Topic 13E: **Answers**
Air & The Atmosphere (Extensions)

SYLLABUS RELEVANCE & TEXTBOOK CHAPTERS		
O-LEVEL PURE (5072)	✓	Chapter 20
O-LEVEL SCIENCE (5116)	✖	
N-LEVEL SCIENCE (5155)	✖	

Lesson Package & Accompanying Slides Designed by Alex Lee (2008)
Last Modified by Alex Lee (2011)

1. **Environmental Issues Arising From Air Pollution**

Reactions of Acidic Gases

Acidic gases, such as sulfur dioxide (SO_2) and nitrogen dioxide (NO_2) react readily with moisture from the environment (e.g. rain) to form acid rain.

$$2\ SO_2\ (g) + 2\ H_2O\ (l) + O_2\ (g) \longrightarrow 2\ H_2SO_4\ (aq)$$

$$4\ NO_2\ (g) + 2\ H_2O\ (l) + O_2\ (g) \longrightarrow 4\ HNO_3\ (aq)$$

Although nitrogen monoxide (NO) is not acidic, it still contributes to acid rain by oxidising readily in air to become nitrogen dioxide.

$$2\ NO\ (g) + O_2\ (g) \longrightarrow 2\ NO_2\ (g)$$

Three problems arise from acidic air pollutants:

① These gases dissolve into rain, forming acid rain. This causes damage to buildings, stonework, vegetation and marine life.

② These gases dissolve into the moisture in our eyes, causing eye irritation.

③ These gases dissolve into the moisture in our lungs, causing lung damage.

Carbon Monoxide Poisoning

Haemoglobin is the chemical in our blood that is responsible for transporting oxygen in our body. It picks up fresh oxygen from our lungs, and brings it to the various part of the body.

If the air we breathe contains carbon monoxide, the haemoglobin will rather bind with the carbon monoxide molecule than an oxygen molecule. Furthermore, this binding is permanent – unlike oxygen, the carbon monoxide molecule will never leave the haemoglobin.

As a result, the haemoglobin molecule loses its ability to transport oxygen.

At higher concentrations, this would cause breathing difficulties, fatigue, headaches and eventually death.

Global Warming

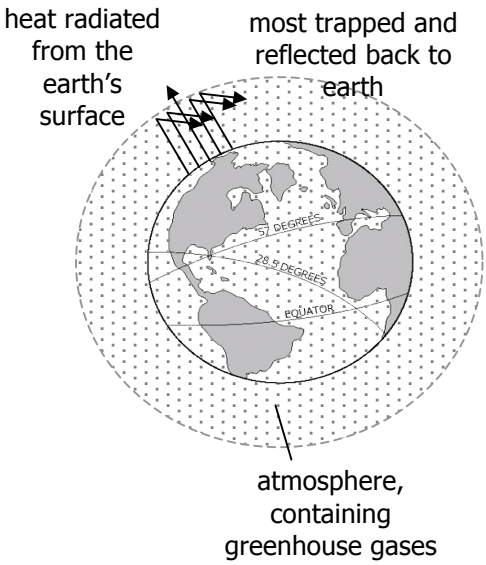
Greenhouse gases like ..methane.. (CH_4) and ..carbon dioxide.. (CO_2) are useful in trapping heat, reducing heat loss to outer space.

However, human activities such as burning of fossil fuels and deforestation have led to an increase of greenhouse gases, causing ..global warming..

Several problems arise from the increasing levels of greenhouse gases:

① Melting of the ..polar ice caps.., leading to rising sea levels and hence ..flooding..

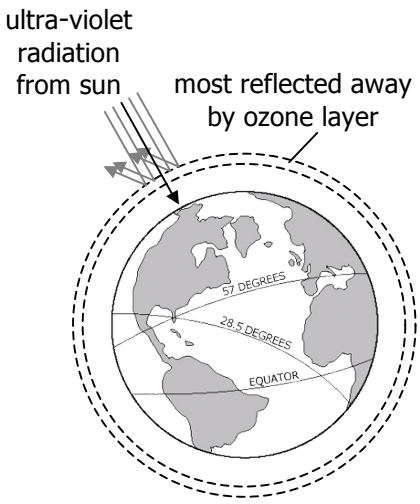
② Drying up of ..water bodies.. such as lakes and rivers, leading to ..droughts..



Depletion of the Ozone Layer

The earth is surrounded by a layer of ..ozone.. (O_3). This layer plays an important role in reducing the intensity of the ..ultra-violet.. radiation received from the sun.

Without this screening effect, ..overexposure.. to ultra-violet radiation on earth would occur, leading to ..skin cancer, genetic mutations and eye damage (cataract)..



..Chlorofluorocarbons.. (or CFCs for short) are compounds which literally contain chlorine, fluorine and carbon only. These compounds, in the presence of ..ultra-violet light.., emit ..chlorine.. atoms which react with ozone (O_3), depleting the ozone layer in the process.

$$CF_3Cl \xrightarrow{\text{ultra-violet light}} CF_3 + Cl$$

$$2\,Cl + O_3 \longrightarrow Cl_2O + O_2$$

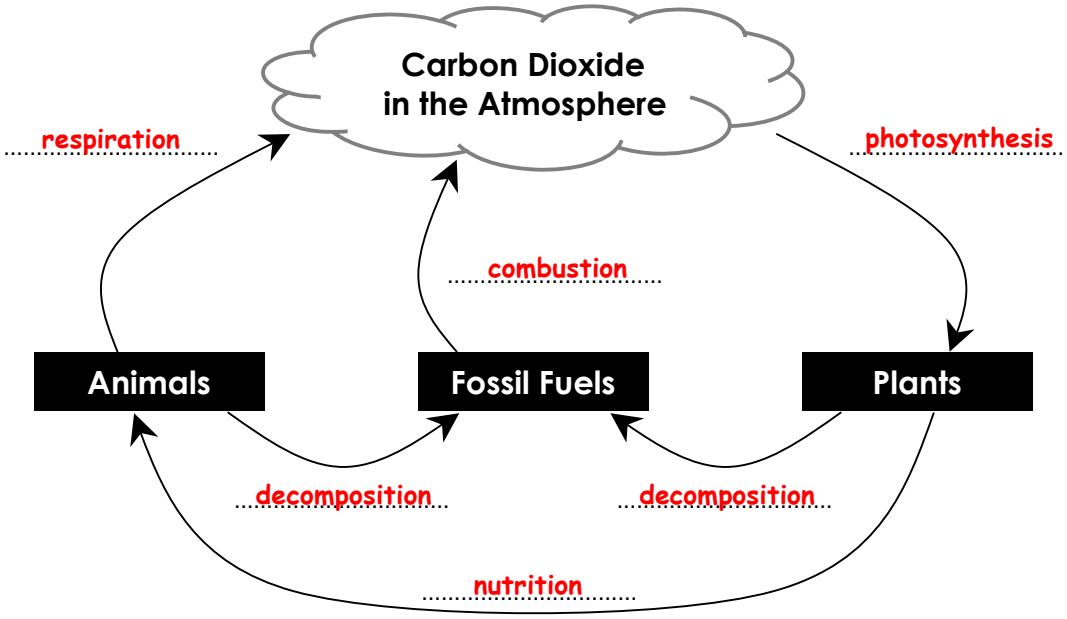
Since 1996, most countries in the world have banned the use of CFC-releasing products, such as certain aerosols and refrigerants.

2. **The Carbon Cycle**

Carbon dioxide can be both harmful and beneficial. For example, a small amount of carbon dioxide provides the necessary greenhouse effect to keep the earth's surface warm. However, excessive levels of carbon dioxide can lead to global warming.

It is thus important to maintain a fixed concentration of carbon dioxide in the atmosphere. This is achieved through what is known as the **carbon cycle**, comprising the key processes of respiration, photosynthesis, combustion, nutrition and decomposition.

The **carbon cycle** is important in ..maintaining the level of carbon dioxide.. in our atmosphere, so as to allow ..respiration.. and prevent ..global warming..



(a) (i) What is the main process in which carbon dioxide is removed from the atmosphere?

Photosynthesis

(ii) The process of respiration involves the breaking down of glucose ($C_6H_{12}O_6$) in our blood, with oxygen, into carbon dioxide and water. Construct an equation for respiration.

$C_6H_{12}O_6 + 6\ O_2 \longrightarrow 6\ CO_2 + 6\ H_2O$

(iii) The process of photosynthesis involves the formation of glucose ($C_6H_{12}O_6$) from carbon dioxide and water. Oxygen is released. Construct a chemical equation for photosynthesis.

$6\ CO_2 + 6\ H_2O \longrightarrow C_6H_{12}O_6 + 6\ O_2$

(b) Name four main greenhouse gases, apart from carbon dioxide.

Methane, unburnt hydrocarbons, ground-level ozone, chlorofluorocarbons

3. **Sources of Air Pollutants**

Pollutant	Source(s)	Due to Vehicle Exhausts?	Due to Coal-Powered Factories?
sulfur dioxide	1. volcanic emissions 2. combustion of sulfur-containing fossil fuels	✓	
carbon dioxide	1. combustion of carbon-based fuels 2. biological processes, e.g. respiration	✓	✓
carbon monoxide	incomplete combustion of carbon-based fuels i.e. with insufficient supply of oxygen/air	✓	✓
unburnt hydrocarbons	incomplete combustion of carbon-based fuels e.g. petrol, diesel		✓
methane *(also a hydrocarbon)*	1. natural gas fields under the earth's surface 2. bacterial decay of vegetable matter		
nitrogen dioxide **nitrogen monoxide**	1. lightning 2. internal combustion engines in motor vehicles		✓

(a) Most motor vehicles run on fossil fuels, such as petrol or diesel. Briefly suggest why vehicle exhausts do not contain sulfur dioxide.

Fuels for motor vehicles, such as petrol or diesel, are treated to remove sulfur impurities ('desulfurisation'), during the oil refinery process, before sale.

(b) Outline how oxides of nitrogen are formed in an internal combustion engine.

Due to the high temperatures in an internal combustion engine, nitrogen from air combusts with oxygen, also from air to form nitrogen dioxide.

(c) Indicate if the following statements are **true** or **false**.

Sulfur dioxide is formed from the combustion of sulfur-based fuels. false

Most fossil fuels naturally have sulfur impurities in them. true

Nitrogen oxides are formed from the combustion of petrol in cars. false

Carbon-based fuels include hydrocarbons and coal. true

All carbon-based fuels are fossil fuels. false

Methane is an example of a hydrocarbon. true

4. **Measures to Control Air Pollution – Flue Gas Desulfurisation (Industrial Plants)**

'Flue gas' refers to emissions from a duct, pipe of chimney conveying exhaust fumes from the combustion of fossil fuels. Fossil fuels that contain sulfur produce the pollutant sulfur dioxide when burnt, and this eventually leads to acid rain.

Flue gas desulfurisation is the process of removing sulfur dioxide from waste gases of factories in industrial areas through the use of limestone.

This process occurs in three steps:

① The limestone thermally decomposes due to the heat of the flue gases, forming quicklime.

Equation: $CaCO_3\ (s) \longrightarrow CaO\ (s) + CO_2\ (g)$

② The quicklime reacts with the sulfur dioxide, forming calcium sulfite.

Equation: $CaO\ (s) + SO_2\ (g) \longrightarrow CaSO_3\ (s)$

③ The calcium sulfite oxidises in air, forming calcium sulfate.

Equation: $2\ CaSO_3\ (s) + O_2\ (g) \longrightarrow 2\ CaSO_4\ (s)$

The gaseous product from flue gas desulfurisation is carbon dioxide, while the residue is calcium sulfate. This residue can be used to manufacture plaster or cement.

(a) (i) Apart from flue gas desulfurisation, suggest another method to reduce the sulfur dioxide emissions from the combustion of fossil fuels.

Desulfurisation of the fossil fuel prior to combustion.

(ii) Suggest why the method as described in (b)(i) is not widely employed in industrial areas.

Very expensive, compared to flue gas desulfurisation.

(b) (i) Suggest why limestone is used instead of using calcium oxide directly.

Limestone is naturally abundant and is hence cheaper than calcium oxide.

(ii) Apart from sulfur dioxide, suggest some other gases that can be removed with limestone.

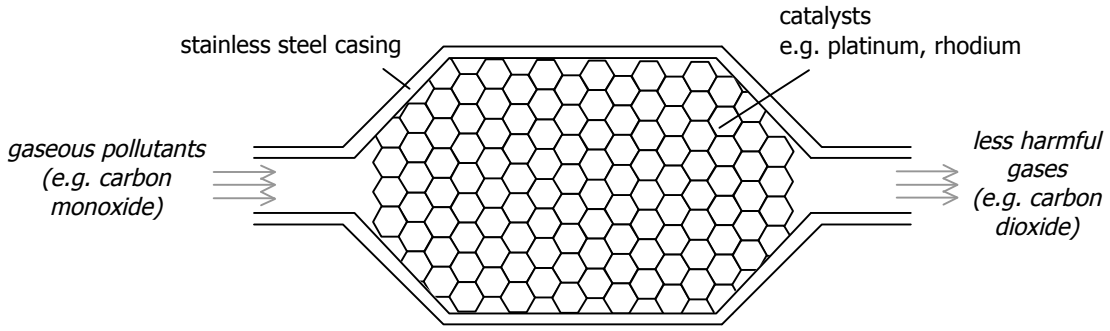
Other acidic gases, e.g. NO_2.

(c) Name a common air pollutant that is present in flue gases which is not removed by the reaction of limestone.

Carbon monoxide

5. **Measures to Control Air Pollution – Catalytic Converters (Motor Vehicles)**

The diagram below shows a **catalytic converter**, which is fitted into exhausts of motor vehicles to reduce the amount of harmful gases emitted.



A **catalytic converter** is a device fitted in motor exhausts to facilitate the removal of air pollutants by ..allowing various air pollutants to react with each other.. through a series of ..redox.. reactions, forming less harmful products.

Complete the diagram below which illustrates the various conversions which take place in a catalytic converter. Also state whether the reactions are reduction or oxidation.

pollutant		*product(s)*			
CO carbon monoxide	catalytic converter →	CO_2 carbon dioxide			☐ Reduced? ☑ Oxidised?
NO nitrogen monoxide	catalytic converter →	N_2 nitrogen			☑ Reduced? ☐ Oxidised?
NO_2 nitrogen dioxide	catalytic converter →	N_2 nitrogen			☑ Reduced? ☐ Oxidised?
CH_4 methane	catalytic converter →	CO_2 carbon dioxide	+	H_2O water vapour	☐ Reduced? ☑ Oxidised?
C_xH_y hydrocarbons	catalytic converter →	CO_2 carbon dioxide	+	H_2O water vapour	☐ Reduced? ☑ Oxidised?

(a) Suggest why it is not necessary for a car's catalytic converter to remove sulfur dioxide.

Vehicle exhaust fumes do not contain sulfur dioxide as petrol fuel is desulfurised.

(b) Construct a equation for the reaction between carbon monoxide and nitrogen dioxide.

$4\ CO + 2\ NO_2 \longrightarrow N_2 + 4\ CO_2$

Self-Designed Summary

Supplementary Questions

1. Use the gases in the box below to answer the questions that follow.

ammonia	**chlorine**	**nitrogen**	**ozone**
argon	**helium**	**nitrogen dioxide**	**sulfur dioxide**
carbon dioxide	**hydrogen**	**nitrogen monoxide**	**water vapour**
carbon monoxide	**methane**	**oxygen**	**xenon**

State all of the above gases which
(a) can be oxidised by a catalytic converter,
(b) can be reduced by a catalytic converter,
(c) is produced near volcanoes,
(d) exists as a pair of gases in equilibrium,
(e) are products of the reactions that occur in a catalytic converter,
(f) are removed from flue gases by reaction with limestone,
(g) are emitted during bacterial decomposition of vegetable matter,
(h) are directly taken in by plants,
(i) is a hydrocarbon,
(j) can be used as a fuel.

2. Which of the following are not responsible for the depletion of the ozone layer?
A CFCs **B** chlorine atoms **C** fluorine atoms **D** ultra-violet light

3. Which of the following statements about ozone is false?
A It has a relative molecular mass of 48.
B It is a compound which takes up a triatomic structure.
C Levels of ozone near the earths surface contributes to global warming.
D The ozone layer protects the earth from excessive ultra-violet radiation.

4. Which of the following pollutants is not due to the combustion of fuel?
A carbon dioxide **B** carbon monoxide **C** nitrogen dioxide **D** sulfur dioxide

5. Which of the following pollutants is not present in the exhaust fumes of cars?
A carbon dioxide **B** carbon monoxide **C** nitrogen dioxide **D** sulfur dioxide

Supplementary Questions (Answers)

Question 1

(a) carbon monoxide, methane
(b) nitrogen dioxide, nitrogen monoxide
(c) sulfur dioxide
(d) nitrogen dioxide, nitrogen monoxide
(e) carbon dioxide, nitrogen, water vapour
(f) sulfur dioxide
(g) methane, carbon dioxide, water vapour
(h) carbon dioxide (for photosynthesis), oxygen (for respiration), water vapour
(i) methane
(j) hydrogen, methane

Multiple-Choice Questions

2 C 3 B 4 C 5 D

Lecture Slides

Air & The Atmosphere (Extensions)

Anglo-Chinese School (Barker Road)

CHEMISTRY
Prepared by Alex Lee

Chapter Overview

In This Chapter, We Will Learn …

1. Environmental Issues from Air Pollution
2. Carbon Cycle
3. Source of Air Pollutants
4. Flue Gas Desulfurisation
5. Catalytic Converters

Air Pollution: Environmental Issues

- In this chapter, we will examine four environmental issues that arise from air pollution:
  - Formation of Acid Rain & Related Problems
  - Carbon Monoxide Poisoning
  - Global Warming
  - Depletion of the Ozone Layer
- The first two issues have already been covered in the earlier tutorial.

Reactions of Acidic Gases [Recap]

- Acidic gases, such as **sulfur dioxide** (SO_2) and **nitrogen dioxide** (NO_2) dissociate readily in water to form acids.
- This means that these gases can react with moisture in our environment and also in our eyes or lungs.

$$2\ SO_2\ (g) + 2\ H_2O\ (l) + O_2\ (g) \longrightarrow 2\ H_2SO_4\ (aq)$$
$$4\ NO_2\ (g) + 2\ H_2O\ (l) + O_2\ (g) \longrightarrow 4\ HNO_3\ (aq)$$

Reactions of Acidic Gases [Recap]

- Although **nitrogen monoxide** (NO) is **not acidic**, it still contributes to acid rain by oxidising readily in air to form nitrogen dioxide.

$$2\ NO\ (g) + O_2\ (g) \longrightarrow 2\ NO_2\ (g)$$

Reactions of Acidic Gases [Recap]

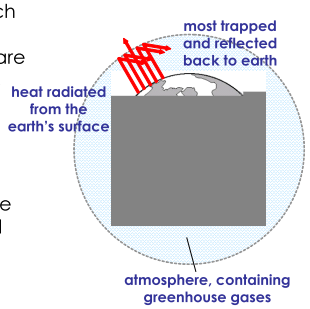
- These gases – sulfur dioxide, nitrogen dioxide and nitrogen monoxide – give rise to some problems:
  - These gases dissolve into rain, forming **acid rain**. This causes **damage to buildings, stonework, vegetation and marine life**.
  - These gases dissolve into the moisture in our eyes, causing **eye irritation**.
  - These gases dissolve into the moisture in our lungs, causing **lung damage**.

Carbon Monoxide Poisoning [Recap]

- Haemoglobin is the chemical in our blood that is responsible for transporting oxygen in our body.
- Carbon monoxide, when inhaled, **binds strongly with the haemoglobin** permanently. The haemoglobin **loses its ability to transport oxygen**.
- At higher concentrations, this will cause **breathing difficulties, fatigue, headaches and eventually death**.

Global Warming

- **Greenhouse gases**, such as methane (CH_4) and carbon dioxide (CO_2) are useful in trapping heat, thus **preventing excessive heat loss to outer space**.
- Without the greenhouse effect, the earth would be too cold to live in.



Global Warming

increases production of carbon dioxide

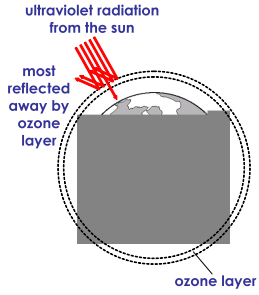
- However, human activities such as **burning of fossil fuels** and **deforestation** have led to an increase of such greenhouse gases – hence causing **global warming**.

decreases removal of carbon dioxide

- This gives rise to several problems:
  - Melting of the **polar ice caps**, leading to rising sea levels and hence **flooding**.
  - Drying up of **water bodies** such as lakes and rivers, leading to **drought** and hence **famine**.

Depletion of Ozone Layer

- The earth is surrounded by a layer of ozone (O_3), or the **ozone layer**.
- This layer plays an important role in **reducing the intensity of ultra-violet radiation** received from the sun.

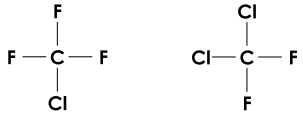


Depletion of Ozone Layer

- Without the screening effect provided by the ozone layer, **overexposure to ultra-violet radiation** would occur.
- This will lead to **skin cancer**, **genetic mutations** and **eye damage (cataract)**.

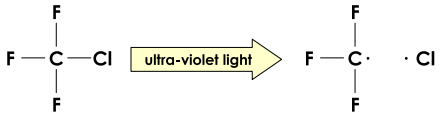
Depletion of Ozone Layer

- **Chlorofluorocarbons** (CFCs) are compounds that contain chlorine, fluorine and carbon only. These compounds react with the ozone layer, destroying it in the process.
- *Examples of CFCs:*



Depletion of Ozone Layer

- CFCs, in the presence of **ultra-violet light**, emit **chlorine atoms** which are extremely unstable.



- The **chlorine atoms produced** subsequently attack the ozone molecules, hence depleting the ozone layer.

$$2\,Cl + O_3 \longrightarrow Cl_2O + O_2$$

ozone — oxygen

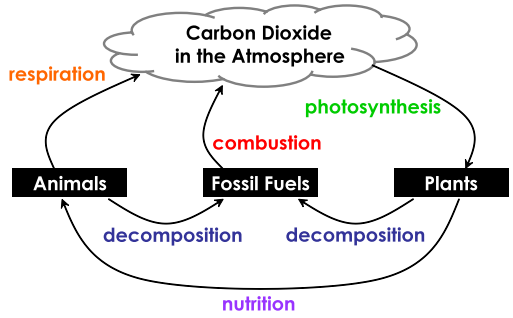
The Carbon Cycle

- Carbon dioxide can be both harmful and beneficial.
- A small amount of carbon dioxide provides the **necessary greenhouse effect** to keep the earth's surface warm.
- However, excessive amounts can lead to **global warming**.
- It is thus important to maintain a fixed concentration of carbon dioxide in the atmosphere.

The Carbon Cycle

- The carbon cycle is important in **maintaining the level of carbon dioxide** in our atmosphere, so as to allow **respiration** and prevent **global warming**.
- This is achieved through the key processes of **respiration**, **photosynthesis**, **combustion**, **nutrition** and **decomposition**.

The Carbon Cycle



The Carbon Cycle

- The main (and only) process in which carbon dioxide is removed from the atmosphere is **photosynthesis**.
- Equation for photosynthesis:

$$6\,CO_2 + 6\,H_2O \longrightarrow C_6H_{12}O_6 + 6\,O_2$$

Remember the formula for glucose!

- The reverse process is respiration:

$$C_6H_{12}O_6 + 6\,O_2 \longrightarrow 6\,CO_2 + 6\,H_2O$$

Sources of Air Pollutants

Caused by Coal-Powered Factories •

Pollutant	Source(s)
sulfur dioxide	1. volcanic emissions 2. combustion of sulfur-containing fossil fuels
carbon dioxide	1. combustion of carbon-based fuels 2. biological processes, e.g. respiration
carbon monoxide	incomplete combustion of carbon-based fuels i.e. with insufficient supply of oxygen/air
unburnt hydrocarbons	incomplete combustion of hydrocarbon fuels e.g. petrol, diesel
methane *(also a hydrocarbon)*	1. natural gas fields under the earth's surface 2. bacterial decomposition of vegetable matter
nitrogen dioxide nitrogen monoxide	1. lightning 2. internal combustion engines in motor vehicles

Caused by Motor Vehicle Exhausts •

Flue Gas Desulfurisation

- A 'flue' is a pipe or chimney which transports waste gases out of a building or factory.
- In industrial areas, flue gases contain a **significant amount of sulfur dioxide**, which can potentially cause acid rain and other environmental damage.
- The process of removing this sulfur dioxide from the flue gases is known as **flue gas desulfurisation**.

Images: http://www.mtrinc.com/

Flue Gas Desulfurisation

- **Flue gas desulfurisation** is the process of **removing sulfur dioxide** from waste gases of factories in industrial areas through the use of **limestone**.
- The flue gases are allowed to pass through a suspension of limestone (calcium carbonate) in water, so that the sulfur dioxide will react.
- This occurs in three stages.

Flue Gas Desulfurisation

- **Stage 1**: Limestone thermally decomposes, due to the heat of the flue gases.

$$CaCO_3\,(s) \longrightarrow CaO\,(s) + CO_2\,(g)$$

- **Stage 2**: The quicklime formed reacts with sulfur dioxide, forming calcium sulfite.

$$CaO\,(s) + SO_2\,(g) \longrightarrow CaSO_3\,(s)$$

- **Stage 3**: The calcium sulfite, on storage, oxidises to form calcium sulfate.

$$2\,CaSO_3\,(s) + O_2\,(g) \longrightarrow 2\,CaSO_4\,(s)$$

Flue Gas Desulfurisation

- The gaseous product from flue gas desulfurisation is **carbon dioxide**.
- The residue from flue gas desulfurisation is **calcium sulfate**. This residue can later be extracted and used to make *plaster of paris* or cement.

Catalytic Converter

- The main pollutants present in vehicle exhausts, apart from carbon dioxide, are:
  - carbon monoxide
  - nitrogen oxides
  - unburnt hydrocarbons and methane
- These pollutants can be removed through the use of a **catalytic converter**, a device fitted inside the exhausts of motor vehicles.

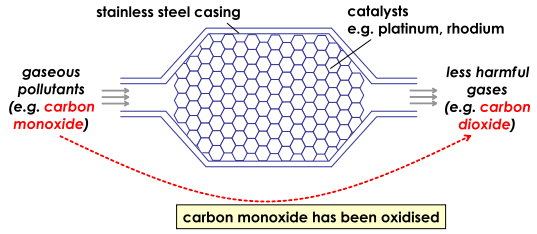
Images: http://davisconverters.com/

Catalytic Converter

- A **catalytic converter** is a device fitted in motor exhausts to facilitate the removal of air pollutants by **allowing various air pollutants to react with each other** through a series of **redox reactions**, forming less harmful products.
- Typically uses platinum or rhodium as a catalyst.

Catalytic Converter

- Facilitates **redox reactions** to form **less harmful products** from these air pollutants.



Catalytic Converter