

## NOTES

Describe the ease in obtaining metals from their ores by relating the elements to the reactivity series

### Extraction of ores from the Earth's crust

- The Earth's crust contains metals and metal compounds such as gold, iron oxide and aluminium oxide.
- When found in the Earth, these are often mixed with other substances.
- To be useful, the metals have to be extracted from their ores through processes such as electrolysis, using a blast furnace or by reacting with more reactive material.
- The extraction of metals is a reduction process.
- Unreactive metals do not have to be extracted as they are often found as the uncombined element as they do not easily react with other substances.

### Extraction of metal and the reactivity series

- The position of the metal on the reactivity series influences the method of extraction.
- Those metals placed higher up on the series (above carbon) have to be extracted using electrolysis.
- Metals lower down on the series can be extracted by heating with carbon.

### The reactivity series and extraction of metals

The reactivity series and extraction of metals

METAL	ABBREVIATION
MOST REACTIVE	EXTRACTED BY ELECTROLYSIS OF THE MOLTEN CHLORIDE OR MOLTEN OXIDE LARGE AMOUNTS OF ELECTRICITY REQUIRED SO EXPENSIVE PROCESS
POTASSIUM	
SODIUM	
LITHIUM	
CALCIUM	
MAGNESIUM	
ALUMINIUM	
CARBON	
ZINC	EXTRACTED BY HEATING WITH A REDUCING AGENT SUCH AS CARBON OR CARBON MONOXIDE IN A BLAST FURNACE CHEAP PROCESS AS CARBON IS CHEAP AND CAN BE SOURCE OF HEAT AS WELL
IRON	
HYDROGEN	
COPPER	
SILVER	FOUND AS PURE ELEMENTS
GOLD	
LEAST REACTIVE	

## Extraction of Iron from Hematite

### Core:

- Describe and state the essential reactions in the extraction of iron from hematite

### The extraction of iron in the blast furnace

The extraction of iron in the blast furnace

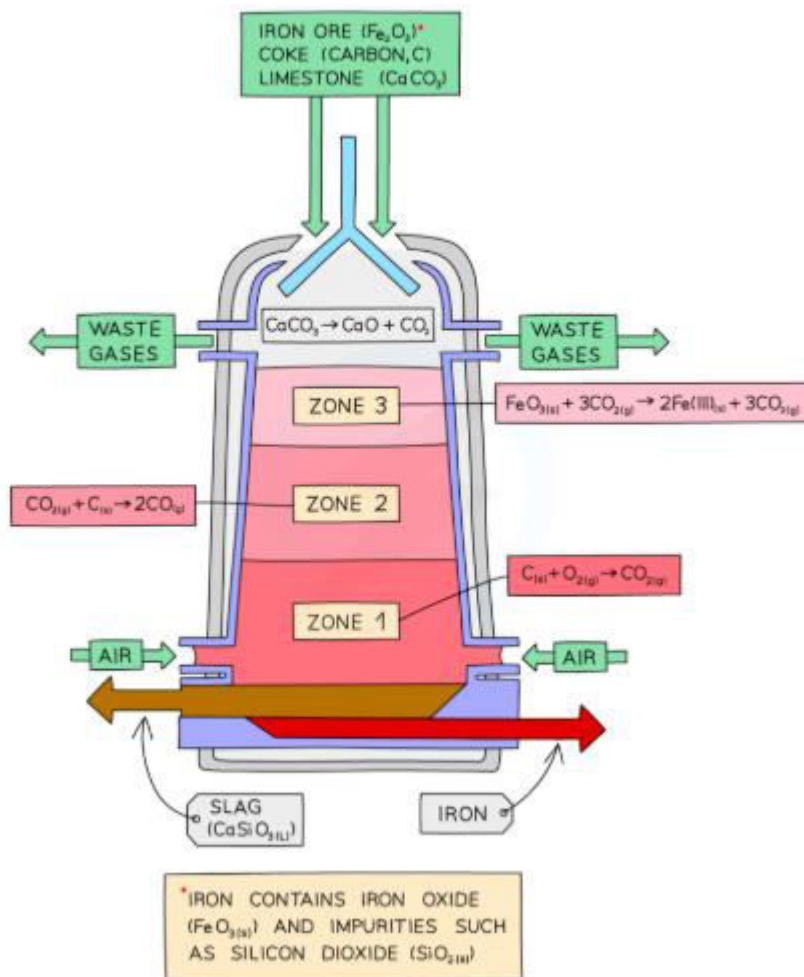


Diagram Showing the Carbon Extraction of Iron

### Raw Materials:

Iron Ore (Haematite), Coke, Limestone and Air

### Explanation:

Iron Ore, Coke and Limestone are mixed together and fed into the top of the blast furnace. Hot air is blasted into the bottom of the blast furnace

### Zone 1

Coke is used as the starting material. It is an impure carbon and it burns in the hot air blast to form carbon dioxide. This is a strongly [exothermic reaction](#):



### Zone 2

At the high temperatures in the furnace, carbon dioxide reacts with coke to form carbon monoxide:



### Zone 3

Carbon Monoxide (the reducing agent) reduces the Iron (III) Oxide in the Iron Ore to form Iron, which will melt and collect at the bottom of the furnace, where it is tapped off:



Limestone is added to the furnace to remove impurities in the ore. The Calcium Carbonate in the limestone decomposes to form calcium Oxide:



The Calcium Oxide reacts with the Silicon Dioxide, which is an impurity in the Iron Ore, to form Calcium Silicate. This melts and collects as a molten slag floating on top of the molten Iron which is tapped off separately:



## The Conversion of Iron into Steel

### Core:

- Describe the conversion of iron into steel using basic oxides and oxygen

### Making steel from iron

- Molten iron is an alloy of 96% iron, with carbon, phosphorus, silicon and sulfur impurities.
- It is too brittle for most uses, so most of it is converted into steel by removing some of the impurities.
- Not all of the carbon is removed as steel contains some carbon, the percentage of which depends on the use of the steel.
- The molten iron is transferred to a **tilting furnace** where the conversion to steel takes place.
- Oxygen** and **powdered calcium oxide** are added to the iron.
- The oxygen oxidises the carbon, phosphorus, silicon and sulfur to their oxides which are all **acidic**.

- CO<sub>2</sub> and SO<sub>2</sub> are gaseous so escape from the furnace.
- The acidic silicon and phosphorus oxides react with the powdered calcium oxide and form a slag which is mainly calcium silicate:



- The slag floats on the surface of the molten iron and is removed.

## Aluminium Extraction and Benefits of Recycling

### Core:

- Know that aluminium is extracted from the ore bauxite by electrolysis
- Discuss the advantages and disadvantages of recycling metals, limited to iron/steel and aluminium

### Extraction of aluminium

- Aluminium is a reactive metal which sits above carbon on the reactivity series.
- It cannot be extracted from its ore (bauxite) by carbon reduction, so electrolysis is used.

### Recycling metals: iron, steel and aluminium

#### Advantages

- Raw materials are conserved (bauxite and haematite).
- Energy use is reduced, especially in the electrolysis of aluminium.
- Less pollution is produced as both processes contribute to air pollution.

#### Disadvantages

- More transport on roads carrying used metals to recycling centres.
- Energy consumed in collecting materials and sorting them per material type.

## Extended Subject Content

### The Process of Aluminium Extraction by Electrolysis

#### Supplement:

- Describe in outline, the extraction of aluminium from bauxite including the role of cryolite and the reactions at the electrodes

#### Raw Materials:

*Aluminium Ore (Bauxite)*

### Explanation:

The Bauxite is first purified to produce Aluminium Oxide  $\text{Al}_2\text{O}_3$

Aluminium Oxide has a very high melting point so it is first dissolved in molten Cryolite producing an electrolyte with a lower melting point, as well as a better conductor of electricity than molten aluminium oxide. This also reduces expense considerably.

The electrolyte is a solution of aluminium oxide in molten cryolite at a temperature of about  $1000^\circ\text{C}$ . The molten aluminium is siphoned off from time to time and fresh aluminium oxide is added to the cell. The cell operates at 5-6 volts and with a current of 100,000 amps. The heat generated by the huge current keeps the electrolyte molten.

A lot of electricity is required for this process of extraction, this is a major expense.

### *Reaction at the Negative Electrode:*

The Aluminium melts and collects at the bottom of the cell and is then tapped off:



### *Reaction at the Positive Electrode:*



Some of the Oxygen Produced at the positive electrode then reacts with the Graphite (Carbon) electrode to produce Carbon Dioxide Gas:



\*This causes the carbon anodes to burn away, so they must be replaced regularly.

## The Process of Zinc Extraction

### *Supplement:*

- Describe in outline, the extraction of zinc from zinc blende

### Extraction of zinc

- Zinc ore is called zinc blende,  $\text{ZnS}$ .
- The zinc blende is first converted to zinc oxide by heating with air:



- The reducing agent is carbon monoxide which is formed inside the furnace through a series of reactions.
- Carbon burns in a blast of very hot air to form carbon dioxide:



- The carbon dioxide produced reacts with more coke to form carbon monoxide:



- The carbon monoxide is the reducing agent and reduces the zinc oxide to zinc:



- Note that the zinc produced is in the **gaseous** state.
- This passes out of the furnace and is cooled and condensed in a tray placed at the top of the furnace.
- This is a key difference between the extraction of iron and aluminium, both of which are collected at the **bottom** of the furnace / electrolytic cell in the **liquid**.

Extended Candidates can read about [\*the uses of zinc for galvanising and making brass\*](#) in Section 10.4.

[PREV](#)[NEXT](#)

## Uses of Aluminium, Copper and Mild Steel

### **Core:**

- Name the uses of aluminium:
  - in the manufacture of aircraft because of its strength and low density
  - in food containers because of its resistance to corrosion
- Name the uses of copper related to its properties (electrical wiring and in cooking utensils)
- Name the uses of mild steel (car bodies and machinery) and stainless steel (chemical plant and cutlery)

### **Uses of Aluminium**

Use	Most Important Property
<b>Aeroplane Bodies</b>	High strength-to-weight ratio (low density)
<b>Overhead Power Cables</b>	Good conductor of electricity
<b>Saucepans</b>	Good conductor of heat
<b>Food Cans</b>	Non-toxic, resistant to corrosion and acidic food stuffs
<b>Window Frames</b>	Resistant to corrosion

### Uses of Copper

Use	Most Important Property
<b>Electrical Wires</b>	Good conductor of electricity and malleable
<b>Water Pipes</b>	Easy to work with and bend, non-toxic and unreactive (does not react with water)

### Uses of Steel

Type Of Steel	Iron alloyed with	Use	Most Important Property
<b>Mild steel</b>	0.25% carbon	Car Body Panels, wires	Soft and malleable
<b>High carbon steel</b>	0.5 - 1.4% carbon	Tools and chisels	Hard
<b>Low alloy steel</b>	1 - 5% of other metals (Cr, Ni, Ti)	Construction, bridges, high speed tools	Hard and strong, low ductility and malleability
<b>Stainless Steel</b>	20% chromium and 10% nickel	Cutlery And Sinks, Chemical Plants	Strong and resistant to corrosion

## Extended Subject Content

### Steel Alloys and Their Properties

#### *Supplement:*

Type Of Steel	Iron alloyed with	Use	Most Important Property
<b>Stainless steel</b>	20% chromium and 10% nickel	Cutlery And Sinks, Chemical Plants	Strong and resistant to corrosion
<b>Tungsten steel</b>	5% tungsten	Edges of high speed cutting tools	Tough and hard at very high temperatures
<b>Manganese steel</b>	13% manganese	Drill bits, springs	Very tough and springy

- Describe the idea of changing the properties of iron by the controlled use of additives to form steel alloys
- The amount of carbon removed depends on the amount of oxygen used.
- By carefully controlling the amount of carbon removed and subsequent addition of other metals such as **chromium**, **manganese** or **nickel**, the particular type of steel alloy is produced.

### Uses of Zinc

#### *Supplement:*

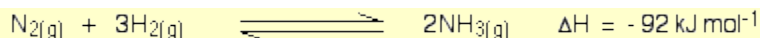
- Explain the uses of zinc for galvanising and for making brass
- Zinc is used in galvanising, the process of coating a metal such as iron or steel with a protective coating of zinc to prevent corrosion or rusting.
- Galvanising is an effective way of rust protection as it works even if the zinc coating becomes scratched or damaged.
- The process can be done **electrolytically** or by dipping the metal parts into **baths** of **molten zinc**.
- Zinc is also used to make an alloy called **brass**.
- Brass contains 70% copper and 30% zinc.
- The addition of zinc makes the alloy much **harder** and **corrosion resistant** than copper alone.



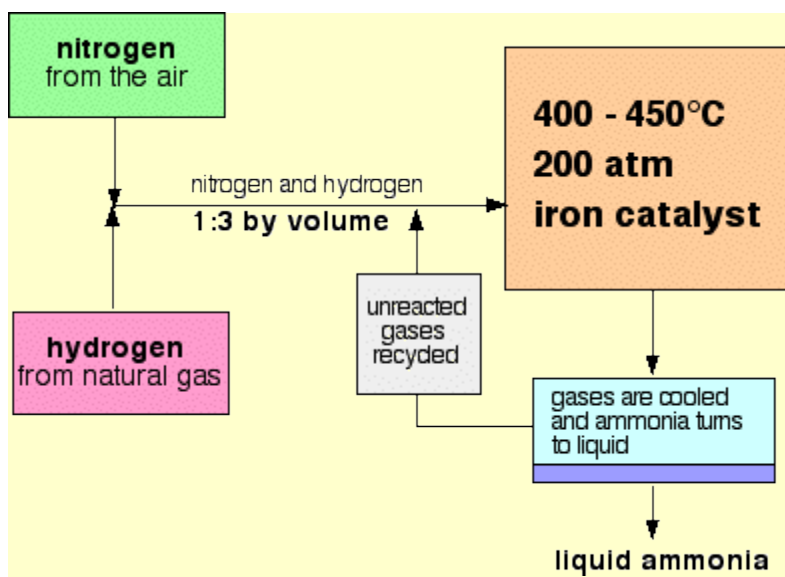
# Ammonia and fertilizers

## A brief summary of the Haber Process

The Haber Process combines nitrogen from the air with hydrogen derived mainly from natural gas (methane) into ammonia. The reaction is reversible and the production of ammonia is exothermic.



A flow scheme for the Haber Process looks like this:



## Some notes on the conditions

### *The catalyst*

The catalyst is actually slightly more complicated than pure iron. It has potassium hydroxide added to it as a promoter - a substance that increases its efficiency.

### *The pressure*

The pressure varies from one manufacturing plant to another, but is always high. You can't go far wrong in an exam quoting 200 atmospheres.

### *Recycling*

At each pass of the gases through the reactor, only about 15% of the nitrogen and hydrogen converts to ammonia. (This figure also varies from plant to plant.) By continual recycling of the unreacted nitrogen and hydrogen, the overall conversion is about 98%.

## **Explaining the conditions**

### **The proportions of nitrogen and hydrogen**

The mixture of nitrogen and hydrogen going into the reactor is in the ratio of 1 volume of nitrogen to 3 volumes of hydrogen.

Avogadro's Law says that equal volumes of gases at the same temperature and pressure contain equal numbers of molecules. That means that the gases are going into the reactor in the ratio of 1 molecule of nitrogen to 3 of hydrogen.

That is the proportion demanded by the equation.

In some reactions you might choose to use an excess of one of the reactants. You would do this if it is particularly important to use up as much as possible of the other reactant - if, for example, it was much more expensive. That doesn't apply in this case.

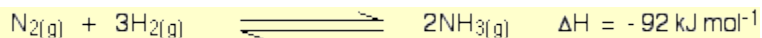
There is always a down-side to using anything other than the equation proportions. If you have an excess of one reactant there will be molecules passing through the reactor which can't possibly react because there isn't anything for them to react with. This wastes reactor space - particularly space on the surface of the catalyst.

## **The temperature**

### ***Equilibrium considerations***

You need to shift the position of the equilibrium as far as possible to the right in order to produce the maximum possible amount of ammonia in the equilibrium mixture.

The forward reaction (the production of ammonia) is exothermic.



According to Le Chatelier's Principle, this will be favoured if you lower the temperature. The system will respond by moving the position of equilibrium to counteract this - in other words by producing more heat.

In order to get as much ammonia as possible in the equilibrium mixture, you need as low a temperature as possible. However, 400 - 450°C isn't a low temperature!

### ***Rate considerations***

The lower the temperature you use, the slower the reaction becomes. A manufacturer is trying to produce as much ammonia as possible per day. It makes no sense to try to achieve an equilibrium mixture which contains a very high proportion of ammonia if it takes several years for the reaction to reach that equilibrium.

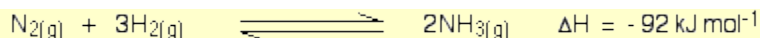
You need the gases to reach equilibrium within the very short time that they will be in contact with the catalyst in the reactor.

### ***The compromise***

400 - 450°C is a compromise temperature producing a reasonably high proportion of ammonia in the equilibrium mixture (even if it is only 15%), but in a very short time.

### **The pressure**

#### ***Equilibrium considerations***



Notice that there are 4 molecules on the left-hand side of the equation, but only 2 on the right.

According to Le Chatelier's Principle, if you increase the pressure the system will respond by favouring the reaction which produces fewer molecules. That will cause the pressure to fall again.

In order to get as much ammonia as possible in the equilibrium mixture, you need as high a pressure as possible. 200 atmospheres is a high pressure, but not amazingly high.

### ***Rate considerations***

Increasing the pressure brings the molecules closer together. In this particular instance, it will increase their chances of hitting and sticking to the surface of the catalyst where they can react. The higher the pressure the better in terms of the rate of a gas reaction.

### ***Economic considerations***

Very high pressures are very expensive to produce on two counts.

You have to build extremely strong pipes and containment vessels to withstand the very high pressure. That increases your capital costs when the plant is built.

High pressures cost a lot to produce and maintain. That means that the running costs of your plant are very high.

### ***The compromise***

200 atmospheres is a compromise pressure chosen on economic grounds. If the pressure used is too high, the cost of generating it exceeds the price you can get for the extra ammonia produced.

## **The catalyst**

### ***Equilibrium considerations***

The catalyst has no effect whatsoever on the position of the equilibrium. Adding a catalyst doesn't produce any greater percentage of ammonia in the equilibrium mixture. Its only function is to speed up the reaction.

### ***Rate considerations***

In the absence of a catalyst the reaction is so slow that virtually no reaction happens in any sensible time. The catalyst ensures that the reaction is fast

enough for a dynamic equilibrium to be set up within the very short time that the gases are actually in the reactor.

## Separating the ammonia

When the gases leave the reactor they are hot and at a very high pressure. Ammonia is easily liquefied under pressure as long as it isn't too hot, and so the temperature of the mixture is lowered enough for the ammonia to turn to a liquid. The nitrogen and hydrogen remain as gases even under these high pressures, and can be recycled.

## Sulfur: Sources and Uses

### Core:

- Name some sources of sulfur
- Name the use of sulfur in the manufacture of sulfuric acid
- State the uses of sulfur dioxide as a bleach in the manufacture of wood pulp for paper and as a food preservative (by killing bacteria)

### Sources of sulfur

- Sulfur is found in its elemental state underground in the USA, Mexico and Poland.
- It is also a by-product from the removal of sulfur from **petroleum** and **natural** gas.
- Sulfur can also be obtained from **sulfide** ores.

### Uses of sulfur

- The main use of sulfur is in making **sulphuric** acid which is a very important chemical used in many industries.
- It is also used extensively in making **rubber** tyres more flexible (vulcanising), where the rubber is heated with sulfur.

### Sulfur dioxide

- Sulfur dioxide can be made by the direct combination of sulphur with oxygen.
- This is the method used in the first stage of the manufacture of sulfuric acid:



### Uses of sulfur dioxide

- As a bleach in the manufacture of wood pulp for paper.
- As a preservative for foods and drinks by killing bacteria.

- Sulfites are often added to foods and these release sulfur dioxide in acidic conditions.

## Extended Subject Content

### Sulfuric Acid: Manufacture, Properties and Uses

#### *Supplement:*

- Describe the manufacture of sulfuric acid by the Contact process, including essential conditions and reactions
- Describe the properties and uses of dilute and concentrated sulfuric acid

#### Manufacture of Sulfuric Acid

Sulfuric acid is synthesised by the **Contact process** which uses sulfur and oxygen from air and is done in three distinct stages.

##### Stage 1

- The first stage is the oxidation of sulfur:



##### Stage 2

- The main stage is the oxidation of sulfur dioxide to sulfur trioxide using a  $\text{V}_2\text{O}_5$  catalyst:



- The conditions for the main stage of production of sulfur trioxide need to be considered:

#### Conditions during Stage 2

##### *Temperature: 450°C*

- The reaction is **exothermic**, so increasing the temperature shifts the position of equilibrium to the left in the direction of the **reactants**.
- Therefore the higher the temperature, the **lower** the yield of sulfur trioxide.
- The optimum temperature is a compromise between a higher rate of reaction at a higher temperature and a lower equilibrium yield at a higher temperature.

##### *Pressure: 2 atm*

- An increase in pressure shifts the position of equilibrium to the **right** in the direction of a smaller number of gaseous molecules.
- However the position of equilibrium lies far to the right (the equilibrium mixture contains about 96% sulfur trioxide).

- So the reaction is carried out at just above atmospheric pressure because:
  - a) it is not worth spending the extra energy or money required to produce high pressures.
  - b) a higher pressure would increase the problems of dealing with the corrosive mixture of gases.

### Stage 3

- Once stage 2 is completed, the sulfur trioxide is absorbed into a solution of 98% sulphuric acid to produce a thick liquid called **oleum**:



- It is not absorbed into water because a fine mist of sulfuric acid would be produced and this would be difficult to condense and is also highly dangerous.
- Oleum is added to water to form concentrated sulfuric acid:

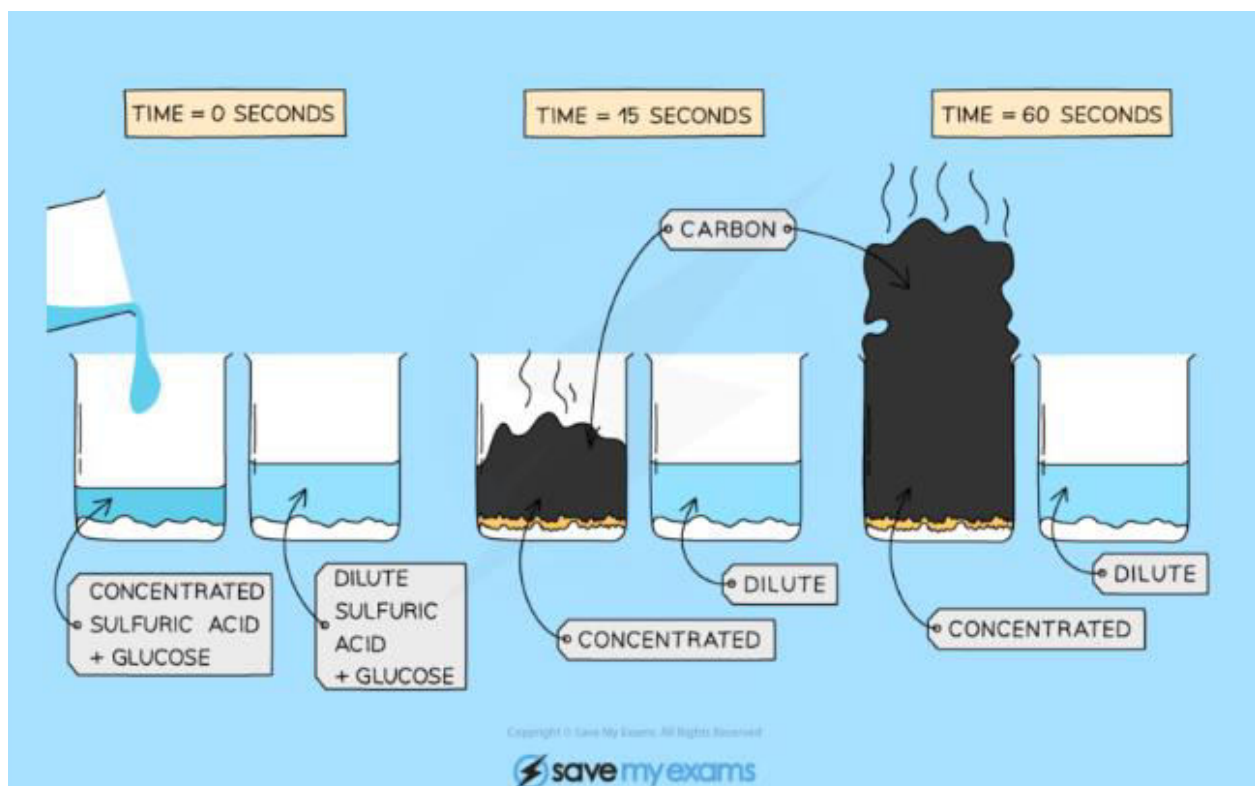


### Properties of Sulfuric Acid

- Sulfuric acid is a **strong dibasic acid** as two of its hydrogen atoms can be replaced by a metal.
- It reacts in a similar way to other acids with metal carbonates, oxides, hydroxides (and ammonia) and metals, e.g:



- Concentrated sulphuric acid is **corrosive** and a powerful **oxidising agent**.
- Concentrated sulphuric acid is also a very powerful **dehydrating** agent and is very good at removing water from other substances.
- For example, if mixed with sugar ( $\text{C}_6\text{H}_{12}\text{O}_6$ ), concentrated  $\text{H}_2\text{SO}_4$  will remove water molecules and leave behind carbon in a spectacular looking reaction that produces a tower of pure carbon.



*The reaction of concentrated  $H_2SO_4$  and sugar, which dehydrates the sugar leaving behind a tower of carbon*

## Uses of Sulfuric Acid

### Dilute

- Used as a catalyst in many **organic** reactions.
- Also used as to clean the **surface** of **metals**.

### Concentrated

- Used in car batteries, making **phosphate fertilisers**, **soaps** and **detergents**.
- It is also used to make **acid drain cleaners** and in the production of **paints** and **dyes**.