady state** of **equilibrium**
- Equilibrium is maintained between the processes of ozone **formation** and **destruction**

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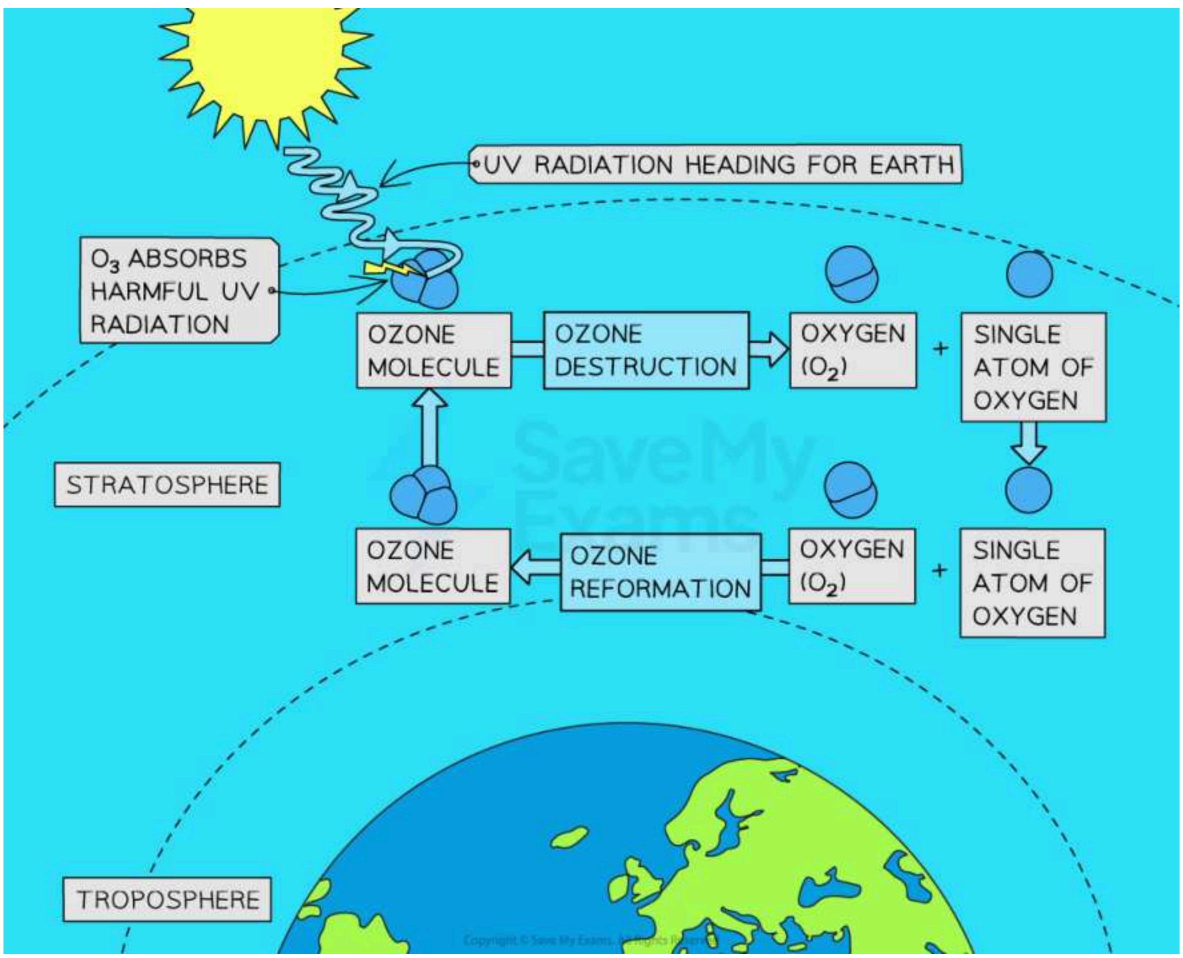
- When UV radiation from the Sun interacts with ozone molecules, some of the ozone **absorbs** the energy and **breaks apart**
- This results in the formation of an oxygen molecule ($O_2$) and a free oxygen atom (O)
  - This process of ozone destruction occurs **naturally** in the stratosphere
  - Under normal conditions, the free oxygen atom (O) can combine with another oxygen molecule ($O_2$) to form ozone ($O_3$) again
  - This ozone destruction and reformation creates a **dynamic equilibrium** in the stratosphere
    - There is a **continuous cycle** of ozone molecules being broken apart and reformed
  - This dynamic equilibrium ensures that the concentration of ozone in the stratosphere remains relatively **stable** over time
    - The rate of the forward reaction equals the rate of the backward reaction in the system, so the concentrations of the **reactants** and **products** remain relatively **constant**



***Ozone destruction and reformation creates a dynamic equilibrium in the stratosphere—there is a continuous cycle of ozone molecules being broken apart and reformed***

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# Ozone Depletion

## Ozone-depleting substances

- Ozone-depleting substances (ODSs) are chemicals that cause **stratospheric ozone depletion**
  - These substances cause the destruction of ozone molecules
  - In other words, they enhance the natural ozone breakdown process (beyond natural levels)
- ODSs are commonly used in various human activities and products:

**Sources of Ozone Depleting Substances**

| Source | Details |
|---|---|
| Aerosols | **Chlorofluorocarbons** (CFCs) were **previously** used as **propellants** in aerosol products like sprays, foams, and deodorants<br><br>When released into the atmosphere during **spraying**, these substances can eventually reach the stratosphere and contribute to ozone depletion |
| Gas-blown plastics | ODSs were also used as blowing agents in the production of foamed plastics<br><br>These agents help create air pockets within the plastic material, making it lightweight<br><br>During **manufacturing** or **disposal** of these products, ODSs can be released into the atmosphere |
| Pesticides | Some pesticides, e.g. those containing methyl bromide, have been used in agricultural practices for soil fumigation<br><br>When applied, these substances can **vaporise** and enter the atmosphere, where they can contribute to ozone depletion |
| Flame retardants | Some flame retardants contain halogen atoms and have been used in various products to reduce their flammability<br><br>When these products **degrade** or are **disposed** of, the halogenated compounds can be released into the atmosphere |

| | |
|---|---|
| Refrigerants | ODSs were widely used as refrigerants in cooling systems, such as air conditioners and refrigerators<br>The most well-known examples are **CFCs**<br>When these refrigerants **leak** or are **improperly disposed** of, they can reach the stratosphere and contribute to ozone depletion |

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## Imbalance in equilibrium

- When ozone formation and destruction rates are **unequal**, equilibrium is **disrupted**
  - This leads to increased ozone depletion
  - Increased **UVB** radiation reaches the Earth's surface
  - Affects **ecosystems** and **human health**
  - Causes increased rates of skin cancer and cataracts
  - Reduces terrestrial and marine productivity

# Ozone holes

- Ozone depletion affects the entire Earth's stratosphere
  - However, **ozone holes** are most prominent at the poles
  - Ozone holes are areas of **low stratospheric ozone**
  - These holes appear every spring due to ODSs and seasonal weather patterns

### Examiner Tips and Tricks

The use of chemical symbols, formulae or equations for the equilibrium of ozone is not required, so you do not need to learn the chemical equations relating to the formation and destruction of ozone.

## The Montreal Protocol

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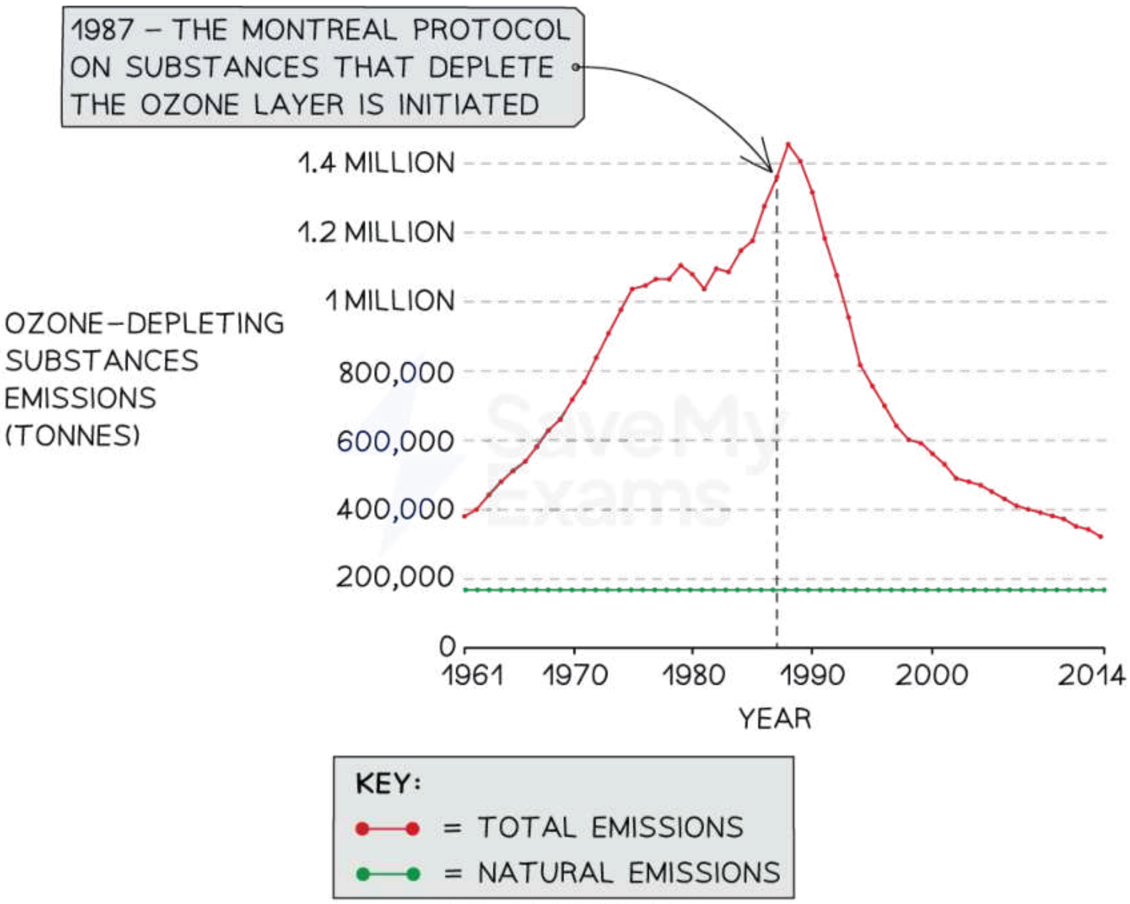
# The Montreal Protocol

## The role of UNEP

- The United Nations Environment Programme (UNEP) has played a critical role in the **protection** of the **stratospheric ozone layer**
  - This have been achieved through its efforts in providing information and creating **international agreements**:
- UNEP has been instrumental in raising awareness about:
  - The fact that the ozone layer was being rapidly depleted
  - The causes of this depletion
  - The associated environmental and health impacts of this depletion
    - Through research and sharing of information, UNEP has helped educate governments, industries and the public about the importance of **ozone layer protection**
    - UNEP has been actively involved in the creation of international agreements aimed at **reducing** the use of **ozone-depleting substances** (ODSs)

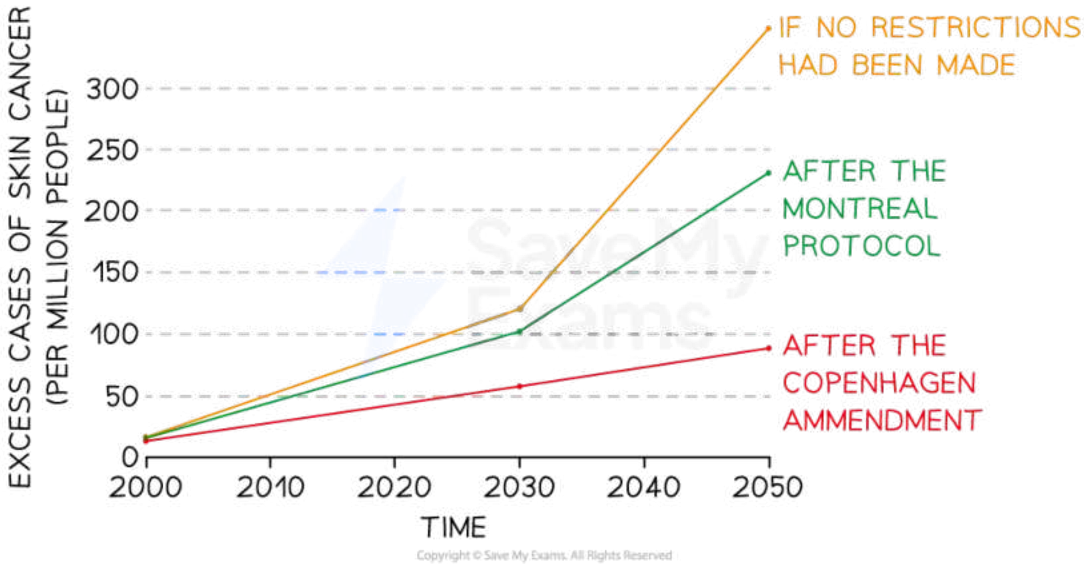





***The Montreal Protocol on Substances that Deplete the Ozone Layer, initiated in 1987, played a crucial role in reducing the production, use and emissions of ozone-depleting substances (natural sources of halogen gases that deplete stratospheric ozone include biological activity in terrestrial and aquatic ecosystems)***

- The **Montreal Protocol on Substances that Deplete the Ozone Layer** was initiated in 1987
  - It was started under the guidance of UNEP
  - It is a landmark international agreement that regulates the production, trade and use of chlorofluorocarbons (CFCs) and other ODSs.
    - 24 countries initially signed the initial protocol, and the total now stands at **197 countries**
    - It has been updated and strengthened (a later amendment at a summit in Copenhagen in 1992 tightened restrictions further)

- It has resulted in emissions of ODSs **falling rapidly** from around 1.5 million tonnes in 1987 to around 400 000 tonnes in 2010
- UNEP hopes to end production of all HCFCs by 2040




***The effects of CFC reduction on predicted skin cancer rates in Northwest Europe***

- The **illegal market** for ozone-depleting substances is a significant challenge to the effectiveness of ozone protection efforts:
  - UNEP recognises the need for consistent **monitoring** and **enforcement** to tackle this issue
  - By collaborating with national authorities, customs agencies and other relevant stakeholders, UNEP works towards:
    - Stopping the illegal trade of ozone-depleting substances
    - Ensuring **compliance with international regulations**
- **Phased reductions:**
  - Gradual reduction schedules for ODSs have allowed industries to adapt
  - The Montreal Protocol provided time for the development and adoption of alternatives to ODSs
- **National governments** play an important role in implementing the agreements made by the UNEP:
  - In response to the Montreal Protocol, governments have enacted **national laws** and **regulations** to decrease the consumption and production of halogenated organic gases, such as chlorofluorocarbons (CFCs)

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- These laws help enforce the reduction targets and promote the **transition** to **ozone-friendly alternatives**
- The collective efforts of UNEP, governments, industries and other stakeholders are vital in achieving goals, including:
  - Ozone layer protection
  - Mitigating the illegal trade of ozone-depleting substances
  - Encouraging global cooperation for a more sustainable future

## Planetary boundary for stratospheric ozone depletion

- Stratospheric ozone depletion is one of the nine planetary boundaries outlined by the planetary boundaries model
  - Planetary boundaries are **thresholds** that lead to significant environmental changes if they are crossed
- The Montreal Protocol is regarded as the most successful example yet of international cooperation in management and intervention to resolve a significant environmental issue
  - Actions taken in response to the Montreal Protocol have prevented the planetary boundary for stratospheric ozone depletion being crossed
- **Evidence from data:**
  - Data shows a decrease in the size of ozone holes over time
  - Continuous monitoring indicates that ozone layer recovery is underway

### Examiner Tips and Tricks

Make sure you understand the key reasons for the Montreal Protocol's success (e.g. international cooperation, legally binding agreements, etc.) and that you are familiar with how the protocol has helped reverse stratospheric ozone depletion.

## Ozone Depletion (HL)

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# Ozone Depletion

- Ozone depletion refers to the gradual **thinning** of the ozone layer in the Earth's stratosphere
- This is due to human-made chemicals called ozone-depleting substances (**ODSs**)
  - These ODSs are released from products such as refrigerants, aerosols, and solvents
- One of the most well known groups of ODSs are **chlorofluorocarbons** (**CFCs**)

# How CFCs cause ozone depletion

- CFCs are stable compounds and do not readily degrade in the lower atmosphere (troposphere)
- As CFCs are released into the atmosphere, they gradually drift upward into the **stratosphere**
- CFCs **absorb UV** radiation in the stratosphere
- This causes them to break down, releasing chlorine radicals
- **Stage 1:**
  - A chlorine radical (Cl•) reacts with an ozone ($O_3$) molecule to form an oxygen ($O_2$) molecule and a chlorate radical (ClO•)

$$Cl\bullet + O_3 \rightarrow ClO\bullet + O_2$$

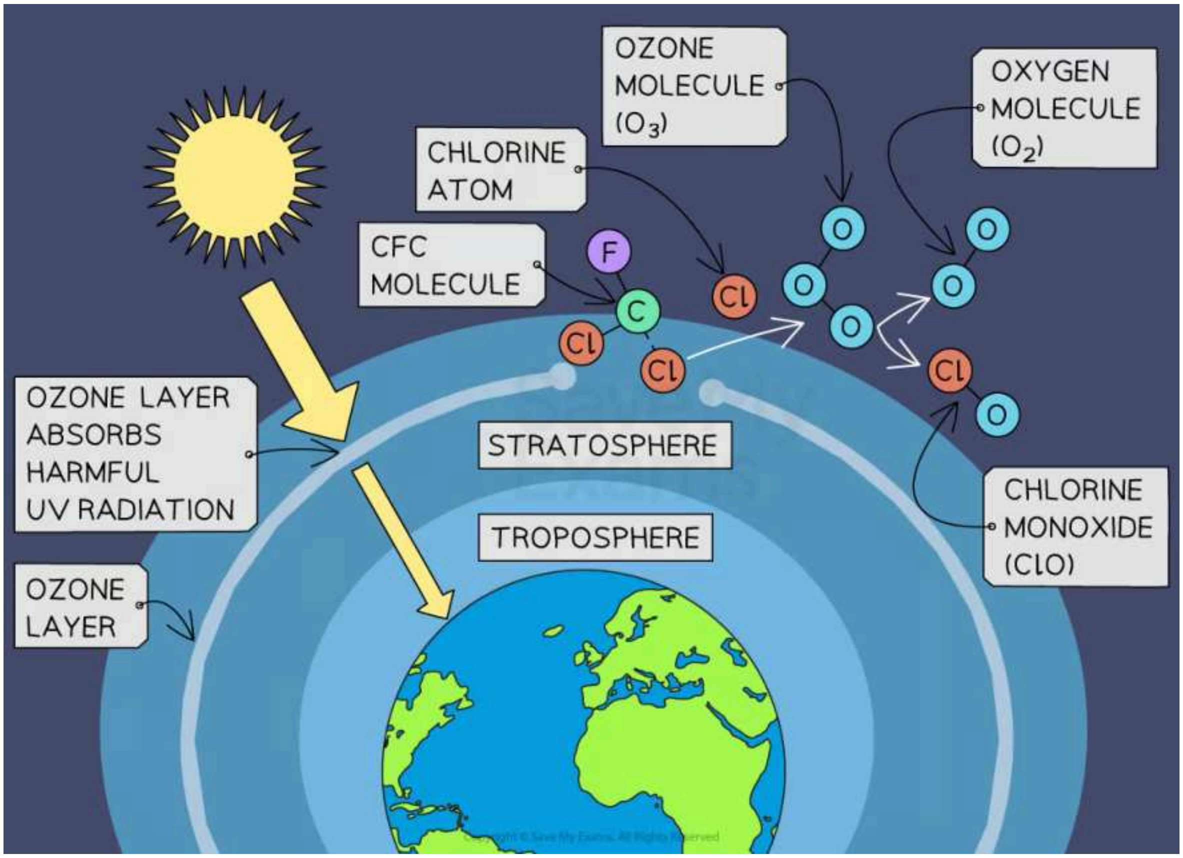
- **Stage 2:**
  - The chlorate radical then combines with another ozone molecule to produce another chlorine radical and two oxygen molecules

$$ClO\bullet + O_3 \rightarrow Cl\bullet + 2O_2$$

- **Overall reaction:**
  - Overall, as a result of these two stages, ozone is converted to oxygen

$$2O_3 \rightarrow 3O_2$$

- As long as chlorine radicals are present in the stratosphere, ozone molecules will be **continuously broken down** through this cycle of reactions
  - The chlorine radicals are **not used up** in these reactions (the act as catalysts)
  - As a result, a single chlorine radical can **destroy thousands of ozone molecules** before being removed from the stratosphere




*UV breakdown of CFCs results in the release of a chlorine atom (in the form of a chlorine radical) that catalyses the destruction of an ozone molecule*

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## Polar Stratospheric Ozone Depletion (HL)

# Polar Stratospheric Ozone Depletion

- Polar stratospheric ozone depletion mainly occurs during **spring** over the **poles**
- Causes of depletion include unique chemical and atmospheric conditions in the **polar stratosphere**
- This process leads to the thinning of the ozone layer, commonly referred to as the '**ozone hole'**
  - An ozone hole is most commonly observed over **Antarctica** during the Southern Hemisphere's spring (September to November)
  - This hole reached record sizes in the early 2000s, drawing attention to global ozone depletion
  - Although the Montreal Protocol reduced CFC emissions, the Antarctic ozone hole persists and is monitored yearly

# Key chemical and atmospheric conditions

## Polar Stratospheric Clouds (PSCs)

- Extremely low temperatures in the polar stratosphere (particularly in the Antarctic) during winter create conditions that favour the formation of **polar stratospheric clouds** (PSCs)
  - The clouds provide "active surfaces" where chlorine compounds are converted into forms that can destroy ozone
  - When **sunlight** returns in **spring**, **UV radiation breaks down chlorine-containing compounds** on the surface of PSCs
  - This releases chlorine radicals that rapidly deplete ozone
  - The presence of PSCs amplifies ozone depletion within the **polar vortex**

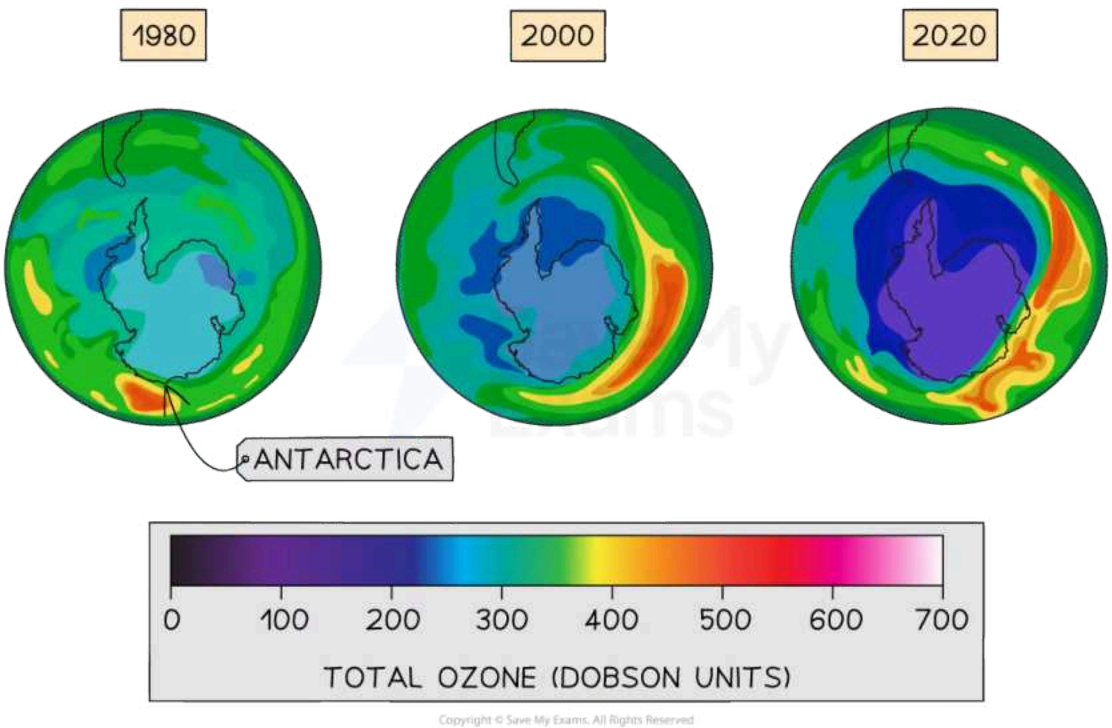
## Polar vortex

- The polar vortex is a persistent, large-scale circulation pattern that forms over the polar regions during winter
  - This vortex isolates the air within it
  - This prevents exchange with air from lower latitudes
  - This traps ozone-depleting substances within the vortex, increasing their concentration
- The **Antarctic** polar vortex is **stronger** and **more stable** than the Arctic vortex due to geographic and temperature differences

- This leads to more severe ozone depletion in Antarctica

## Volcanic aerosols

- Volcanic eruptions release **aerosols** that reach the stratosphere and **enhance ozone depletion**
  - These aerosols contribute **additional surfaces** for **ozone-destroying reactions**
  - Their effect is **amplified** in polar regions due to :
    - The presence of PSCs
    - The isolated polar vortex




*Ozone depletion is particularly pronounced over Antarctica*

### Examiner Tips and Tricks

Remember, an 'ozone hole' is **not** a literal hole in the atmosphere. It is an area where ozone is **much less concentrated,** i.e. the concentration of ozone has fallen below a certain level. This means

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harmful UV radiation can reach the Earth's surface more easily in these areas, as there is less protective ozone to block these UV rays.

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## Chlorofluorocarbons & Hydrofluorocarbons (HL)

# Chlorofluorocarbons & Hydrofluorocarbons

## Overview of HCFCs

- **What are CFCs?**
  - Chlorofluorocarbons (CFCs) are chemical compounds containing **chlorine**, **fluorine**, and **carbon**
  - They were commonly used in the 20th century in products like **aerosols**, **refrigerators**, and **air conditioning systems**
- **Impact of CFCs:**
  - CFCs release **chlorine radicals** in the stratosphere, which deplete the ozone layer
  - Ozone depletion increases harmful ultraviolet (UV) radiation reaching the Earth's surface
- **Regulation:**
  - The **Montreal Protocol (1987)** banned CFCs globally due to their harmful environmental effects
  - **Alternative chemicals**, including **HFCs**, have largely **phased out** ODSs like CFCs

## Overview of HFCs

- **What are HFCs?**
  - Hydrofluorocarbons (HFCs) are chemical compounds containing **hydrogen**, **fluorine**, and **carbon**
  - They were introduced as **replacements for CFCs** because they **do not deplete ozone significantly**
- **Impact of HFCs:**
  - Although less harmful to the ozone, HFCs are **potent greenhouse gases** (GHGs)
  - They have a **high global warming potential** (GWP)
  - HFC emissions contribute to climate change by trapping heat in the atmosphere
- **Regulation:**
  - The **Kigali Amendment (2016)** to the Montreal Protocol set targets to **reduce the production and consumption of HFCs globally**
  - Developed and developing countries have agreed to phase down HFCs gradually

# Air Conditioning

- Air conditioning regulates indoor temperature and humidity to improve comfort
- It is widely used in homes, workplaces, vehicles, and public buildings
- **Environmental impacts:**
  - Air conditioning is **energy-intensive**, increasing electricity consumption
  - It contributes to greenhouse gas (GHG) emissions through:
    - Fossil fuels used in electricity generation
    - Leakage of refrigerants, some of which are potent GHGs
  - Traditional air conditioning units used ozone-depleting substances (ODSs) like **CFCs**

## Refrigerants in air conditioning

- **ODSs:**
  - **CFCs and HCFCs:**
    - CFCs and HCFCs caused ozone depletion
  - **HFCs:**
    - Introduced as alternatives with low ozone depletion potential but high **global warming potential (GWP)**
    - Their use is now being phased down under the Kigali Amendment
- **New refrigerants:**
  - **Hydrofluoroolefins** (**HFOs**) have **lower GWP** and are being increasingly adopted in air conditioning systems
  - Natural refrigerants, like ammonia and carbon dioxide, are also being explored

## Alternatives to air conditioning

### Improved building design

- Incorporating natural ventilation, insulation, and reflective materials into buildings can stop them getting too hot
- **Cool roofs** reflect sunlight, reducing indoor heat absorption
  - Materials used:
    - Cool roofs can be made using reflective paint, tiles, or shingles designed to reflect sunlight

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- How they work:
  - They are usually lighter in colour or use materials that reflect solar radiation effectively
- Benefits:
  - Reduces urban heat island effect
  - Improves indoor comfort in warm climates
  - Reduces need for air conditioning, lowering energy consumption and related emissions
- **Window shading** or **double glazing** can be used to minimise solar heat gain

## Urban greening

- Urban greening refers to the process of incorporating vegetation, trees, parks, and green spaces into urban environments
- It is a sustainable approach to improving city landscapes and mitigating the effects of urbanisation and climate change
- **How it works**:
  - Trees, shrubs, and green spaces cool the air through shade and evapotranspiration (release of water from plants)
  - Vegetation absorbs carbon dioxide and reduces air pollution, improving air quality
  - Green roofs and walls add greenery to buildings, improving insulation and reducing heat absorption
- **Benefits**:
  - Lowers urban temperatures and combats the urban heat island effect
  - Reduces need for air conditioning in densely urbanised areas

## Passive cooling

- Passive cooling involves architectural and design strategies that naturally reduce indoor temperatures without using energy-intensive cooling systems like air conditioning
- It is a sustainable way to create comfortable indoor climates
- **How it works**:
  - Utilises shading, ventilation, and thermal insulation to minimise heat gain and maximise heat loss
  - Structures are designed to capture natural breezes or block direct sunlight
- **Key techniques**:

- **Shading**: overhangs, awnings, and trees block direct sunlight from entering buildings
- **Ventilation**: windows, vents, or courtyards are designed to enhance airflow
- **Reflective materials**: roofs and walls use reflective coatings to reduce heat absorption
- **Thermal mass**: materials like concrete or stone store and release heat slowly, moderating temperature fluctuations
- **Green roofs**: plant-covered roofs provide natural cooling by insulating buildings and reducing heat absorption

- **Benefits**:
  - Reduces reliance on artificial cooling systems, cutting energy consumption and costs
  - Minimises greenhouse gas emissions associated with air conditioning

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