Topic 26 – Air

Subject content:

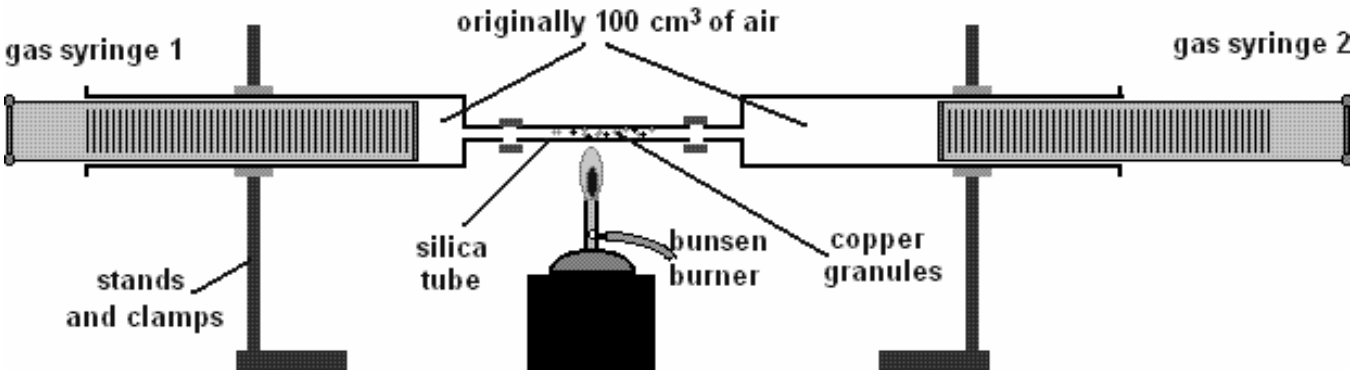
- describe the volume composition of gases present in dry air as being approximately 78% nitrogen, 21% oxygen and the remainder being noble gases (with argon as the main constituent) and carbon dioxide
- name some common atmospheric pollutants, e.g. carbon monoxide; methane; nitrogen oxides (NO and NO_2); ozone; sulfur dioxide; unburned hydrocarbons
- state the sources of these pollutants as
  (i) carbon monoxide from incomplete combustion of carbon-containing substances
  (ii) nitrogen oxides from lightning activity and internal combustion engines
  (iii) sulfur dioxide from volcanoes and combustion of fossil fuels
- describe the reactions used in possible solutions to the problems arising from some of the pollutants named in (b)
  (i) the redox reactions in catalytic converters to remove combustion pollutants
  (ii) the use of calcium carbonate to reduce the effect of ‘acid rain’ and in flue gas desulfurisation
- discuss some of the effects of these pollutants on health and on the environment
  (i) the poisonous nature of carbon monoxide
  (ii) the role of nitrogen dioxide and sulfur dioxide in the formation of ‘acid rain’ and its effects on respiration and buildings
- discuss the importance of the ozone layer and the problems involved with the depletion of ozone by reaction with chlorine-containing compounds, chlorofluorocarbons (CFCs)
- describe the carbon cycle in simple terms, to include
  (i) the processes of combustion, respiration and photosynthesis
  (ii) how the carbon cycle regulates the amount of carbon dioxide in the atmosphere
- state that carbon dioxide and methane are greenhouse gases and may contribute to global warming, give the sources of these gases and discuss the possible consequences of an increase in global warming

26.1 Volume composition of gases

Gas	Volume composition (%)
nitrogen	78
oxygen	21
carbon dioxide	0.03
noble gases (mainly argon)	0.97

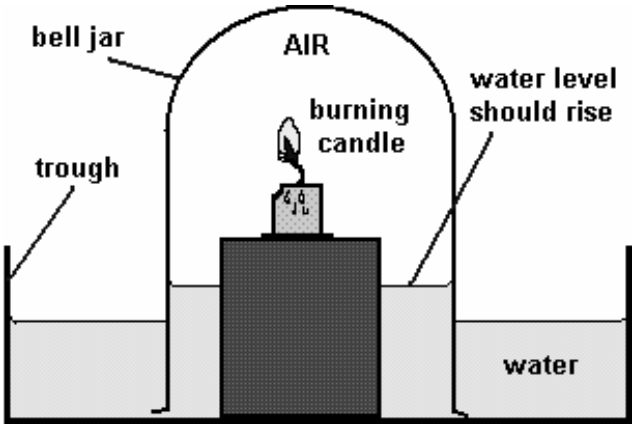
Determine % composition of oxygen in air

Method 1: gas syringe



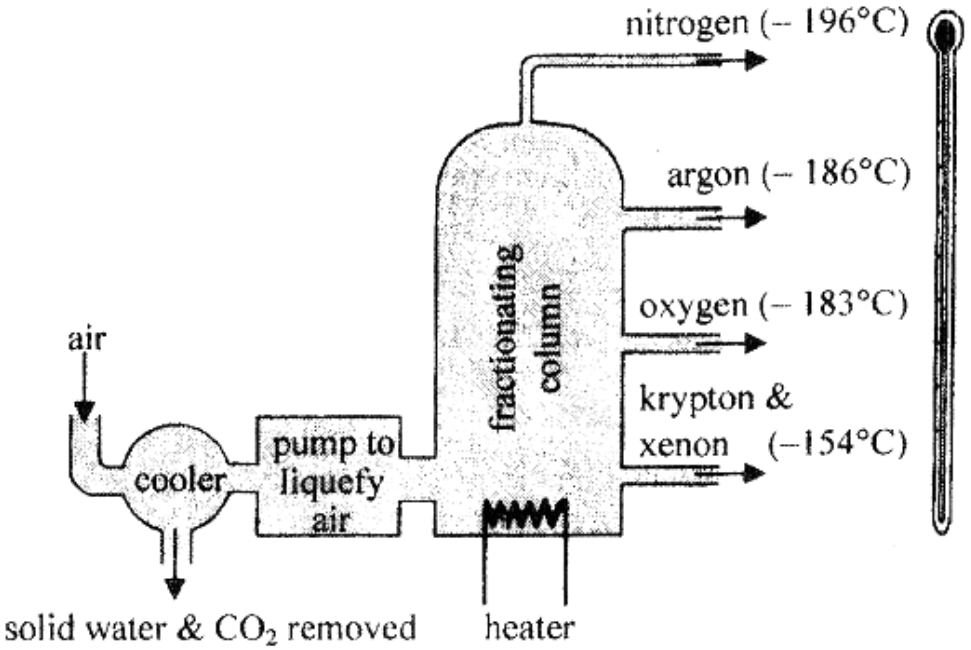
Procedure	Results
• One syringe is empty and the other filled with exactly 100 cm^3 air. • Strongly heat tube + move gas syringes 1 and 2 to and fro (pass air over hot copper so ALL the air comes into contact with hot copper)	• Oxygen in air reacts with copper to form copper(II) oxide: copper + oxygen → copper(II) oxide $2\ Cu(s) + O_2(g) \rightarrow 2\ CuO(s)$ • Eventually total volume reading reaches min value when all oxygen in air has reacted with copper • ≈ 80 cm^3 air left (mainly unreactive nitrogen) → ≈ 20% oxygen

Method 2: burn candle in bell jar of air inverted over water



Procedure	Results
●	● level rise by 1/5 as oxygen in air inside bell jar is used up by combustion of wax ● all oxygen converted into carbon dioxide (does not support burning) → candle stop burning

<u>Separation of gases from air</u>: fractional distillation



26.2 Atmospheric pollutants

Summary

Pollutant	carbon monoxide	sulfur dioxide	nitrogen oxides	unburned hydrocarbons	ozone	methane
Source	• incomplete combustion of carbon-containing substances (petrol) in car engine ○ insufficient oxygen	• combustion of sulfur-containing fossil fuels **$S + O_2 \rightarrow SO_2$** • volcanic activity	• nitrogen + oxygen in air at high temp e.g. internal combustion engine • lightning activity (large amt of heat energy) **$N_2 + O_2 \rightarrow 2\ NO$** **$2\ NO + O_2 \rightarrow 2\ NO_2$**	• vehicle exhaust fumes • chemical plants	• unburnt hydrocarbons + nitrogen oxides in presence of sunlight	• bacterial decay of vegetation • digestion of food by animals • decay of rubbish in landfills

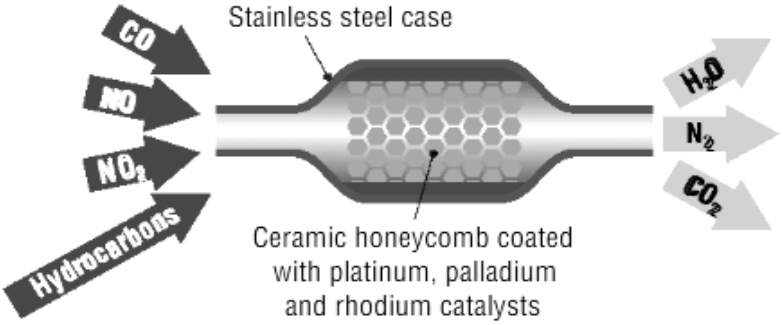
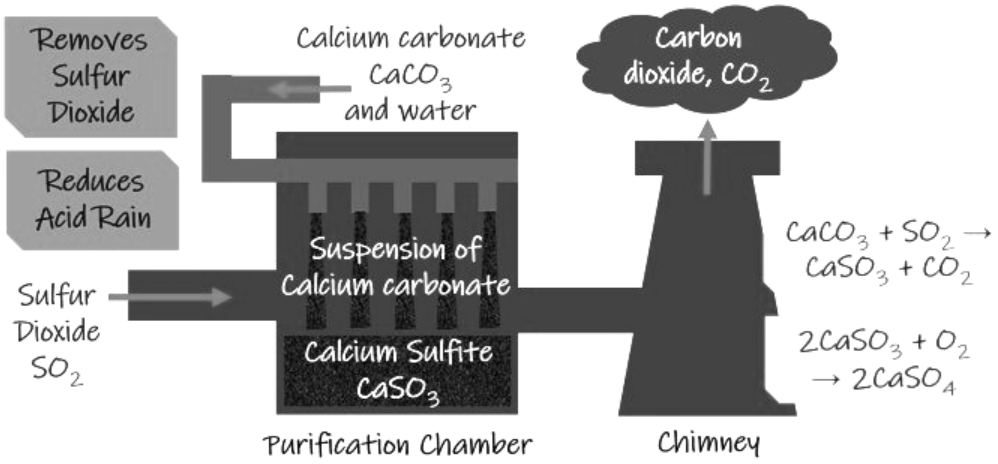
Effect	• carboxyhaemoglobin
	  ○ fatigue
	  ○ breathing difficulties
	  ○ headaches
	  ○ death
		• acid rain
		  ○ corrode buildings
		  ○ attack metals
		  ○ kill aquatic plants and animals
		• irritate eyes, lungs + breathing difficulties
		• bronchitis
			• acid rain
			  ○ corrode buildings
			  ○ attack metals
			  ○ kill aquatic plants and animals
			• photochemical smog
			  ○ irritate eyes, lungs + breathing difficulties
			• bronchitis
				• photochemical smog
				  ○ irritate eyes, lungs + breathing difficulties
				• increase risk of cancer
					• part of photochemical smog
					  ○ irritate eyes, lungs + breathing difficulties
					• damage crops
						• greenhouse effect → global warming

Solution	• catalytic converter	• Flue Gas Desulfurisation	• catalytic converter	• catalytic converter	• catalytic converter	• no easy sol^{n}

Effects

carbon monoxide	• Combine readily with haemoglobin in blood → carboxyhaemoglobin → reduce ability of haemoglobin to transport oxygen to rest of body
sulfur dioxide	• Acid rain Formation ○ sulfur dioxide + water → sulfurous acid **$SO_2(g) + H_2O(l) \rightarrow H_2SO_3(aq)$** ○ sulfurous acid + oxygen → sulfuric acid **$2H_2SO_3(aq) + O_2(g) \rightarrow 2H_2SO_4(aq)$** Effect ○ corrode buildings ○ attack metals ○ kill aquatic plants and animals • irritate eyes, lungs + breathing difficulties • bronchitis
nitrogen oxides	• Acid rain Formation ○ nitrogen dioxide + water + oxygen → nitric acid **$4NO_2(g) + 2H_2O(l) + O_2(g) \rightarrow 4HNO_3(aq)$** Effect ○ corrode buildings ○ attack metals ○ kill aquatic plants and animals • unburnt hydrocarbons + nitrogen dioxide in presence on sunlight → photochemical smog ○ irritate eyes, lungs + breathing difficulties ○ bronchitis

Solution

Catalytic converter	 Convert harmful pollutants → harmless substances (redox rxn) 1. Carbon monoxide <u>oxidised</u> to carbon dioxide **$2\ CO(g) + O_2(g) \rightarrow 2\ CO_2(g)$** 2. Nitrogen oxides <u>reduced</u> to nitrogen **$2\ NO(g) + 2\ CO(g) \rightarrow N_2(g) + 2\ CO_2(g)$** 3. Unburnt hydrocarbons <u>oxidised</u> to carbon dioxide and water **$2\ C_8H_{18}(l) + 25\ O_2(g) \rightarrow 16\ CO_2(g) + 18\ H_2O(g)$**
Flue Gas Desulfuration (FGD)	 1. Sulfur dioxide + aq suspension of calcium carbonate → solid calcium sulfite + carbon dioxide gas **$SO_2(g) + CaCO_3(s) \rightarrow CaSO_3(s) + CO_2(g)$** 2. Calcium sulfite + atmospheric oxygen → calcium sulfate **$2\ CaSO_3(s) + O_2(g) \rightarrow 2\ CaSO_4(s)$** **OR** 1. Sulfur dioxide + calcium oxide → calcium sulfite **$SO_2(g) + CaO(s) \rightarrow CaSO_3(s)$** 2. Calcium sulfite + atmospheric oxygen → calcium sulfate **$2\ CaSO_3(s) + O_2(g) \rightarrow 2\ CaSO_4(s)$**
Liming	Use powdered limestone to neutralise polluted water bodies polluted by acid rain

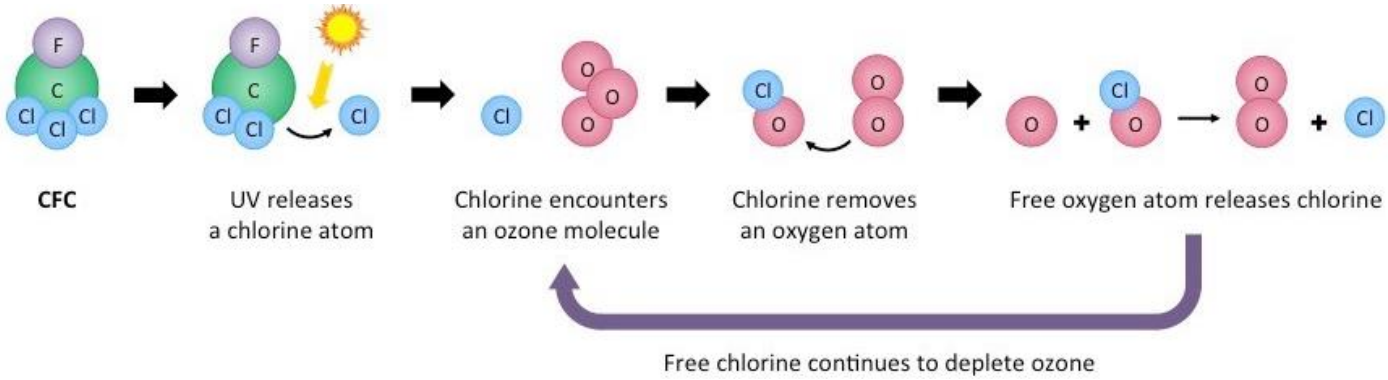
26.3 Ozone layer

Ozone (O_3): allotrope of oxygen

ground level	pollutant – toxic at conc above 100 ppm
atmosphere	filter out excessive harmful ultraviolet (UV) radiation from sun

Depletion of ozone layer

Chlorofluorocarbons (CFCs): compounds containing elements carbon, fluorine, chlorine
→ destroy ozone layer



1. Some harmful UV radiation from sun is absorbed by ozone layer
2. CFC released (propellants in aerosols, coolants in air conditioners) into atmosphere → reach stratosphere
3. CFC decompose in presence of UV radiation → chlorine atom
   e.g. chloromethane: $Cl–CH_3 \rightarrow Cl + CH_3$
4. Chlorine atom + ozone → chloride oxide + oxygen
   $Cl + O_3 \rightarrow ClO + O_2$
   $ClO + O_3 \rightarrow Cl + 2\ O_2$

Chlorine atom: catalyst
used up → re-generated as product
continue to break down ozone + remain chemically unchanged

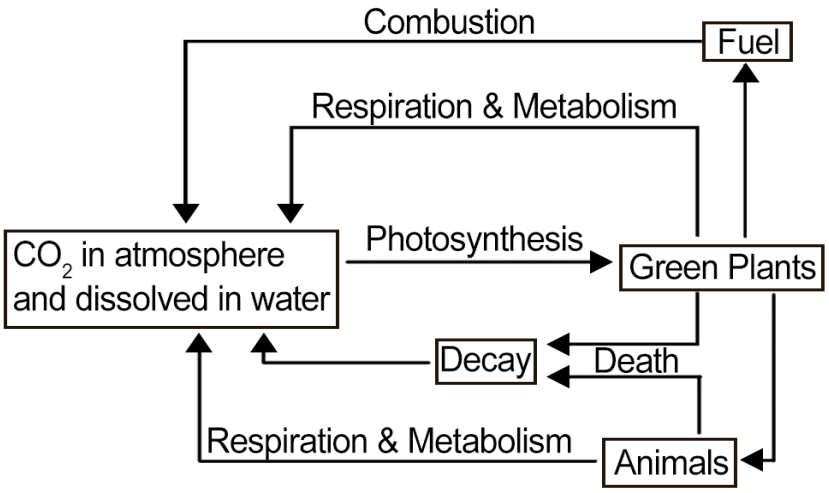
Overall eqn: $2\ O_3 \rightarrow 3\ O_2$

Consequence: exposure to excessive harmful UV radiation

- skin cancer
- cataracts
- genetic mutation

26.4 Carbon cycle

Carbon cycle: mechanism that maintain carbon dioxide level in atm
→ rate of release CO_2 > rate of remove CO_2



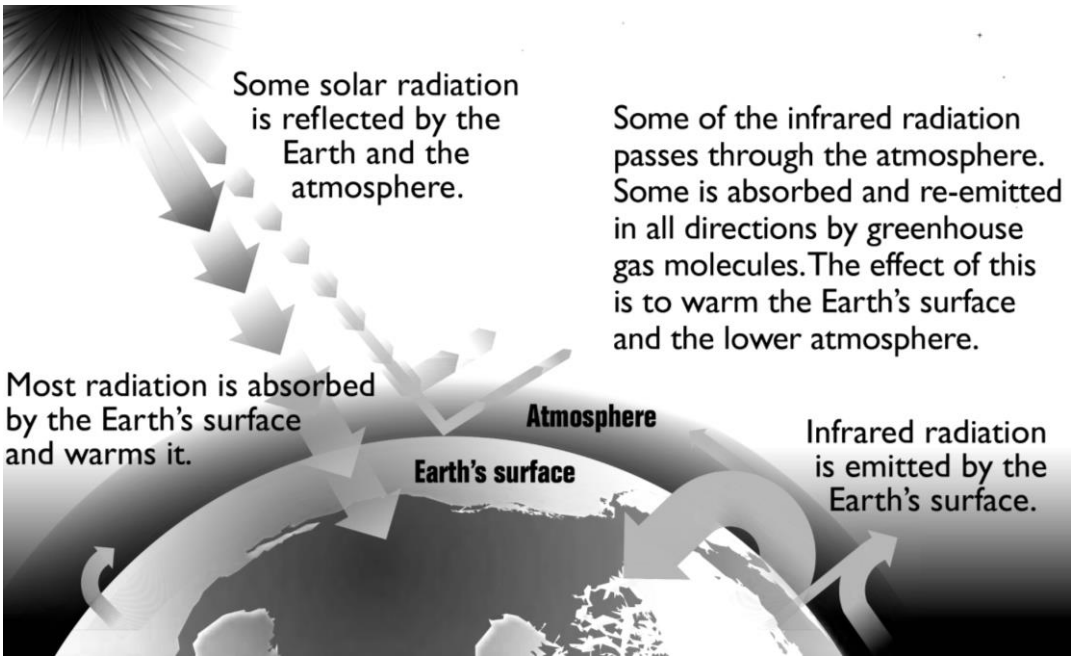
Release CO_2	Remove CO_2
1. Respiration ● oxidise glucose → carbon dioxide + water + energy **$C_6H_{12}O_6(aq) + 6\ O_2(g)$** **$\rightarrow 6\ CO_2(g) + 6\ H_2O(l)$** 2. Combustion of fuels ● burn fuels → carbon dioxide + water **$CH_4(g) + 2\ O_2(g)$** **$\rightarrow CO_2(g) + 2\ H_2O(g)$** 3. Decay and bacterial decomposition ● bacteria break down carbon compounds in dead organisms → produce carbon dioxide	1. Photosynthesis ● green plants convert carbon dioxide + water → glucose + oxygen in presence of sunlight **$6\ CO_2(g) + 6\ H_2O(l)$** **$\rightarrow C_6H_{12}O_6(aq) + 6\ O_2(g)$** 2. Ocean uptake ● ocean: carbon sink that traps carbon dioxide ● dissolved carbon dioxide used by plants and marine organisms ● converted into calcium carbonate in the form of shells & skeletons → settle on seabed to form limestone

26.5 Global warming

Greenhouse effect

Greenhouse effect: warming effect when heat energy is retained in atm by greenhouse gases
Greenhouse gases: trap infrared radiation

- carbon dioxide
- methane
- nitrous oxide
- water vapour



Global warming

Global warming: increase in Earth average temp due to build-up of greenhouse gases in atm

- carbon dioxide build up rapidly in atm due to deforestation, burning of fossil fuels
- rate of release CO_2 > rate of remove CO_2

Consequences of increase in global warming:

1. more occurrences of unusual weather conditions e.g. warm spells, droughts, floods
2. decrease in crop yields (areas that are currently covered by vegetation become deserts)
3. melting of large quantities of ice in polar regions → ocean level rise → flood low-lying areas
4. rapid evaporation of water from earth surface → carbon dioxide dissolved in oceans is released into atm

Past year questions

Multiple-choice questions

1 The depletion of the ozone layer can result in an increase in cases of skin cancer.
What is the reason for this? (2021 P1 Q29)

A Less infrared radiation reaches the Earth
B Less ultraviolet radiation reaches the Earth
C More infrared radiation reaches the Earth
D More ultraviolet radiation reaches the Earth

2 Which row shows air pollutants and their sources? (2021 P1 Q30)

	pollutant	source	pollutant	source
A	carbon dioxide	photosynthesis	nitrogen dioxide	lighting flashes
B	carbon monoxide	incomplete combustion of petrol	nitrogen dioxide	oxygen and nitrogen from air combining in an internal combustion engine
C	sulfur dioxide	burning fossil fuels	methane	incomplete combustion of petrol
D	sulfur dioxide	lighting flashes	carbon dioxide	burning fossil fuels

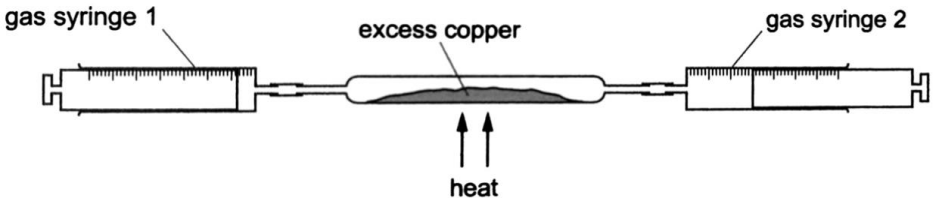
3 In a catalytic converter of a car, what type of chemical reaction takes place to change the harmful exhaust gases, carbon monoxide and nitrogen monoxide, into less harmful gases?
(2020 P1 Q29)

A combustion
B evaporation
C precipitation
D redox

4 Which process removes carbon dioxide from the atmosphere? (2020 P1 Q30)

A combustion of fuels
B photosynthesis
C respiration
D volcanic activity

5 The oxygen in air can be removed by passing air over heated copper.



$50cm^3$ of air is collected in gas syringe 1. Each syringe, 1 and 2, is pushed alternately so that the air passes repeatedly over the heated copper.
When the volume of gas no longer changes, and the gas has cooled to room temperature, what volume of gas will remain? (2019 P1 Q23)

A 10 cm^3
B 20 cm^3
C <u>40 cm^3</u>
D 80 cm^3

6 100 cm^3 of methane is burned in 150 cm^3 of oxygen.
When cooled to room temperature, what could be the resulting mixture of gases?
(2018 P1 Q33)

A <u>CH_4, CO, CO_2</u>
B CH_4, CO, H_2O
C CH_4, CO_2, O_2
D CO_2, H_2, O_2

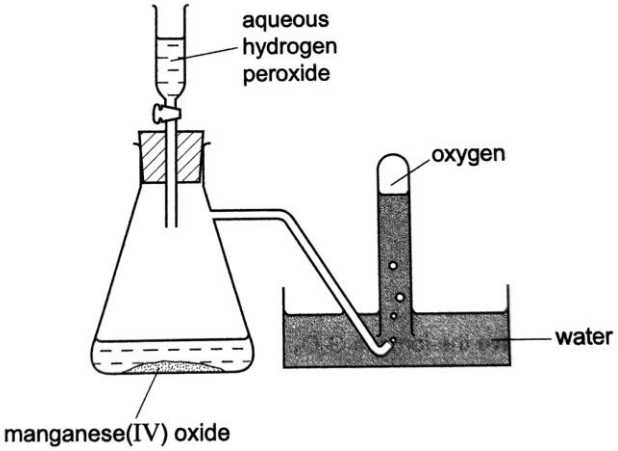
7 Catalytic converters are used in the removal of harmful pollutants from exhaust gases.
Which equations show reactions that are useful in removing such pollutants? (2017 P1 Q33)

1 $N_2(g) + O_2(g) \rightarrow 2\ NO(g)$
2 $NO(g) + CO(g) \rightarrow ½\ N_2(g) + CO_2(g)$
3 $NO(g) + ½\ O_2(g) \rightarrow NO_2(g)$
4 $NO_2(g) + 2\ CO(g) \rightarrow ½\ N_2(g) + 2\ CO_2(g)$

A 1 and 2 only
B 1 and 3 only
C <u>2 and 4 only</u>
D 3 and 4 only

8 Oxygen was prepared by the decomposition of hydrogen peroxide, in the presence of manganese(IV) oxide. The oxygen was collected as shown in the diagram.

$2\ H_2O_2 \rightarrow 2\ H_2O + O_2$



Which substance contaminated the first few tubes of oxygen collected? (2015 P1 Q32)

A hydrogen
B hydrogen peroxide
C manganese(IV) oxide
D nitrogen

9 Which pair of car exhaust gases can both be oxidised? (2014 P1 Q28)

A carbon dioxide and carbon monoxide
B carbon dioxide and nitrogen dioxide
C carbon monoxide and unburnt petrol gases
D steam and unburnt petrol gases

10 An atmospheric pollutant can be removed by the process of reduction.
Which pollutant is removed by this process? (2014 P1 Q30)

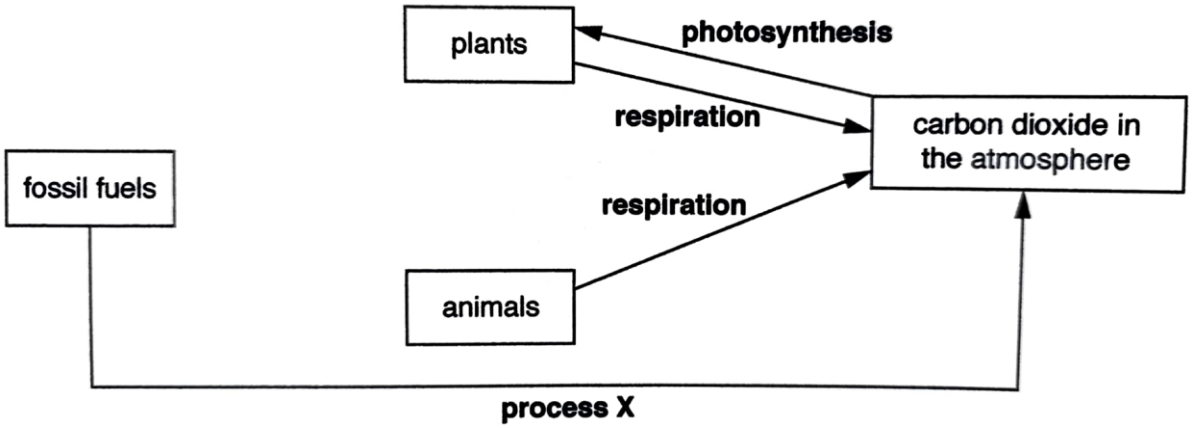
A carbon monoxide in a catalytic converter
B nitrogen dioxide in acid rain by reaction with calcium carbonate
C nitrogen oxide in a catalytic convertor
D sulfur dioxide from flue gases by reaction with calcium carbonate

11 In what way do chlorofluorocarbons, methane and nitrogen dioxide affect the atmosphere and the environment? (2012 P1 Q28)

	chlorofluorocarbons	methane	nitrogen dioxide
A	acid rain	depletion of ozone layer	greenhouse gas
B	depletion of ozone layer	acid rain	global warming
C	depletion of ozone layer	greenhouse gas	acid rain
D	global warming	depletion of ozone layer	acid rain

Structured questions

1 The diagram shows some of the processes that happen in the carbon cycle.



(2017 P2 A3)

(a) Name process X. [1]

Combustion

(b) Write equations for the processes that happen during photosynthesis and respiration. [2]

Photosynthesis:

$6\ CO_2(g) + 6\ H_2O(l) \rightarrow C_6H_{12}O_6(aq) + 6\ O_2(g)$

Respiration:

$C_6H_{12}O_6(aq) + 6\ O_2(g) \rightarrow 6\ CO_2(g) + 6\ H_2O(l)$

(c) Use your equations above to explain how the processes of photosynthesis and respiration help regulate the amount of carbon dioxide in the atmosphere. [1]

The amount of carbon dioxide removed from the atmosphere by photosynthesis is the same as the amount of carbon dioxide returned to the atmosphere by respiration.

(d) The amount of carbon dioxide in the atmosphere is increasing due to our use of fossil fuels. One approach to this problem is to plant more trees.
Suggest why planting more trees is **not** a long-term solution to the increase in the amount of carbon dioxide. [2]

In the long term, when trees die and decay, bacteria will break down the carbon compounds in them. Thus, the decomposition of trees will release additional carbon dioxide into the atmosphere.

2 Chlorofluorocarbons (CFCs) were widely used as aerosol propellants until the mid-1980s. They are now banned in most countries because they lead to the depletion of the ozone layer.

(2017 P2 A6)

(a) CFCs cause the breakdown of ozone in several steps.

The first step happens when energy from sunlight breaks a bond in a CFC to produce a chlorine atom.

For example: $CF_2Cl_2 \rightarrow CF_2Cl + Cl$

The table shows the bond energies for some of the bonds in CFCs.

bond	bond energy / kJ/mol
C–F	485
C–Cl	327

Use the data in the table to explain why the ozone layer contains many more chlorine atoms than fluorine atoms. [2]

- The amount of energy required to break C–Cl bond (327 kJ/mol) is lower than the amount of energy required to break C–F bond (485 kJ/mol).
- More C–Cl bonds are broken than C–F bonds, causing more chlorine atoms in the ozone layer.

(b) Chlorine atoms cause the breakdown of ozone in a two-step reaction.

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

(i) Use the equations to write an overall equation for the reaction. [2]

$2\ O_3 \rightarrow 3\ O_2$

(ii) Explain how the equations show that chlorine atoms act as a catalyst for the breakdown of ozone. [1]

- Chlorine atom that is used up previously is regenerated as product.
- It continues to break down ozone while remaining chemically unchanged.

3 Car engines are adjusted to work at a particular air : fuel ratio.
The amount of air that is mixed with the fuel affects the temperature of the engine, the amount of pollutant gases that form and how efficiently the catalytic converter works.
Two major pollutant gases are carbon monoxide (CO) and nitrogen monoxide (NO).
(2015 P2 B8)

(a) A 'lean burn' engine runs with a higher ratio of air to fuel than a normal car engine.
This means that the mixture contains a higher amount of air compared to fuel.
One effect of this is a lower running temperature of the engine.
How will a lean burn engine affect the amount of carbon monoxide and nitrogen monoxide formed compared to a normal car engine? Explain your reasoning. [3]

- With a higher amount of air, there will be a greater amount of oxygen for complete combustion of the fuel. Hence, less carbon monoxide is formed.
- Oxygen and nitrogen in air react to form oxides of nitrogen at high temperatures. With a lower running temperature, less nitrogen monoxide is formed.

(b) The catalytic converter removes pollutant gases of carbon monoxide and nitrogen monoxide by oxidation and reduction.

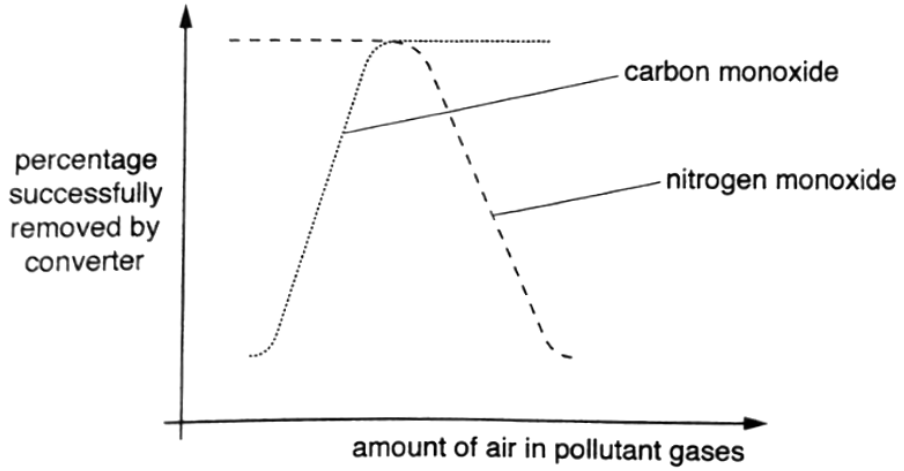
from oxidising agent ↓ $CO + [O] \rightarrow CO_2$

to reducing agent ↓ $2NO \rightarrow N_2 + 2[O]$

Write an overall equation to show how carbon monoxide and nitrogen monoxide react together in the converter. [1]

$2\ CO + 2\ NO \rightarrow 2\ CO_2 + N_2$

(c) The amount of air in the pollutant gases that enter the catalytic converter affects the reactions in the converter.
The graph shows the percentage of carbon monoxide and nitrogen monoxide that the catalytic converter successfully **removes**.



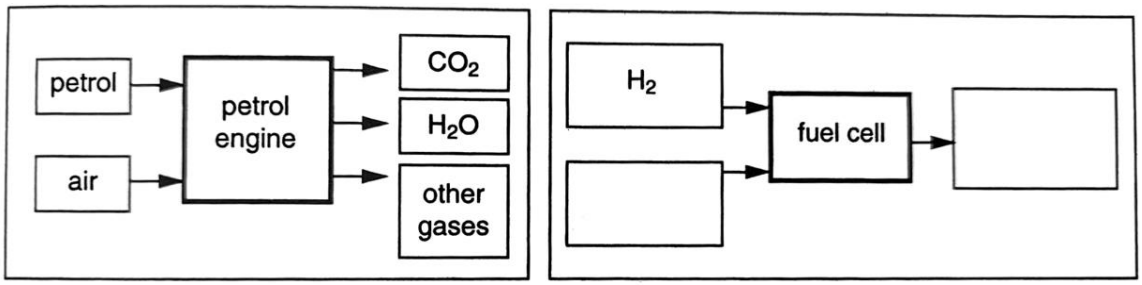
(i) Describe and explain how an increased amount of air affects the removal of carbon monoxide and nitrogen monoxide. [3]

- At a low amount of air, some CO undergoes complete combustion while most CO reacts with NO and the percentage of NO removed is at a maximum high.
- As the amount of air increases, the percentage of CO removed increases until a maximum high, from there the percentage of NO removed decreases since there is little CO to react with NO.

(ii) In the converter, apart from reacting with each other, carbon monoxide and nitrogen monoxide react with other substances as well.
How does the graph show that this statement is true? [1]

At the maximum percentage of CO and NO removed, the percentage of NO and CO removed respectively is not at zero.

4 Most vehicles have petrol or diesel engines, but some use fuel cells.
The flow charts show the substances entering and leaving a petrol engine and a fuel cell.



(2013 P2 A5)

(a) Complete the flow chart for the fuel cell by filling in the empty boxes. [1]

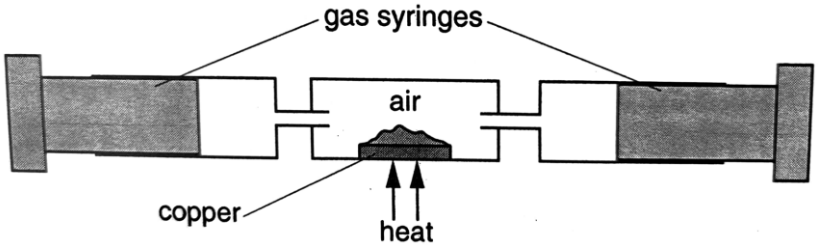
(b) The waste products from vehicles with petrol engines cause more harm to human health than those from vehicles with fuel cells.
Explain why this statement is true. [3]

- The only waste product from fuel cells is water which is non-polluting and harmless to human health.
- Carbon dioxide from petrol engines is added to the atmosphere at a higher rate than photosynthesis can remove the excess gas. This build-up of greenhouse gases causes global warming that may cause a decrease in crop yields and a rise in sea levels that results in flooding of low-lying areas.
- Carbon monoxide from incomplete combustion of petrol is a toxic gas that causes breathing difficulties and even death.
- Sulfur dioxide and oxides of nitrogen are irritants and can irritate eyes and lungs.

(c) Some people think that hydrogen is a completely non-polluting fuel.
Explain why this is incorrect. [2]

- While combustion of hydrogen does not produce pollutants, the production of hydrogen requires electricity which is generated by burning fossil fuels such as coal, petroleum and natural gas.
- These produce much carbon dioxide and other atmospheric pollutants such as oxides of nitrogen and sulfur dioxide.

5 An experiment (Experiment 1) was set up to heat copper in air.



At the start of experiment 1, the apparatus contained a total of 200 cm^3 of air.
During heating, the copper reacted with oxygen in air to form black copper(II) oxide.
The copper was heated until the volume of gas, measured at room temperature and pressure, remained constant. (2013 P2 B9 OR)

(a) Explain why it was important to continue heating until the volume remained constant. [1]

Ensure that the reaction is complete, and all the oxygen gas in the air has reacted with the heated copper.

(b) The table shows some data about the mass change during the experiment.

mass of copper at start of the experiment	**mass of solid left at the end of the experiment**
1.00 g	1.07 g

Use the data in the table to show that the solid left at the end of the experiment contains unreacted copper. [3]

$2\ Cu + O_2 \rightarrow 2\ CuO$
No. of moles of Cu used = 1 / 64 = 0.015625 mol
Mass of CuO formed = 0.015625 x 80 = 1.25 g

Since the mass of solid at the end of the experiment is 1.07 g which is less than the maximum possible mass of CuO formed, there is unreacted copper.

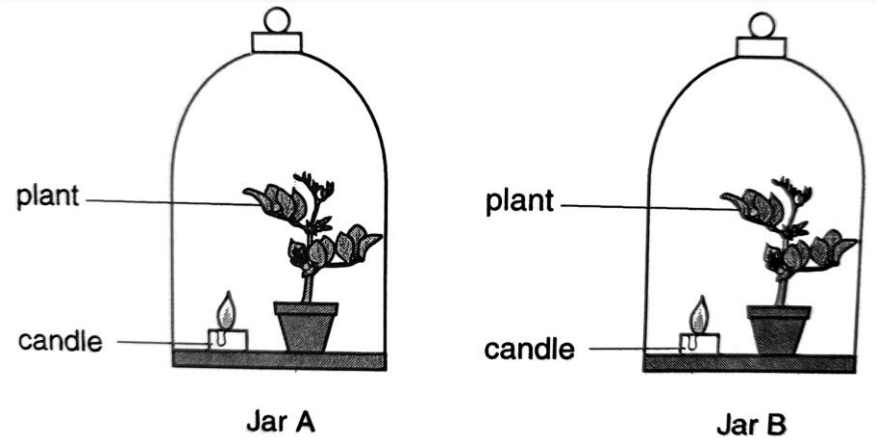
(c) Name the gas that is left in the gas syringes, in the largest amount, at the end of the experiment. [1]

Nitrogen

(d) Estimate the total volume of gas left in the gas syringes at the end of the experiment. Explain your reasoning. [2]

Since 21% of air is oxygen, the volume of air used in the reaction would be 42 cm^3, leaving a total of 158 cm^3 of unreacted air in the syringes.

(e) A burning candle and a plant were placed in two jars of air. Both jars were left in sunlight.



A 200 cm^3 sample of the air from Jar A was tested immediately after the candle burned out using the same procedure as in Experiment 1.
A 200 cm^3 sample of the air from Jar B was tested a few days after the candle burned out using the same procedure as in Experiment 1.
Describe and explain how the results of the tests would differ for each jar. [3]

Jar A:

- Mass of solid left at the end of experiment 1 will be the same as the mass of copper at the start of the experiment.
- The oxygen gas in Jar A has been used up by burning the candle.

Jar B:

- Mass of solid left at the end of experiment 1 will be greater than the mass of copper at the start of the experiment.
- The oxygen gas in Jar B has been replenished by the photosynthesis of the green plants. There is now oxygen available to react with the heated copper to form copper(II) oxide solid.