DP IB Environmental Systems & Societies (ESS): HL

Your notes

8.3 Urban Air Pollution

Contents

Causes of Urban Air Pollution

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Causes of Urban Air Pollution

What is urban air pollution?

- Human activities that release harmful substances into the atmosphere cause urban air pollution
  - Pollutants in the air can come from many sources and impact both human health and the environment
- Common pollutants include:
  - **Nitrogen oxides (NOx)**
  - **Sulphur dioxide (SO_2)**
  - **Carbon monoxide (CO)**
  - **Particulate matter (PM)**
    - Particulate matter refers to tiny solid particles or liquid droplets in the air
    - These particles can come from dust, soot, smoke, and vehicle emissions
- Particulate matter can be classified by size:
  - **PM2.5**: fine particles with a diameter of 2.5 micrometres or smaller
  - **PM10**: larger particles with a diameter of 10 micrometres or smaller

Primary pollutants

- Primary pollutants are harmful substances that are:
  - **Directly emitted from a source**
  - **Immediately active** in the atmosphere
- They enter the air through various activities like burning fossil fuels, industrial processes, or natural events such as volcanic eruptions

Sources of primary pollutants

- **Natural sources**:
  - Some air pollutants come from **natural events** that occur without human involvement
    - **Forest fires**: release smoke, ash, and particulate matter into the air

    - **Dust storms**: strong winds lift dust from dry areas, which spreads to cities
    - **Volcanic eruptions**: these produce large amounts of SO_2 and ash
- **Anthropogenic (human-made) sources**:
  - Many pollutants in urban areas come from **human activities**, especially those involving the burning of fuels
    - **Burning fossil fuels**: emissions from vehicles, power plants, and factories produce NOx, SO_2, CO, and PM
    - **Agricultural burning and deforestation**: these release large quantities of smoke, dust, and other pollutants into the atmosphere
    - **Construction sites and roads**: create dust and PM from the movement of machinery and vehicles
    - **Industrial processes**: factories release pollutants like NOx and PM from smokestacks and chemical processing

Common pollutants from urban activities

- The most common pollutants in urban areas are usually linked to the **combustion of fossil fuels**
  - Particulate matter (**PM2.5 and PM10**): tiny particles from exhaust fumes, industrial activities, and construction dust
  - **CO**: released by cars and industrial processes that burn fuels
  - **NOx**: produced by vehicle emissions and power plants
  - **SO_2**: released mainly by burning coal and oil

Secondary pollutants

- Secondary pollutants are **not emitted directly** but **form in the atmosphere** when primary pollutants react with other chemicals
  - **Tropospheric ozone (O_3)**: forms when nitrogen oxides (NOx) react with sunlight
    - It is a major component of urban smog

Examples of urban air pollution

- **Beijing, China**: often experiences high levels of **PM2.5**, mainly due to coal burning for energy and industrial activity
- **Los Angeles, USA**: struggles with **ozone pollution** due to a high number of vehicles and sunny weather, which speeds up the reaction that forms ozone

- The burning of crops, industrial activity, and vehicle emissions frequently cause severe **air pollution** in **New Delhi, India**

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Air Pollution Management Strategies

Air Pollution Management Strategies

- Air pollution management strategies are designed to **reduce harmful emissions** and **improve air quality** in **urban areas**
- These strategies focus on:
  - **Reducing** the sources of pollution
  - **Promoting** cleaner technologies
  - **Encouraging** sustainable urban living

Reducing the use of fossil fuels

- One of the most effective ways to manage urban air pollution is to reduce the **reliance** on fossil fuels
- This includes:
  - Promoting the use of **renewable energy sources** like wind, solar, and hydro to power cities
  - **Improving public transport** systems in cities to reduce car usage, e.g.
    - Electric buses
    - Efficient metro systems
  - Creating infrastructure for **cycling,** e.g.
    - More cycle lanes
    - Cycle-hire schemes
  - Pedestrianising city centres

Emission zones and car restrictions

- Emission zones are areas where only vehicles meeting certain **environmental standards** are allowed to enter
  - **Low Emission Zones** (LEZs) restrict high-polluting vehicles, reducing air pollution in the city centre
  - For example, **London** has an Ultra Low Emission Zone (ULEZ) where only vehicles meeting strict emission standards can drive
- Some cities also restrict car use on certain days or at peak times to decrease congestion and emissions

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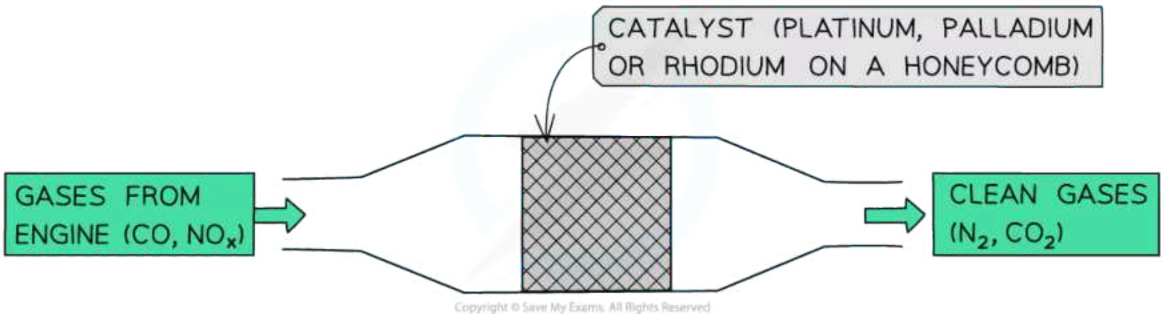
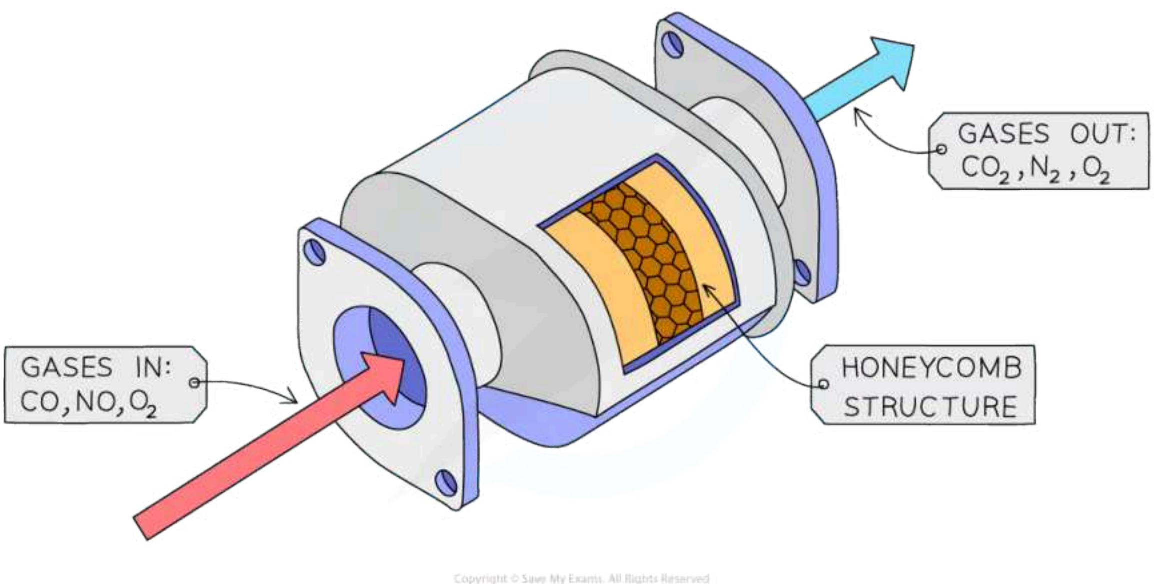
Catalytic converters

- Catalytic converters are devices fitted to car exhaust systems that **reduce harmful emissions**
  - They contain catalysts that speed up chemical reactions to convert pollutants like nitrogen oxides and carbon monoxide into less harmful gases such as nitrogen and carbon dioxide
  - In many countries, it is **compulsory** for vehicles to have catalytic converters





Catalytic converters are designed to reduce the polluting gases produced in car exhausts

Growing trees and natural screens

- Trees and green spaces play an important role in **filtering pollutants** from the air
- Trees can reduce air pollution and improve air quality by:
  - Absorbing carbon dioxide
  - Trapping particulate matter
- **Natural screens** such as hedges, tree lines and green walls can also help reduce pollutants near roads and buildings

Green walls and green roofs

- Green walls and green roofs are covered with vegetation and can improve air quality by filtering pollutants
  - They also help regulate temperature, reducing the urban heat island effect

Examiner Tips and Tricks

Remember that some strategies reduce pollution at the **source** (e.g. reducing fossil fuel use), whereas others aim to manage the **effects** (e.g. planting trees). Although the first type is preferable, it is not possible for cities to remove **all** sources of air pollution, so a combined approach is required.

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Acid Rain

Acid Rain Formation

- Acid rain refers rainfall that has a pH lower than normal rainwater
  - Regular rain has a pH between 5 and 5.5, meaning it is naturally slightly acidic
  - Acid rain is more acidic, has a pH lower than 5, and is frequently the result of human activity

Chemical reactions leading to acid rain

- **Nitrogen oxides (NOx)** and **sulphur dioxide (SO_2)** are the main gases responsible for acid rain
  - These gases react with water and oxygen in the atmosphere to form nitric acid and sulfuric acid

Formation of nitric acid

- Nitrogen oxides are mainly produced from **vehicle exhausts**
- The reactions are as follows:
  - Nitrogen monoxide (NO) reacts with oxygen (O_2) to form nitrogen dioxide (NO_2)

$$2NO + O_2 \rightarrow 2NO_2$$

- The nitrogen dioxide then reacts with water (H_2O) and oxygen in the air to produce nitric acid (HNO_3)

$$4NO_2 + O_2 + 2H_2O \rightarrow 4HNO_3$$

Formation of sulphuric acid

- Sulphur dioxide is produced by **burning fossil fuels** and reacts with water in the atmosphere
- The reactions are as follows:
  - Sulphur dioxide (SO2) dissolves in rainwater, producing sulphurous acid (H_2SO_3)

$$SO_2 + H_2O \rightarrow H_2SO_3$$

- The sulphurous acid is then oxidised by oxygen in the air to produce sulfuric acid (H_2SO_4)

$$2H_2SO_3 + O_2 \rightarrow 2H_2SO_4$$

Types of deposition

- **Wet deposition** refers to acidic precipitation falling to Earth in the form of **rain**, **snow**, **or fog**

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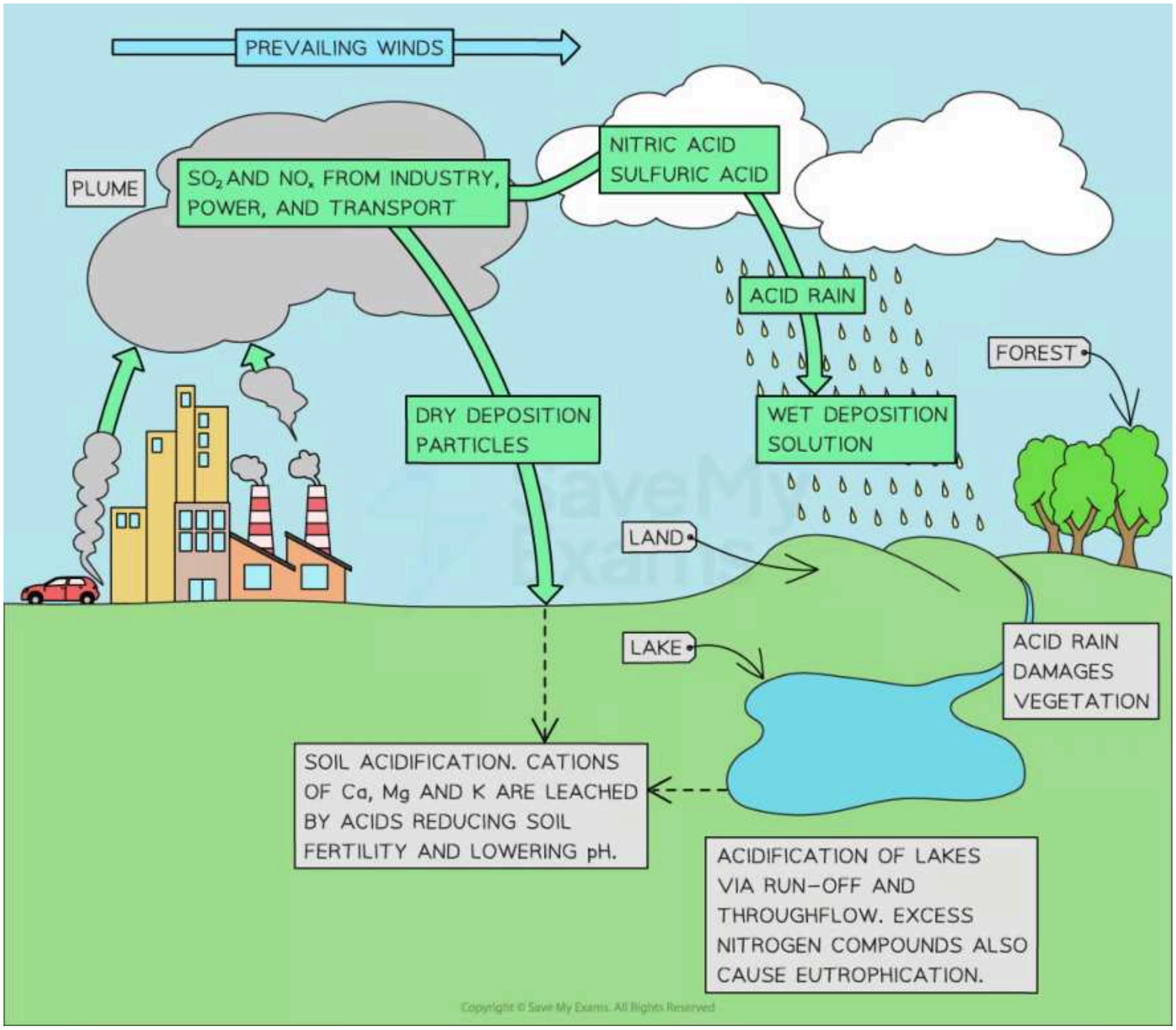
- Sulphuric acid and nitric acid can also combine with ash and other particles present in the air, forming **dry particles** (i.e. acidic dust and gases)
  - **Dry deposition** occurs when these particles settle on surfaces, including vegetation, buildings, cars and soil



Causes of acid deposition

Acid Rain Impacts

Impacts on ecology

Impacts on terrestrial habitats

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- Acidic deposition from acid rain accelerates the **leaching** of essential **nutrients** from soil, such as calcium, magnesium and potassium
  - Leaching of these nutrients reduces their availability for plants
  - This leads to **nutrient deficiencies**
  - This reduces plant growth and overall ecosystem **productivity**
- Acidic rain can **increase soil toxicity**
  - This can occur by **mobilising** harmful metals like aluminium
  - This damages plant roots and affects their ability to absorb water and nutrients
- Acid rain causes **direct damage to foliage**
  - This weakens trees, making them more vulnerable to disease and harsh weather
- Coniferous forests, e.g. forests of pine or spruce trees, are sensitive to acid rain
  - This is due to their shallow root systems and thin bark
  - Acid rain also damages their foliage and **inhibits nutrient absorption**

Acid rain directly affects plants by damaging the leaves and roots

Impacts on freshwater habitats

- Acid rain can make water bodies more acidic
- This is due to a process referred to as **solubilisation of aluminium**
  - Acid rain causes aluminium, which is normally bound in the soil, to dissolve
  - This allows the aluminium to enter nearby water bodies
- This aluminium is **toxic to aquatic life**, such as fish and freshwater invertebrates
  - Fish gills can become coated with aluminium
    - This makes it harder for them to breathe
  - Some invertebrates with **exoskeletons** may have difficulty maintaining their protective shells
    - They rely on calcium to build and maintain their hard outer shells
    - When acid rain increases the acidity of water, it reduces the availability of calcium and other minerals that these organisms need
    - This makes it harder for them to properly develop or maintain their exoskeletons

Impacts on buildings and infrastructure

Corrosion of construction materials

- Acid rain erodes materials like **marble, limestone, steel, and paint** used in buildings and monuments
- Marble and limestone both contain calcium carbonate ($CaCO_3$)
- The calcium carbonate reacts with sulphuric acid or nitric acid, causing stonework to corrode and weaken
  - For example, the **Taj Mahal** in India, made of marble, has shown signs of erosion and discolouration due to acid rain
  - Acid rain has also had an impact on historical statues and structures, such as those in Rome and Greece

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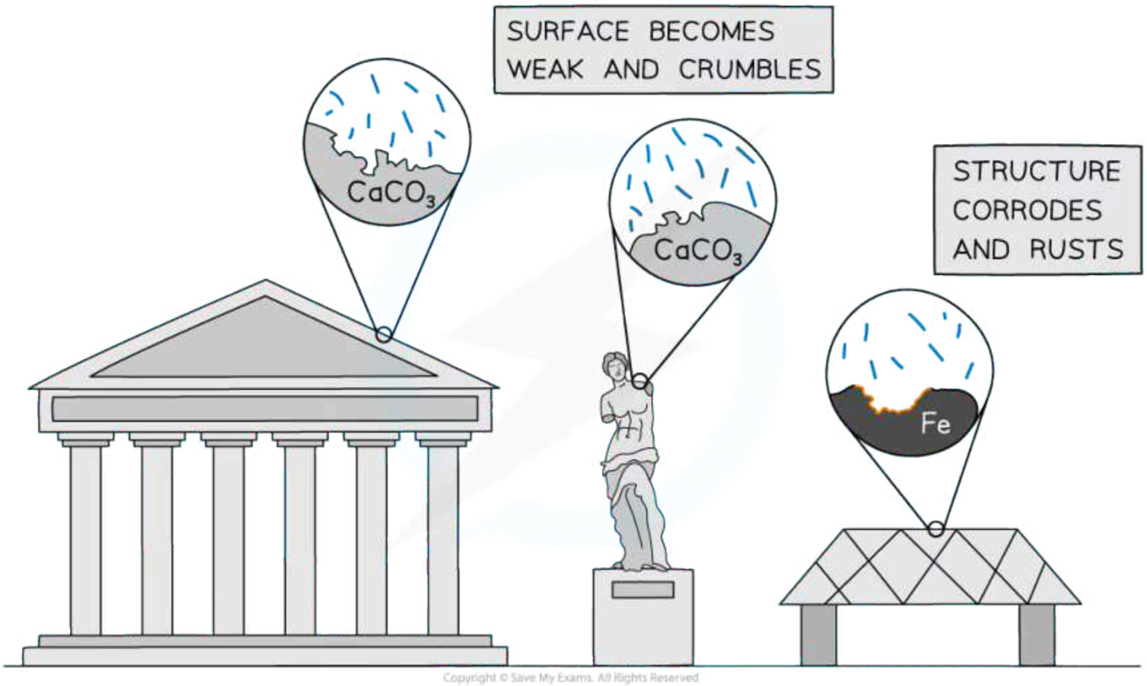


The impact of acid rain can be seen on buildings, statues and metallic structures, particularly in polluted cities

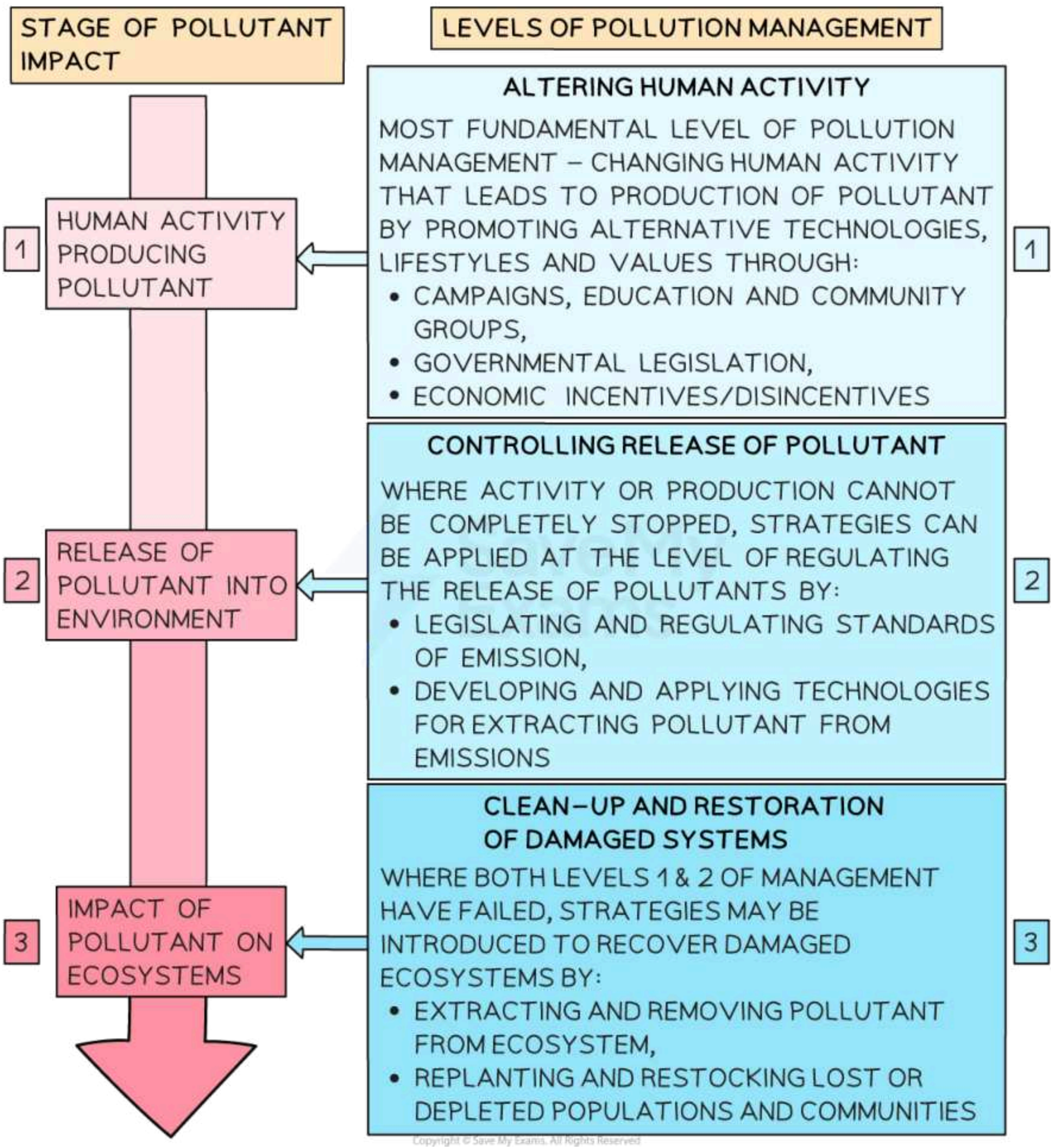
Impacts on human health

Respiratory issues

- Acid rain does not **directly** harm humans
- However, **nitrate** and **sulphate particles** from acid rain can cause **respiratory problems**
  - **PM2.5 particles** (tiny air pollutants) from acid rain can enter the lungs
  - This leads to:
    - Tissue damage
    - Lung inflammation
    - An increased risk of conditions such as asthma and bronchitis
  - As a result, areas with heavy industrial activity, such as parts of China and Eastern Europe, experience greater respiratory health risks

Acid Rain Management Strategies

- There are three main levels of pollution management strategies:
    1. Changing human activity
    2. Regulating and reducing quantities of pollutants released at the point of emission
    3. Cleaning up the pollutants and restoring the ecosystem after pollution has occurred



The main strategies for managing the impacts of pollution

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- These levels can also be applied to acid rain management strategies
  - Acid rain requires effective pollution management strategies to mitigate its harmful effects on the environment and human health

1. Altering human activity

- Reducing the consumption of fossil fuels is a key strategy to minimise acid rain
  - Encourage the use of alternative energy sources, such as **renewable energy**, can significantly reduce emissions of sulphur dioxide and nitrogen oxides
- International agreements and national governments play a vital role in:
  - Promoting sustainable practices
  - Supporting the development of clean technologies
  - Lobbying for emissions reductions

2. Regulating and monitoring pollutant release

- Government regulations and **monitoring systems** are essential to **control** and **reduce** the release of pollutants that contribute to acid rain
  - Coal-burning power plants and vehicles are major sources of sulphur dioxide and nitrogen oxide emissions
  - Installing pollution control devices such as **scrubbers** and **catalytic converters** can effectively remove these pollutants from emissions

3. Clean-up and restoration measures

- In areas heavily affected by acid rain, certain strategies may be used to mitigate the damage caused
  - For example, **spreading ground limestone** or **lime** in acidified lakes and rivers can **neutralise acidity** and restore the water's pH balance
- Restoring damaged ecosystems can also be achieved through re-colonisation efforts, such as **planting acid-tolerant vegetation**
  - This can help restore ecological balance to these damaged ecosystems

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Photochemical Smog (HL)

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Formation of Photochemical Smog

What is photochemical smog?

- Photochemical smog is a type of air pollution formed when **sunlight** triggers **chemical reactions** between **primary pollutants**
  - These reactions produce **secondary pollutants**
- It is often seen as a **brown** or **grey haze** over urban areas

Primary pollutants

- **Nitrogen oxides** (NOx):
  - Released from combustion of fossil fuels, such as in vehicles and power plants
  - Includes nitrogen dioxide (NO_2) and nitric oxide (NO)
  - Reacts in sunlight to form secondary pollutants like **tropospheric ozone**
- **Volatile organic compounds** (VOCs):
  - Emitted from vehicle exhausts, industrial processes, and chemical solvents
  - Includes hydrocarbons like benzene and methane
  - These can form secondary pollutants in the presence of sunlight

Secondary pollutants

- **Peroxyacyl nitrates** (PANs):
  - Formed from the reaction of VOCs and NOx under sunlight
  - Irritate eyes and respiratory systems
  - Harm plants by reducing growth and photosynthesis
- **Tropospheric ozone** (O_3):
  - Created when NOx reacts with oxygen in sunlight
  - A major component of photochemical smog
  - Causes respiratory problems and damages crops

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Primary pollutants from car exhaust fumes can turn into secondary pollutants (photo by Matt Boitor on Unsplash)

Factors Intensifying Smog Formation

- Photochemical smog formation is affected by meteorological and topographical factors

Meteorological factors

Abundant insolation (high sunlight levels)

- Strong sunlight leads to photochemical reactions between pollutants like nitrogen oxides (NOx) and volatile organic compounds (VOCs)
    - Long sunny days increase smog intensity
    - E.g. cities in warm climates, such as Los Angeles and New Delhi, experience severe smog due to high levels of insolation

Reduced wind

- Stagnant air **prevents dispersion** of pollutants

- This traps them near ground-level
- This allows pollutants to accumulate and react to **form smog**

Temperature inversion

- Occurs when a layer of warm air traps cooler air near the ground
  - Pollutants accumulate in the trapped cool air, leading to **high concentrations**
  - This typically occurs during winter nights or early mornings
- **How temperature inversion occurs**:
  - During the **day**:
    - The ground heats up, warming the air above
    - Warm air rises, allowing pollutants to disperse
  - During the **night**:
    - The ground cools rapidly, cooling the air near the surface
    - A layer of warm air above traps the cooler air and pollutants
  - Inversions are more likely in **valleys** or areas with **minimal wind**

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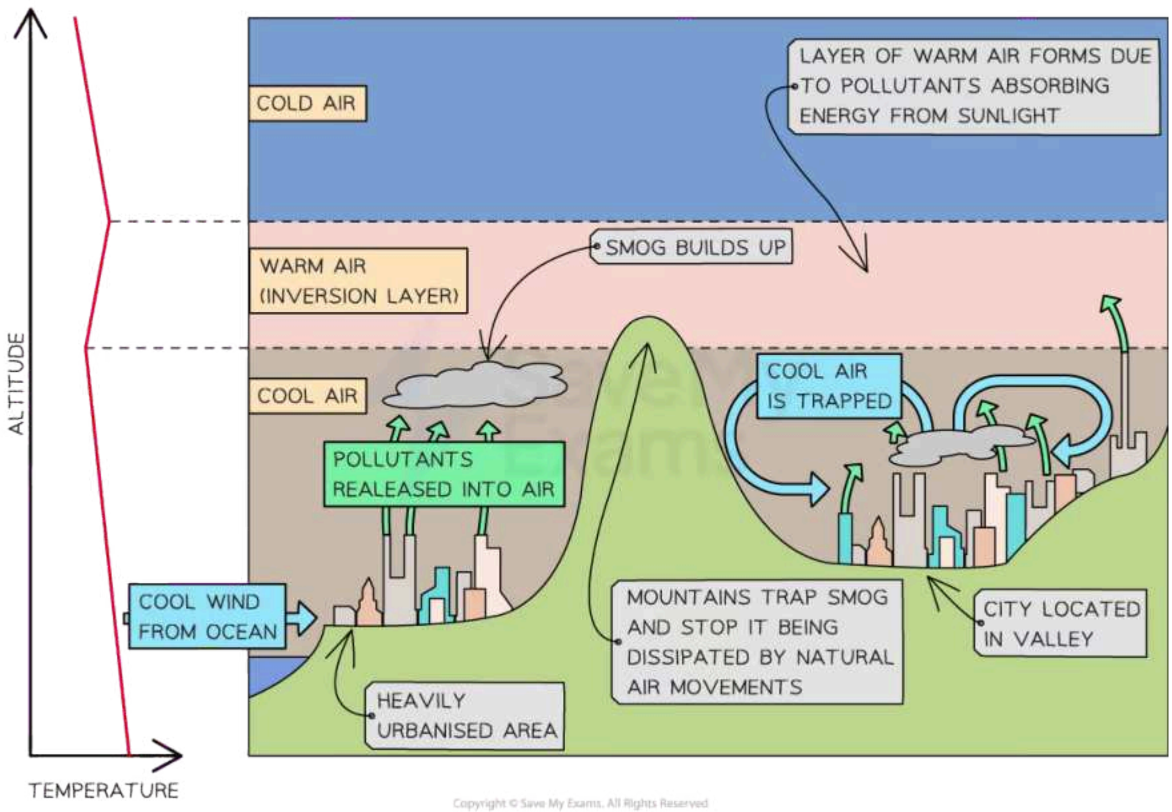

Thermal inversions can cause a serious build up of smog in urban areas that are located in basins and valleys

Topographical factors

Mountainous terrain

- Cities surrounded by mountains (e.g. Mexico City) are prone to smog formation
  - Mountains **block wind**, trapping pollutants in the valley

Urban infrastructure

- High-rise buildings can create "urban canyons"
  - These **restrict air movement**, reducing pollutant dispersal
  - E.g. Hong Kong experiences smog intensified by dense urban development

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Only the highest city buildings protrude above this smog, which has been trapped in the cooler air near ground-level by a layer of warm air above the city (photo by Mikel Letona on Unsplash)

Tropospheric Ozone Impacts (HL)

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Direct Impacts of Tropospheric Ozone

Biological effects

- **Damage to plant cuticles and membranes:**
  - Tropospheric ozone damages the outer layer (cuticle) of plant leaves
  - It disrupts cellular membranes, affecting nutrient and water balance
  - Leads to **reduced photosynthesis** and **slower plant growth**
    - E.g. crops like wheat and soybeans show **reduced yields** in regions with high ozone levels
- **Eye irritation in humans and mammals:**
  - Causes **stinging** and **redness** in the eyes
  - Common in urban areas with high ozone concentrations during sunny periods
- **Respiratory illnesses in humans:**
  - Inhalation of tropospheric ozone **inflames** the **airways**
    - This causes coughing, throat irritation, and shortness of breath
    - This aggravates asthma, bronchitis, and other chronic respiratory diseases

Physical effects

- **Damage to fabrics:**
  - Ozone accelerates the **deterioration** of **natural fibres** like cotton and **synthetic fibres** like nylon
    - This reduces the lifespan of outdoor clothing and tents
- **Damage to rubber materials:**
  - Reacts with natural and synthetic rubbers, causing **cracking** and **brittleness**
  - Commonly affects tyres, seals, and gaskets in urban and industrial areas

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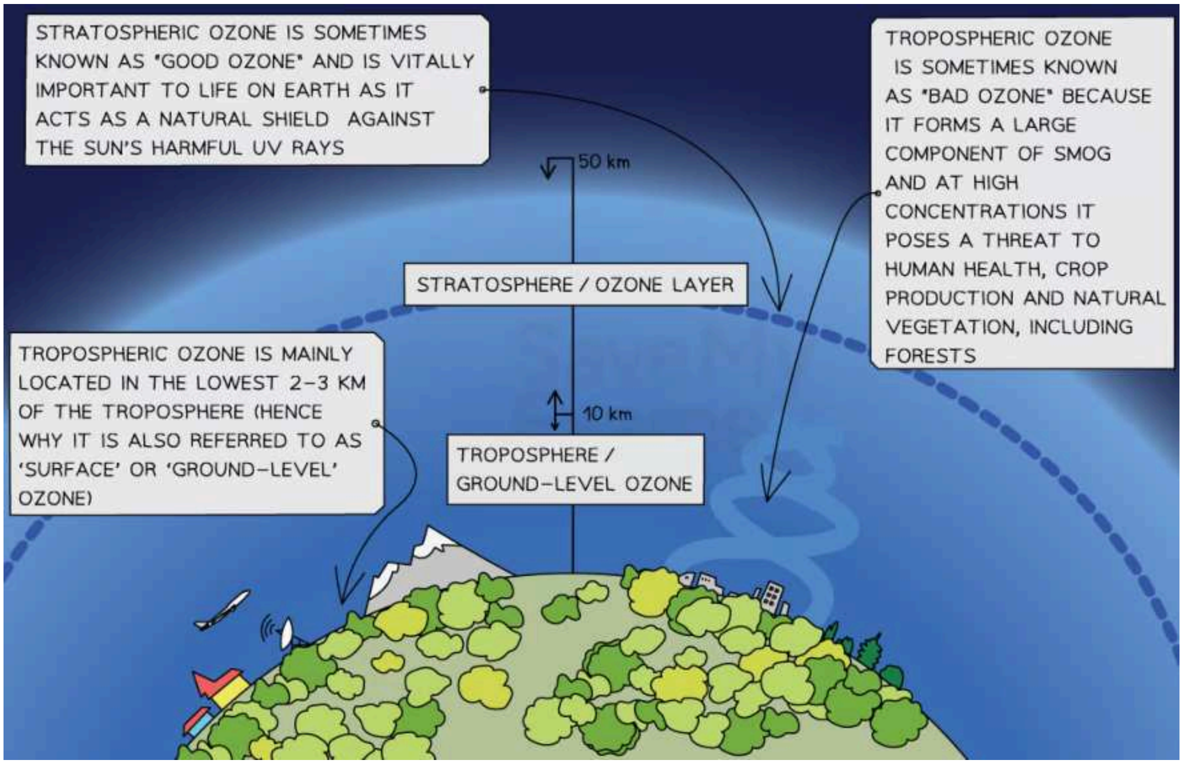

The difference between stratospheric and tropospheric ozone

- The impacts of tropospheric ozone extend beyond local areas, as it can be **transported** over long distances by **wind**
  - This makes it a **global environmental issue** with the potential for widespread damage to vegetation, human health and materials

Examiner Tips and Tricks

Don't get confused between the "good" ozone in the atmosphere (**stratospheric ozone**), which provides organisms with protection from harmful ultraviolet radiation, and the "bad" ground -level ozone (**tropospheric ozone**), which can negatively impact life on Earth at high concentrations.

Indirect Impacts of Tropospheric Ozone

Societal costs

- **Increased healthcare costs:**

- Tropospheric ozone exposure increases **respiratory** and **cardiovascular illnesses**
  - This leads to higher healthcare expenses
- Governments and families must spend more on **treatments** and **hospitalisations**
- **Strain on healthcare systems:**
  - Hospitals and clinics can become overwhelmed during **high-ozone periods**
    - This is due to a surge in patients with respiratory distress
    - E.g. in the United States, healthcare costs rise during **ozone peaks** in **summer**, particularly in cities like Los Angeles and Houston
  - Emergency services may face resource shortages during these times

Lost economic output

- **Reduced workforce productivity:**
  - Workers exposed to high ozone levels may experience health problems
    - This leads to **missed workdays**
  - Fatigue, breathing difficulties, and hospital visits **reduce overall productivity**
- **Crop losses:**
  - Ozone reduces agricultural yields
    - This impacts farmers' incomes and **increases food prices**
- **Cost of material damage:**
  - Repairing or replacing materials like rubber and fabrics degraded by ozone adds to economic costs
    - E.g. increases costs for industries that have to replace materials and equipment due to this problem

Different impacts on communities

- **Disproportionate effects on poorer communities:**
  - Poorer communities often live closer to **industrial areas** and **busy roads**, where ozone levels are highest
  - Limited access to healthcare worsens the health outcomes for these communities
- **Greater vulnerability to economic losses:**

- Poorer populations depend more on **physical labour**, which is directly affected by health problems caused by ozone
  - **Farmworkers** and **outdoor labourers** in polluted areas face the highest risks
- These factors widen social inequality and health outcomes between different groups in society

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