Atmospheric pollution

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Learning outcomes

Secondary pollutants

Acid rain

Smoke smog

Temperature inversions

Tropospheric ozone

Photochemical smog

Hydrocarbons

Carbon monoxide

Many atmospheric pollutants are secondary pollutants

- What are Secondary Pollutants?
- Occur when an original pollutant undergoes a physical or chemical change
  - synergistic reaction between primary pollutants and/or other substances e.g. ozone, sunlight, water

- Examples include:
  - Formation of acid rain; sulfur or nitric oxides dissolve in water
  - Formation of photochemical smog; Nitrogen dioxide (NO_2) + sunlight = Peroxyacetyl nitrates (PAN's)
  - Formation of tropospheric ozone: nitrogen oxides + oxygen + sunlight
  - All cause damage to human health, plants and animals

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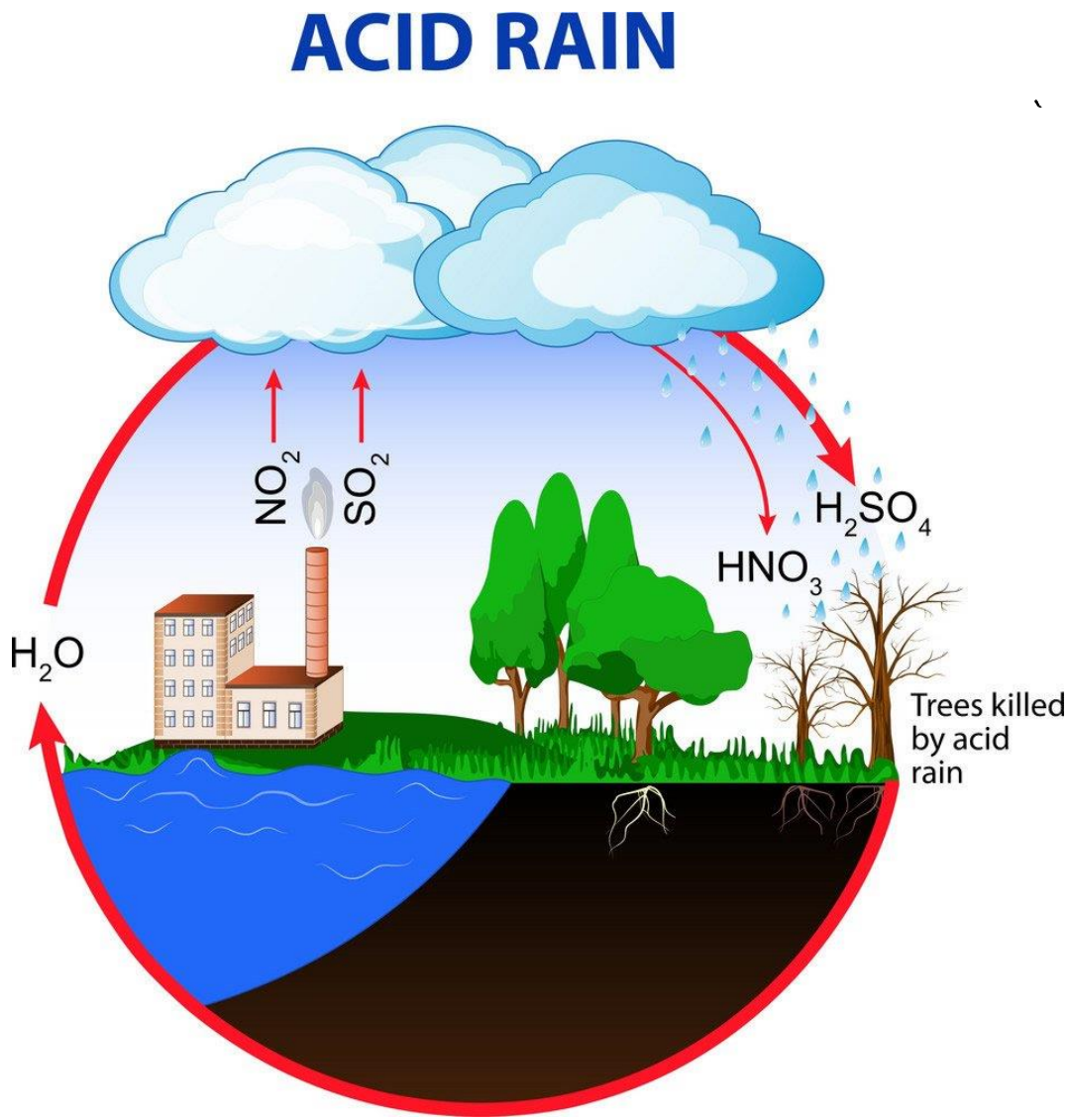
What is acid rain and how is it created?

Synergistic reaction with oxygen and water vapour



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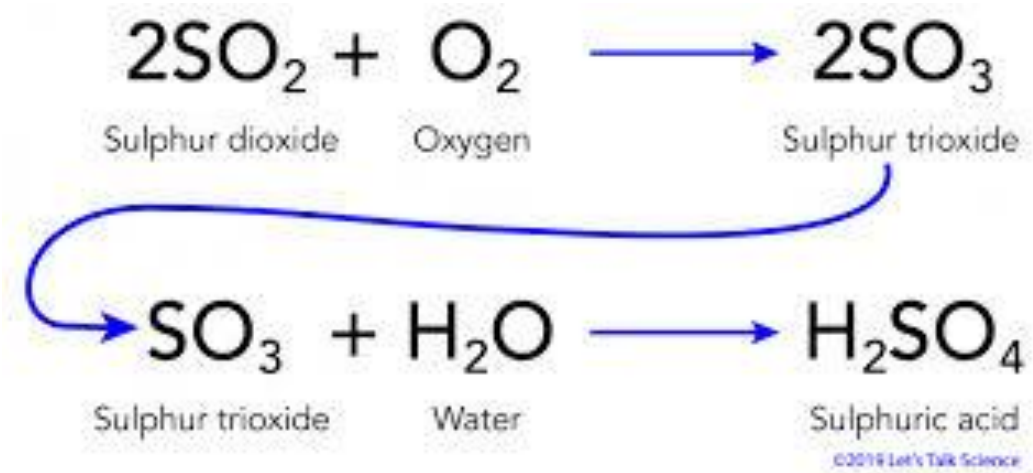
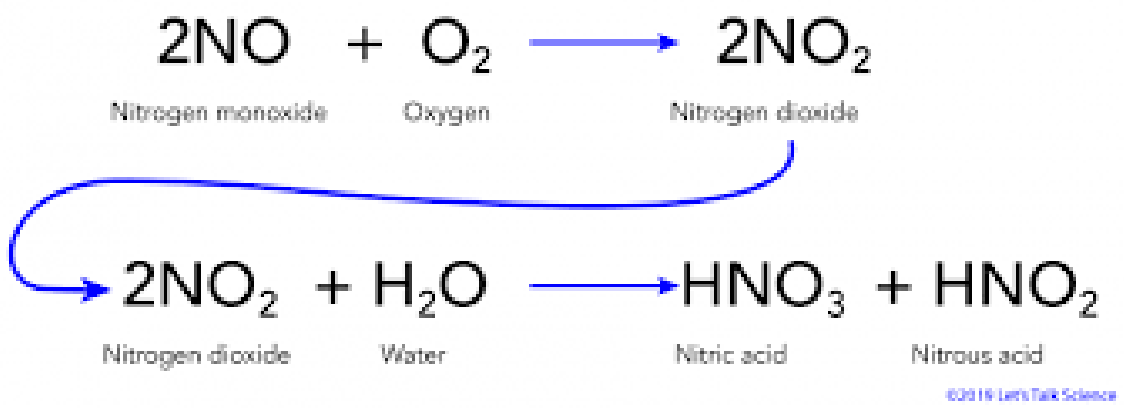
Acid rain equations





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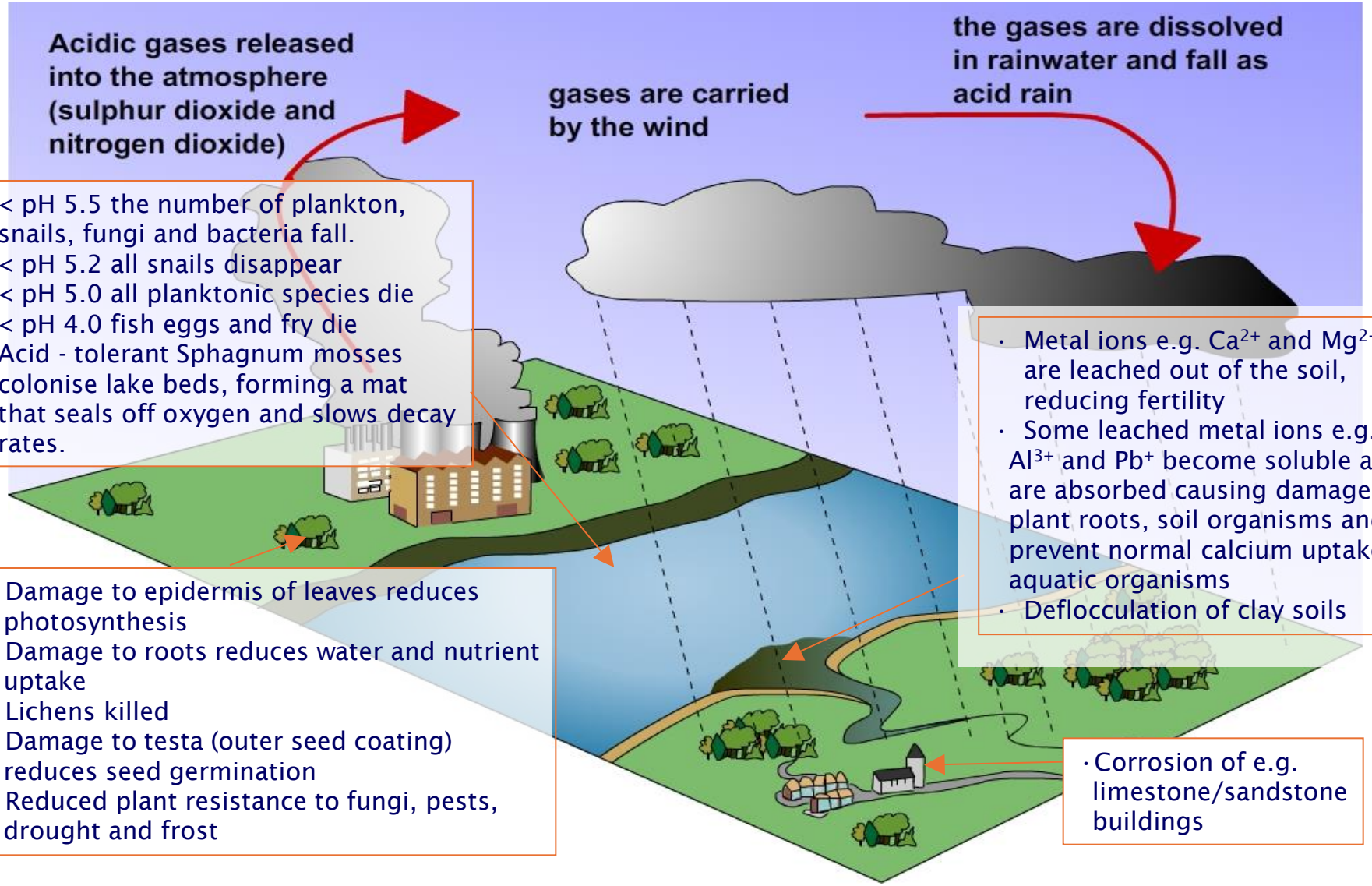
What are the effects of acid rain?



< pH 5.5 the number of plankton, snails, fungi and bacteria fall.
< pH 5.2 all snails disappear
< pH 5.0 all planktonic species die
< pH 4.0 fish eggs and fry die
Acid - tolerant Sphagnum mosses colonise lake beds, forming a mat that seals off oxygen and slows decay rates.

- Metal ions e.g. Ca^{2+} and Mg^{2+} are leached out of the soil, reducing fertility
- Some leached metal ions e.g. Al^{3+} and Pb^{+} become soluble and are absorbed causing damage to plant roots, soil organisms and prevent normal calcium uptake by aquatic organisms
- Deflocculation of clay soils

- Damage to epidermis of leaves reduces photosynthesis
- Damage to roots reduces water and nutrient uptake
- Lichens killed
- Damage to testa (outer seed coating) reduces seed germination
- Reduced plant resistance to fungi, pests, drought and frost

- Corrosion of e.g. limestone/sandstone buildings

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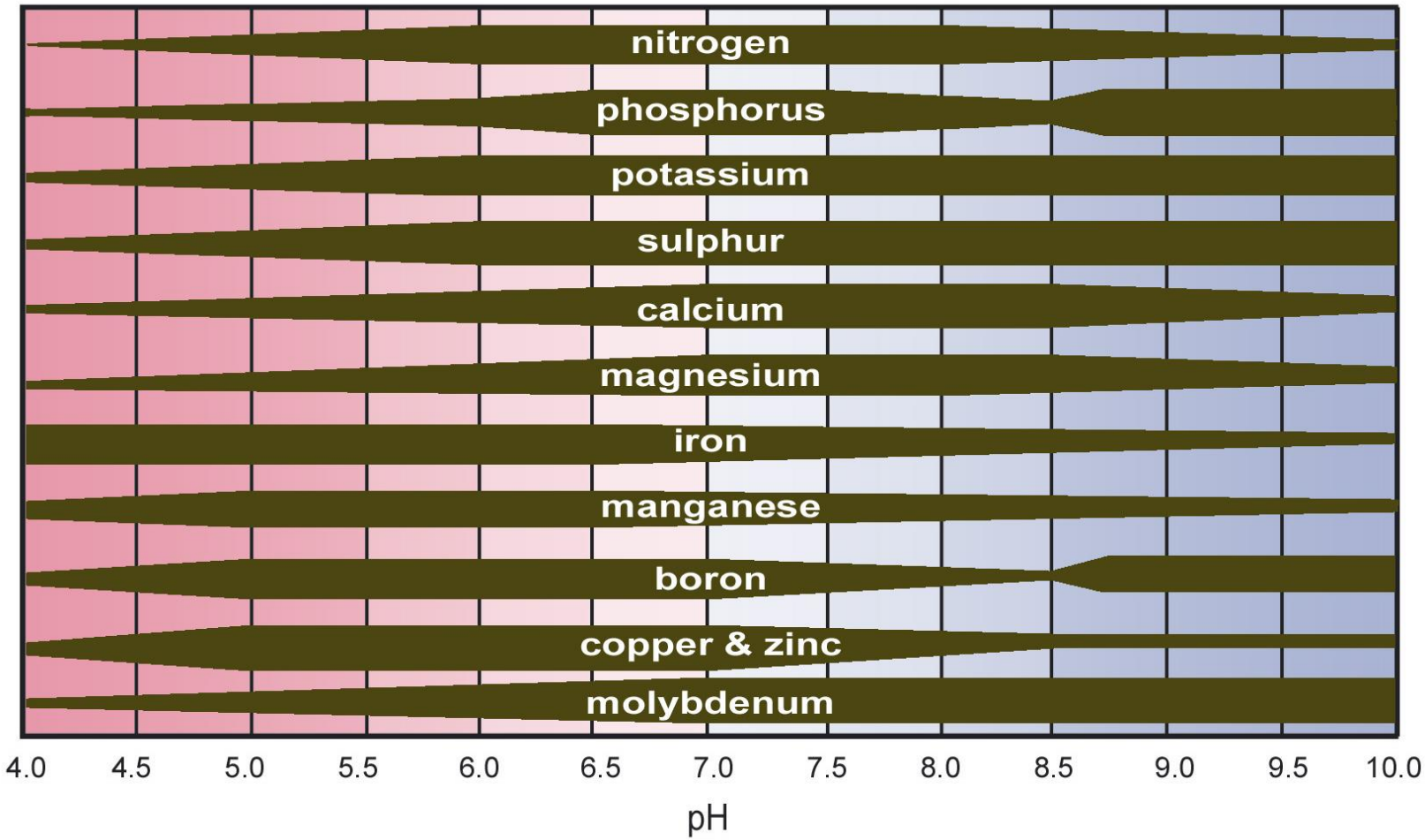
Soil pH and nutrient availability

As soils acidify, concentrations of heavy metals e.g. Cu and Zn, may reach toxic levels



The wider the bar, the more available that element is.

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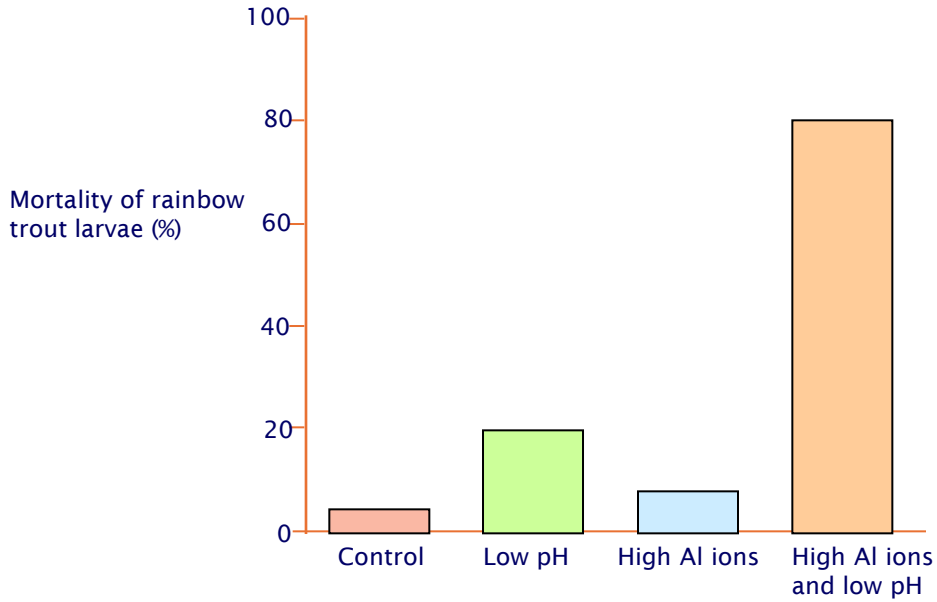
Question

The graph shows the effect of low pH and dissolved aluminium (Al) ions on the mortality of rainbow trout larvae



Describe what this data shows (2)

- Both low pH and high Al increase mortality;
- Low pH more damaging than high Al;
- Combination of low pH and high aluminum has greater effect than sum of the individual effects (synergism)

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What are Lichens and why are they suitable as biotic indicators?

- Lichens are formed from an alga and a fungus (symbiotic relationship)
- The alga photosynthesise and the fungus gains some of the sugars produced
- The fungi provide attachment to a surface e.g. tree/rock and offer the alga some physical protection
- Sensitive to acidic conditions
- Size, health, abundance and diversity of lichens can be used to indicate sulphur dioxide levels – air pollution
- Foliose, fruticose and crustose lichen

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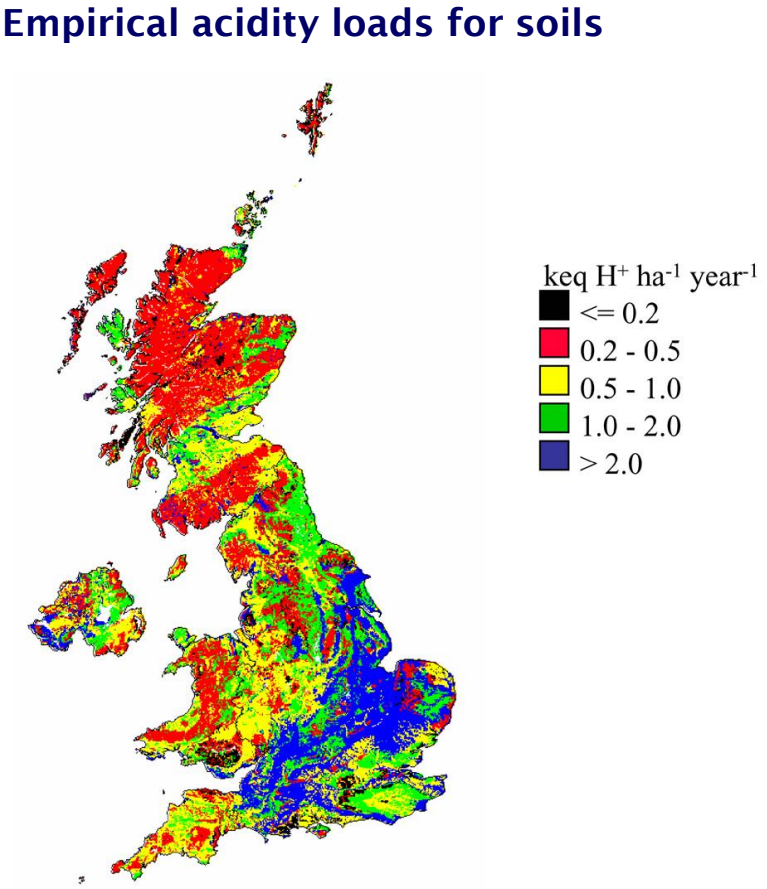
What factors influence how sensitive an environment will be to acid rain?

- Underlying geology: limestone will help to neutralise acidity
- Rainfall patterns: heavy downpours of acid rain can have acute effects
- Snow-melt: sudden melting of acidic snow can quickly acidify aquatic habitats



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What is Smoke pollution?

Sources:

- Incomplete combustion of fossil fuels and vegetation e.g. forests
- Creates suspended particulate matter (PM) following deforestation/burning

Effects:

- Reflection of sunlight back out to space (increased albedo) → cooling effect
- Carbon-containing particles may form carbonic acid and the sulfur-containing particles may form sulfurous and sulfuric acid. These will chemically weather limestone and sandstone buildings

- PM-10s (diameter <10 micrometres) are small enough to penetrate deep into the lungs → lung irritation, bronchitis & cancer
- Blocks stomata on leaves, reducing respiration and can cover leaf surfaces, reducing photosynthesis
- Synergistic action of PM with sulphur dioxide – highly toxic
- Smoke may contain toxic heavy metals

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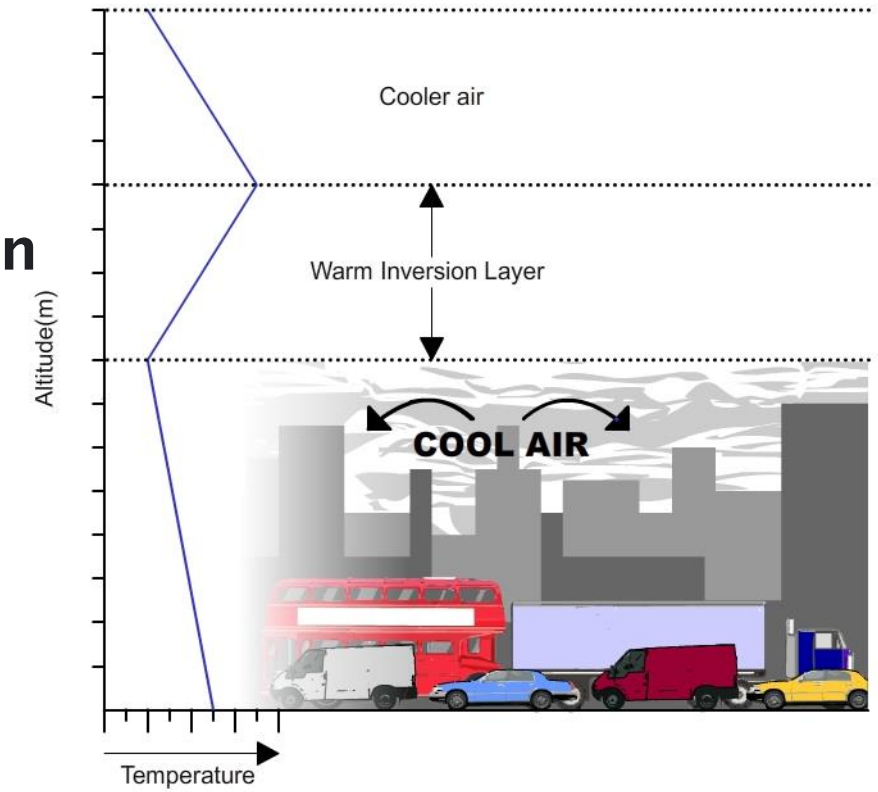
What is Smoke smog?

- Smoke smog = smoke + fog (water vapour) – it is a secondary pollutant
- It often occurs when a temperature inversion occurs.

- What is a temperature inversion?

What is a Temperature Inversion?

- Air temperature in the troposphere normally falls with altitude
- **Temperature inversion is a reversal of the normal behaviour of temperature in the troposphere**
- Occurs when there is a layer of unusually cold air near the ground



Temperature inversions are most likely when:

- skies are cloudless
- OR mist or fog reflects sunlight
- little or no wind
- valley topography allows cold air to collect

Gaseous pollutants in this layer are cooled, become more dense, less buoyant and disperse less – air pollution

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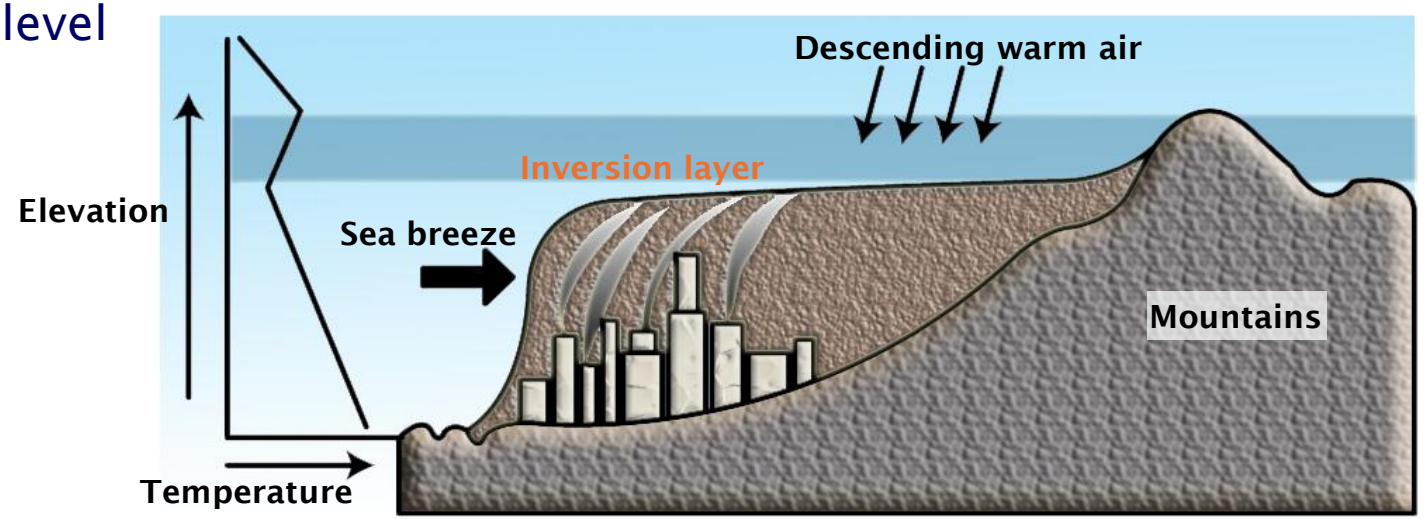
Temperature inversions

Los Angeles basin

The LA basin is a low, sloping plain between the Pacific Ocean and huge mountain ranges lying to the north and east. Describe what is happening in this image?

- Cool air blows in from the coast and is trapped by the mountain ranges
- Subsiding, warming air descends into the basin and an inversion often develops at about 600m
- UV intensity can very high (if cold temperature and no cloud) leading to high O3 (tropospheric ozone)
- Pollutants from vehicles and industry are trapped in the cool air below this level



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What is Tropospheric ozone?

- Ozone in the stratosphere filters out harmful UV radiation – good!
- Ozone in the troposphere is mainly produced by human activity >>
- **formed from the photochemical breakdown (photolysis) of primary pollutants (mainly NO2 and some SO2)**
- It causes breathing difficulties and permanent lung damage, exacerbates asthma, increases sensitivity of the eyes and causes leaf damage, reducing growth rates of trees and crops

Sources

Photo-dissociation (breakdown) of nitrogen dioxide (e.g. from exhaust fumes)

$$NO_2 \xrightarrow{\text{UV-A}} NO + O$$

$$O + O_2 \longrightarrow O_3$$

(Nitrogen dioxide beaks down by UV to create Nitrogen monoxide and monatomic oxygen)

Tropospheric ozone is a secondary pollutant = formed from the photochemical breakdown of primary pollutants (mainly NO2) and its interaction with oxygen

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What is Photochemical Smog?

Formation:

- Nitrogen oxides (NO_X), hydrocarbons (HC) and tropospheric ozone (O_3) react together in the presence of sunlight to form peroxyacetyl nitrates (PANs)

NOx + HC + O3 → (Sunlight (UV); Temperature> 18°C) PANs

	NOx	HC	O3		PANs
Source	Combustion of oil, coal and gas Forest fires	Evaporation of solvents, fuels, incomplete combustion of fossil fuels	Naturally, as well as photodissoc. of NO2 NO2 + sunlight → NO + O O + O2 → O3		
Effects	Reduced visibility due to brown/yellow of colour of NO2 Heart and lung problems Leaf damage	Eye irritation Reduced visibility Respiratory problems	Lung and eye irritation Increased susceptibility of humans to disease Decreased plant growth Leaf tissue damage Weakens rubber, bleaches materials		Eye irritation Respiratory irritation Toxic to plants

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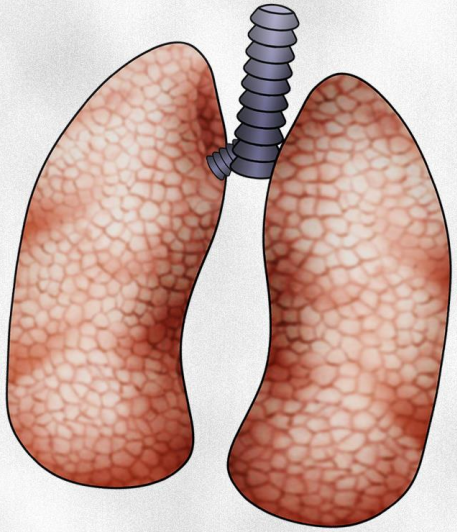
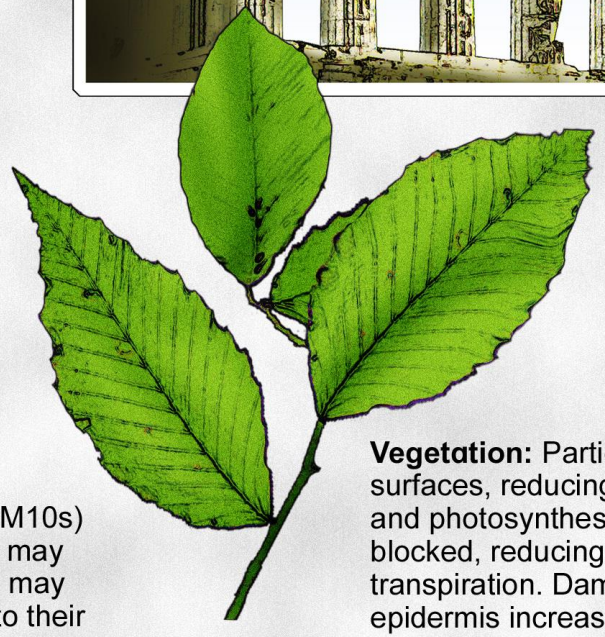
Photochemical smog -effects

Buildings: Carbon-containing particles form carbonic acid, sulphur-containing particles form sulphurous and sulphuric acids that chemically weather limestone buildings. The calcium carbonate is converted into calcium sulphate which is water-soluble.

e.g. The Acropolis in Greece; the Colosseum in Rome



Health: The smallest particulates (PM10s) penetrate deep in to the lungs. They may be directly toxic themselves but they may also have other toxins adsorbed on to their surface which are released in the alveoli.



Vegetation: Particulates cover leaf surfaces, reducing light absorption and photosynthesis. Stomata may be blocked, reducing gas exchange and transpiration. Damage to the leaf epidermis increases the chances of bacterial, fungal and viral infection.

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Photochemical smog -incidence

What are the main 3 contributing factors:

1.Time: Rush hour
(vehicles greatest source of NOx and HCs)

2. Meteorological conditions
A temperature inversion will increase the likelihood of photochemical smog developing

3.Topography
Valleys are more susceptible because the surrounding hills decrease air flow, allowing the development of stronger temperature inversions

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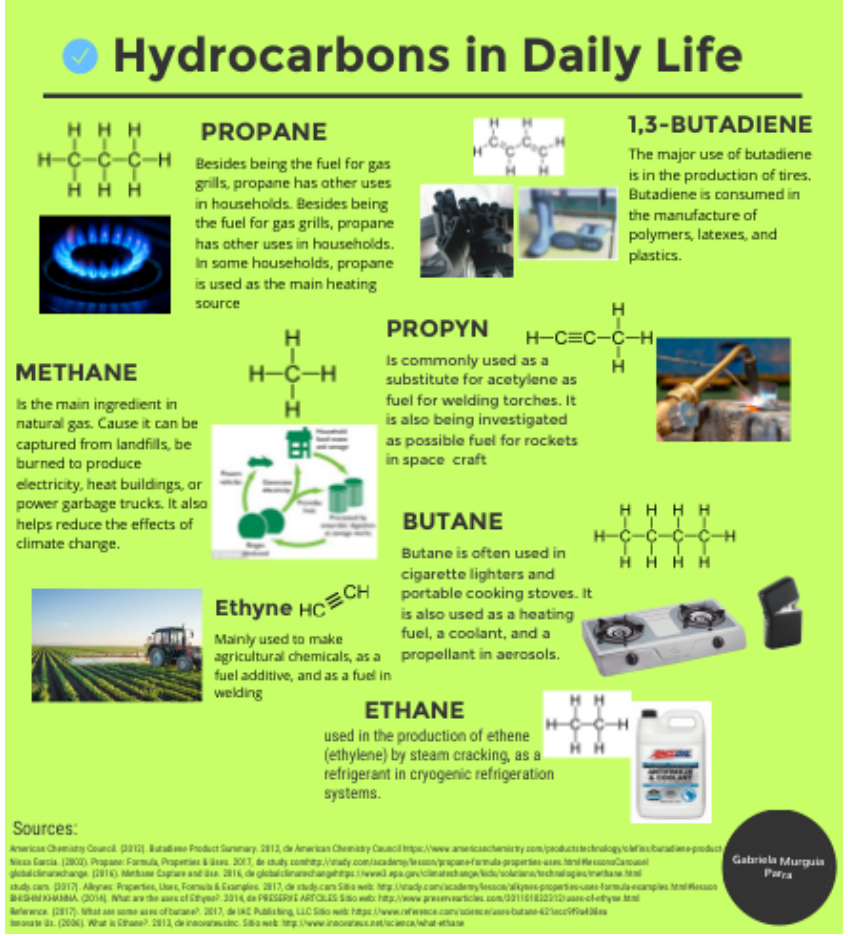
What are hydrocarbons?

- A hydrocarbon is an organic compound consisting of only hydrogen and carbon atoms.
- Almost all hydrocarbons occur naturally in crude oils, like petroleum and natural gas. Crude oil is made of decomposed organic matter, so it is abundant in hydrogen and carbon atoms.
- They are also present in different trees and plants, and form a natural pigment called carotene, that can be found in carrots and green leaves.
- The majority of natural crude rubber, 98%, is made of a hydrocarbon polymer.
- Hydrocarbons are the most widely used organic compound on the planet, and are considered the driving force for modern civilization, because they makeup fossil fuels.

Hydrocarbon Uses

- Hydrocarbon fuels are used for combustion, specifically in heating and motor fuel applications.
- Hydrocarbons like propane and butane are used in lanterns, lighters, grills, and as fuel for internal combustion units.
- Pentane, another common hydrocarbon is used as a solvent, in transport fuels, and cleaning products.



- Slightly larger hydrocarbon molecules, known as kerosene, is used in jet fuel, diesel fuel, and oil for heating.
- The larger the hydrocarbons, the thicker the compound.
- Large hydrocarbons are often used as engine lubricants, and greases. Anything thicker than that, and they form a wax or tar like substance, which is commonly used in highway construction, and roofing.

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Burning hydrocarbons releases Carbon Monoxide (CO)

Formation of CO:

- it is produced by the incomplete combustion of hydrocarbons e.g. petrol and diesel

Major health concerns:

- CO binds to haemoglobin and prevents O2 being carried around the body
- CO poisoning from breathing in CO from smoke / charcoal fires / vehicle fumes (in closed environment)

Is CO a GHG?

- No, it does not absorb IR radiation like CO2

How is CO controlled?

- Reduced by catalytic converters – oxidises CO to CO2 (GHG) but in small amounts.

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Exam Questions

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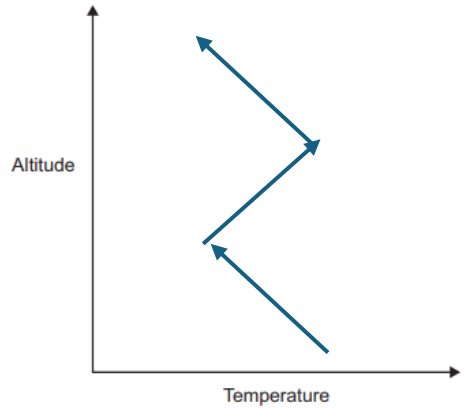
5 **Figure 4** is an outline graph that may be used to show the changes in temperature with increasing altitude during a temperature inversion.

Figure 4



5 (a) Complete **Figure 4** to show conditions during a temperature inversion.

[1 mark]

5 (b) Describe the factors that make it more likely that a temperature inversion will occur.

[3 marks]

Any combination of the following that contribute to the ground getting cold:

Cloudless sky and low temperature

OR mist / fog that reflects sunlight

AND valley topography that allows cold air to collect

Little or no wind

Explain what a temperature inversion is [2]

temperature inversion is a reversal of the normal behaviour of temperature in the troposphere

a layer of cool air at the ground is overlain by a layer of warmer air - under normal conditions, air temperature decreases with altitude.

How does a temperature inversion contribute to atmospheric pollution (4)

- During an inversion, a layer of cold dense air is trapped close to the ground surface below a layer of warm air.
- Gasses and smoke from burning fossil fuels are unable to disperse so collect in this cold layer of air.
- These gases are cooled, become more dense, less buoyant and disperse less causing smog and atmospheric pollution.
- Some gases e.g. NOx can have a synergistic reaction with other gases/elements such as UV, water vapor and oxygen to create peroxyacetyl nitrates (PAN's)/ photochemical smog

Do not write outside the box

5 (c) Outline the differences between smoke smogs and photochemical smogs.

[5 marks]

Smoke from incomplete combustion of FF/wood/rubbish

Creates SPM which mixes with water vapour to create smoke smog

Smoke smog is a secondary pollutant but no involvement in UV

Photochemical smog is a secondary pollutant that does involve UV

created by the mixing of NOx (released from vehicles/burning petroleum based products) with HC, tropospheric O3 and UV to create PAN's

NOx + HC + O3 + UV = PAN's / photochemical smog

Photochemical smoke is created from synergistic reactions between primary and secondary pollutants (O3)

smoke smog is created only from the primary pollutant smoke.

- 1. (a) Explain how emissions from power stations and cars contribute to the formation of acid rain (2)

1. (a) sulphur dioxide combines with water to form sulphuric/ sulphurous acid;
nitrogen oxides combine with water to form nitric/nitrous acid;

(b) Outline the effects of acid rain on:

(i) forests (4)

(b) (i) crown dieback /loss of chlorophyll (chlorosis);
evergreens particularly susceptible;
damage to shoots and leaf epidermis;
denatured proteins/enzymes in leaf;
defoliation;
blocked stomata;
reduced transpiration/CO_2 uptake;
loss of acid-intolerant species leading to change in community;
disruption to food chain;
decrease in photosynthetic rates;
damage to root hairs;
reduced nutrient and water uptake;
increase in solubility of toxic Al^{3+} ions;
leaching/toxicity to invertebrates;
loss of Mg^{2+} / Ca^{2+} via leaching
decreased resistance to drought/ disease/ frost;
reduced decomposition;
mineral deficiency;
reduced seed germination;
increased susceptibility to insect/viral pathogens;

(b) Outline the effects of acid rain on:

(ii) lakes (4)

(ii) gills unable to regulate cations such as sodium;
osmotic imbalance;
gills clogged with excess mucus;
reduced gas exchange/ suffocation;
Inhibited calcium uptake;
death of fry/ reduced recruitment;
death of invertebrates and microorganisms;
food chains disrupted;
reduced decomposition;
reduced nutrient availability;

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Next time: water pollutants

Pollution Unit