

METALS

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Organizer



Objectives

By the end of this topic the learner should be able to:

- Name the chief ores of certain metals.
- Describe and explain the general methods used in the extraction of metals from their ores.
- Select and describe suitable methods of extraction of certain metals from their ores.
- Describe and explain physical and chemical properties of some metals.
- State and explain various uses of these metals and their alloys.
- Describe the effects of the industrial production processes of metals on the environment.

METALS

Some metals occur naturally in a free uncombined state while others are found combined with other elements. Compounds in which metals can be extracted are called **ores**.

Chief Ores of Metals

An ore from which a metal can be obtained on a commercial scale is referred to as the **chief ore**.

The table below gives the chief ores of some common metals.

Metal	Ores of the metal	Formula of ores
Sodium	Sodium chloride Rock salt*	NaCl
Aluminium	Bauxite* Mica Corundum	$\text{Al}_2\text{O}_3 \cdot 2\text{H}_2\text{O}$ $\text{K}_2\text{Al}_2\text{Si}_6\text{O}_{16}$ Al_2O_3
Zinc	Zinc blende* Calamine* Zinc oxide	ZnS ZnCO_3 ZnO
Iron	Haematite* Magnetite Siderite Pyrite	Fe_2O_3 Fe_3O_4 FeCO_3 FeS_2
Copper	Copper pyrites* Malachite Cuprite Azurite	CuFeS_2 $\text{CuCO}_3\text{Cu}(\text{OH})_2$ Cu_2O $\text{Cu}_3(\text{OH})_2(\text{CO}_3)_2$
Lead	Galena* Cerussite Anglesite	PbS PbCO_3 PbSO_4

* Chief ore

Before any extraction process is carried out, qualitative and quantitative analysis is done to determine the metal present and the quantity of the metal in the ore.

General Methods of Extraction

Extraction of metals involves several stages. The stages involved include:

- Mining the metal ores from the earth's crust.
- Concentrating the ores to remove most of the impurities. The process of concentrating an ore may include:
 - Removing** any **magnetic** materials with a magnet.
 - Dissolving** the mineral in a suitable solvent.
 - Washing** with water to remove earthy matter.
 - Froth flotation**. The ore is ground into a fine powder. It is then mixed with water containing special oils such as pine oil as frothing agents. A froth rich in minerals is formed at the top while the impurities sink to the bottom. The froth is skimmed and dried. Copper pyrites, zinc blende and galena are concentrated this way.
- Roasting the ore to obtain metal oxides.
- Reducing the oxide using suitable reducing agents to obtain the desired metals.

(e) In case of more reactive metals, electrolytic extraction is applied.

The method of extraction of a metal **depends on the metal's reactivity**. The most reactive metals such as **sodium** are obtained by **electrolysis**. The less reactive metals such as iron are extracted by **reduction** of their oxides using suitable **reducing agents**.

This can be summarized in the table below.

Metal	Main ore	Main constituent compound in ore	Methods of extraction
Sodium	Rock salt	Sodium chloride, NaCl	Electrolysis of molten sodium chloride.
Aluminium	Bauxite	Hydrated aluminium oxide, $\text{Al}_2\text{O}_3 \cdot 2\text{H}_2\text{O}$	Electrolysis of aluminium oxide in molten cryolite.
Zinc	Zinc blende	Zinc sulphide, ZnS	Roasting in air followed by reduction of zinc oxide by carbon
Iron	Haematite	Iron (III) oxide, Fe_2O_3	Reduction of iron (III) oxide by carbon (II) oxide.
Copper	Copper pyrites	Copper (II) sulphide, CuFeS_2	Heating copper sulphide in regulated amounts of air to form copper (II) oxide, Reduction of copper (II) oxide by the copper sulphide.
	Malachite	Basic copper (II) carbonate, $\text{CuCO}_3 \cdot \text{Cu}(\text{OH})_3$	Heating in air followed by reduction by carbon.

Sodium

Occurrence

Sodium occurs as **dissolved chloride** in sea water and **salt lakes**. It also occurs as a double salt, **$\text{NaHCO}_3 \cdot \text{Na}_2\text{CO}_3 \cdot 2\text{H}_2\text{O}$ (trona)** in salty lakes in the Rift valley such as Lake Magadi. Sodium also occurs as **rock salt (solid sodium chloride)** at various places and as **saltpetre** (solid sodium nitrate).

Saltpetre is mainly found in Chile, hence its common name, **Chile saltpetre**. The **chief ore** from which sodium is extracted is **rock salt**.

Extraction

Sodium metal is extracted by the Down's process where molten sodium chloride is electrolysed.

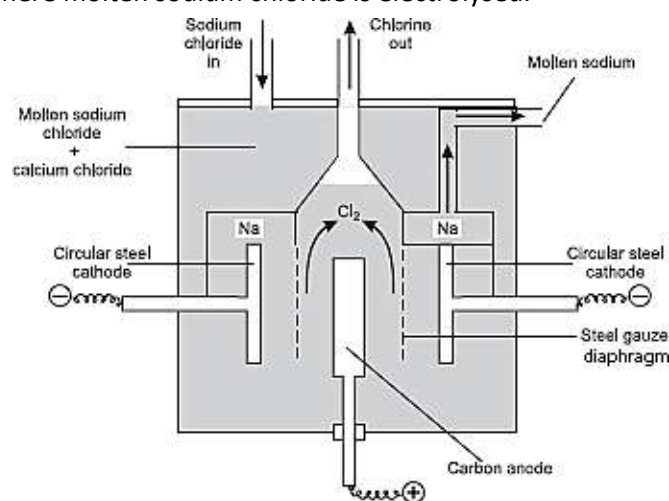
- The Down's cell consists of an **iron shell** lined with **heat bricks** on the outside to **maintain the high temperature** so that the **electrolyte does not crystallise**.

At the centre of the cell is a carbon anode surrounded by a steel cathode.

- Calcium chloride** is **added** to the sodium chloride to **lower the melting point of sodium chloride from about 800°C to 600°C** . This is economical because it saves on electricity used in heating.

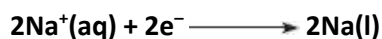
During electrolysis, sodium metal forms at the cathode whereas chlorine gas forms at the anode.

At the Anode



At the cathode

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- A **steel diaphragm** is suspended between the electrodes to **prevent sodium and chlorine from recombining**.

Molten sodium is **less dense** than molten sodium chloride, hence it **rises to the top of the cathode** from where it is periodically removed. However, chlorine is not allowed into the atmosphere because it is a poisonous gas and hazardous to the environment.

Liquid calcium metal may also be produced at the cathode. However, calcium liquid **does not mix with sodium liquid as it is much denser**. In addition, calcium has a **higher melting point** compared to sodium. During cooling, **calcium crystallises first** leaving liquid sodium which is trapped.

Uses of Sodium

- Manufacture of sodium compounds such as sodium cyanide (NaCN) and sodium peroxide (Na_2O_2). Sodium cyanide is used in the extraction of gold.
- An alloy of sodium with lead is used in the manufacture of tetraethyl lead ($\text{Pb}(\text{C}_2\text{H}_5)_2$) used as an anti-knock additive in petrol. This has been discontinued as use of leaded fuel has been phased out.
- Making an alloy of sodium and potassium which is used as a coolant in nuclear reactors because the alloy is a liquid over a wide range of temperatures.
- Sodium vapour is used in street lamps which give yellow orange light.
- Sodium is used as a reducing agent in some reactions such as reduction of titanium(IV) chloride to form titanium metal.
- Sodium hydroxide, a compound of sodium, is used in the manufacture of detergents, paper glass and artificial silk.

Aluminium

Occurrence

Chief ore is **bauxite ($\text{Al}_2\text{O}_3 \cdot 2\text{H}_2\text{O}$)** found in France, South America, Jamaica and Ghana.

Bauxite ore has **impurities of iron(III) oxide and silica (SiO_2)**. Other ores are **mica ($\text{K}_2\text{Al}_2\text{Si}_6\text{O}_{16}$)** and **corundum (Al_2O_3)**.

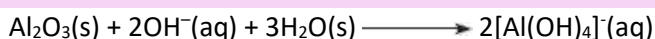
Extraction

Aluminum is extracted by the **electrolytic** method because it is a **reactive metal**.

The ore is concentrated before it is electrolysed.

Bauxite is **ground** into a fine powder and then dissolved in **hot concentrated sodium hydroxide under pressure**.

The **amphoteric** aluminium oxide and **acidic** silicon (IV) oxide **dissolve in the base** while iron(III) oxide which is **insoluble** in the base is filtered out as **red mud**.



Carbon(IV) oxide gas is bubbled through the filtrate to **precipitate** the aluminium hydroxide.



Alternatively, aluminium hydroxide may be precipitated by **seeding** process using **pure aluminium hydroxide** crystals



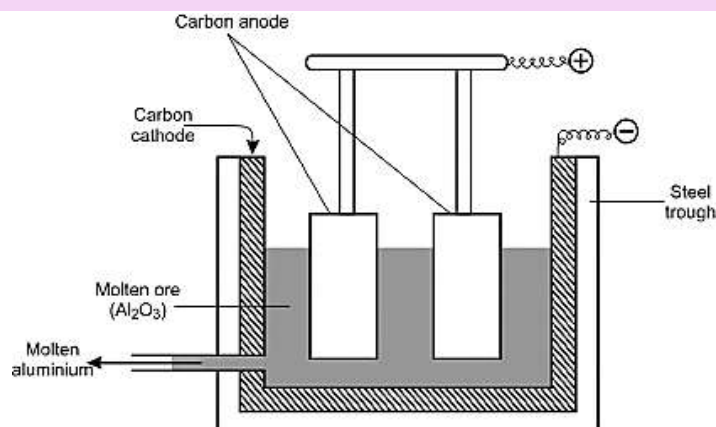
The Aluminium hydroxide is then **heated** to obtain aluminium oxide, (Al_2O_3).



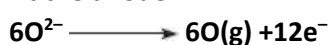
The Aluminium oxide is **dissolved** in molten **cryolite** (Na_3AlF_6) to **lower** its melting point from **2015°C** to **around 800°C** to save on the amount of heat needed to melt it.

The molten mixture is then **electrolysed** in a steel tank lined with **graphite** which acts as the **cathode**. **Graphite rods** dipping into the electrolyte act as the **anode**.

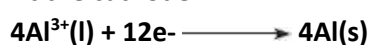
During electrolysis, aluminium is deposited at the cathode and oxygen is liberated at the anode.



At the anode



At the cathode



At the high temperature of about 800°C, the oxygen evolved **reacts** with the carbon electrode to form carbon(IV) oxide. This **corrodes** the carbon anode which should be replaced from time to time.

Uses of Aluminium

1. An alloy of aluminum and magnesium is used in making parts of aeroplanes, railway trucks, trains, buses, tankers, furniture and cars because of its low density. Aluminium **can easily be stretched** due to its **low tensile strength**; therefore, its alloys such as **duralumin** are used as they are **light, hard and strong**. Duralumin is used in the construction of aircraft and car window frames.
2. For cooking vessels such as *sufurias*, because it is a **good conductor of heat**. It is **NOT easily corroded** by cooking liquids because of the **unreactive coating of aluminium oxide**.
3. For making **overhead cables**, because it is **light and is a good conductor of electricity**.
4. As a **reducing agent** in the **thermite process** in the extraction of some elements such as chromium, iron, cobalt, manganese and titanium.



5. **Corundum (emery)** is a natural oxide of aluminium which is useful as an **abrasive**.

Iron

Occurrence

Iron is the second most abundant metal after aluminium. The chief ore is **haematite** (Fe_2O_3). The other ores are **Magnetite** (Fe_3O_4) and **siderite** (FeCO_3).

The ores of iron contain **silica** (SiO_2) and **aluminium oxide** as impurities.

Extraction

Iron is usually extracted from its oxides or siderite. When extracting iron from siderite, the ore is **first roasted** in air to convert it to **iron(II) oxide** which is the stable oxide of iron.

The siderite (**carbonate**) is first decomposed by heat to form iron(II) oxide and carbon(IV) oxide.



Iron(II) oxide is then **oxidised** by oxygen in the atmosphere to form **iron(III) oxide**. (haematite).



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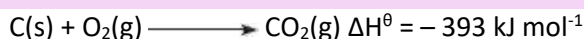
Iron(III) oxide is also mined as the ore. The iron(III) oxide obtained by either method is ground **into a powder** then **mixed with limestone** and **coke** then fed into a furnace from the top.

The mixture is **heated by blasts of hot air** at temperatures of between **800°C – 1000°C** from the bottom of the furnace.

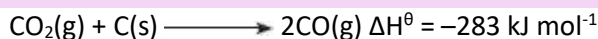
The blast furnace is about **30 m high**. It is made of **steel** and the inner side is lined with **bricks made from magnesium oxide** which **conserve heat energy** in order to maintain the **optimum temperature** needed for the reduction of iron(III) oxide.

In the blast furnace three important reactions take place.

1. At the **bottom** of the furnace, **coke (carbon)** is **oxidised to carbon(IV) oxide**. The reaction **raises the temperature of the furnace to 1600 °C** since it is **exothermic**.



2. In the **middle** part of the furnace, **carbon (IV) oxide** is **reduced by coke to carbon(II) oxide** and the **temperature drops to about 1000°C** since the reaction is **endothermic**.



3. At the **upper** part of the furnace where the temperature has fallen to about 700 °C, **iron(III) oxide** is **reduced to iron metal**. Both **carbon** and **carbon(II) oxide** act as **reducing agents**.



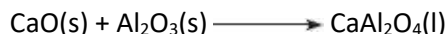
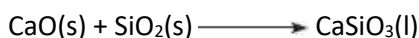
Carbon(II) oxide is the **main reducing agent** because of the **large surface** that is in contact with the iron(III) oxide.

The iron produced falls to the lower part of the furnace where the temperatures are high enough to keep it molten. The **carbon(IV) oxide** produced is **recycled**.

The limestone fed into the furnace alongside coke and iron(II) oxide is decomposed by heat in the furnace to form **calcium oxide** and **carbon(IV) oxide**.



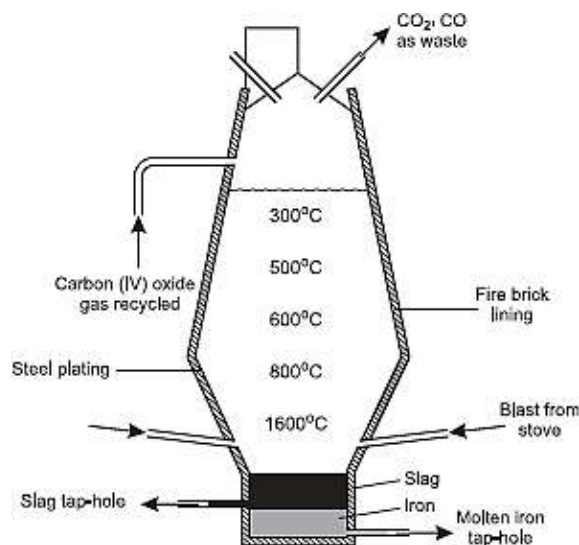
Calcium oxide being basic reacts with **acidic** and **amphoteric** oxide in the furnace to form **slag**.



The slag formed is **tapped off** at a higher level of the furnace because of its **lower density**.

The iron obtained from the blast furnace is **90–95%** pure and it is called "**pig Iron**". The main impurities in pig iron are **carbon, silicon, manganese, sulphur and phosphorus**, depending on the composition of the original ore.

These impurities considerably affect the properties of iron by **making it less hard and brittle** as well as **lowering the melting point of the iron**.



Uses of Iron

Cast Iron (Pig Iron)

This is the name given to the iron after it has been produced in the blast furnace. It contains about 3–5% carbon 1% silicon and 2% phosphorus. Although this type of iron has the disadvantages of being very brittle, it is extremely hard and is used in making furnaces, gates drainage pipes, engine blocks, iron boxes, etc. An important use of cast iron is the manufacture of wrought iron and steel railings for balconies.

Wrought Iron

Contains about 0.1% carbon. It is malleable and thus can be easily forged (moulded) and welded. It is used to make iron nails, iron sheets, horse shoes and agricultural implements, wrought iron is becoming less important due to increased use of mild steel.

Steel

The name is given to many different alloys whose main component is iron. The other substances may be carbon, vanadium, manganese, tungsten, nickel and chromium. Mild steel contains about 0.3% carbon. Special steel contains a small percentage of carbon together with other substances.

Mild steel is used to make nails, car bodies, railway lines, ship bodies, gliders, rods for reinforced concrete, pipes. Mild steel contains 99.75% iron and 0.75% carbon. It is easily worked on.

Stainless steel

Stainless steel contains 74% iron, 18% chromium and 8% nickel. Stainless steel containing 10–12% chromium and some nickel is used to make cutlery, sinks and vats. Steel containing 5–18% tungsten is used for making high speed cutting and drilling tools because it is tough and hard.

Cobalt Steel

This contains about 97.5% iron and 2.5% cobalt. It is tough and hard. It is highly magnetic and so it is used to make electromagnets.

Zinc

Occurrence

It occurs in many parts of the world as calamine (zinc carbonate), zinc blende (zinc sulphide). Zinc blende is often found mixed with galena (PbS). The **chief ores** of zinc are **calamine** and **zinc blende**.

Extraction

The ore is concentrated by **froth floatation**. The concentrated ore is then **roasted** to form the metal oxide. In the case of **calamine**, carbonate decomposes to zinc oxide and carbon(IV) oxide.



In the case of **zinc blende**, two reactions occur:

(i) Zinc sulphide is roasted in air to produce zinc oxide and sulphur(IV) oxide gas.



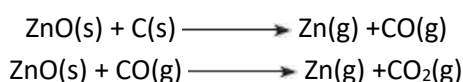
(ii) The impurity, lead(II) sulphide in the ore produces lead(II) oxide and sulphur(IV) oxide.



Zinc metal may be obtained from the oxide either by **reduction** using **carbon** or carbon monoxide or it may be **converted to zinc sulphate and electrolysed**.

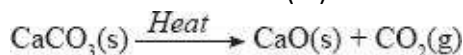
(a) Reduction using carbon and carbon(II) oxide

Zinc oxide from the roaster is mixed with coke and limestone and heated in a blast furnace where it is reduced to zinc.



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The limestone decomposes into calcium oxide and carbon(IV) oxide.



The carbon(IV) oxide is reduced by coke to carbon(II) oxide.



The **carbon(II) oxide** and the **coke** are the **reducing agents**.

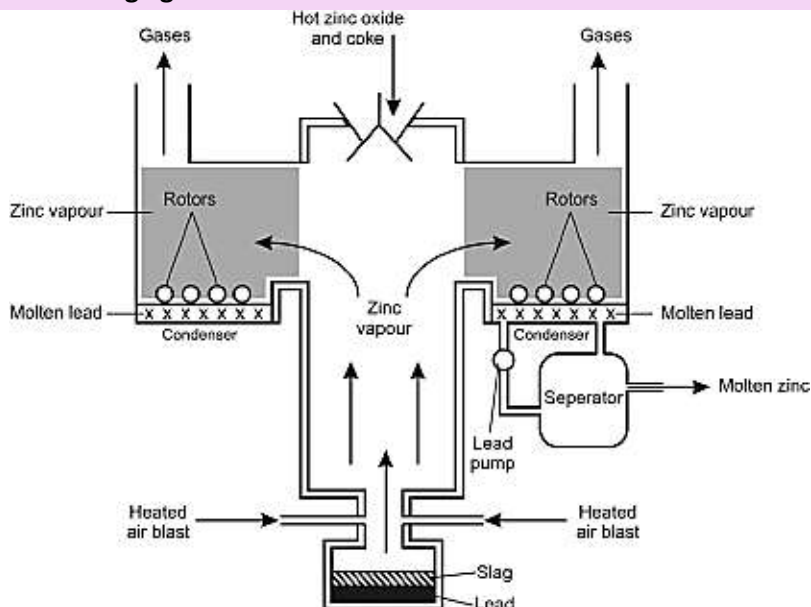
Zinc has a boiling point of 913°C. At the furnace temperatures which are maintained above 1,000°C, zinc exists in **vapour form**. The **zinc vapour** leaves at the top of the furnace with the hot gases.

It is cooled very rapidly to 600°C by mixing it with a **spray of molten lead**. The lead spray **condenses** the zinc and **prevents it from being re-oxidised**.

At this temperature liquid zinc separates and settles above the molten lead since it is less dense and is run off.

The zinc can be **purified by distillation**.

The lead produced during the extraction is a liquid at the furnace temperatures and it trickles to the bottom of the furnace from where it is tapped off. **Calcium oxide** combines with **silica** and is removed as **slag**.



(b) Electrolytic Extraction of Zinc

The zinc oxide obtained from the roaster is converted to zinc sulphate.



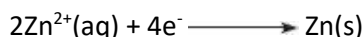
Any lead oxide present reacts with the acid to form lead(II) sulphate which is **insoluble** and is therefore **precipitated**.



The zinc sulphate is then **dissolved in water** and the solution electrolysed. The **cathode** is made of **lead containing 1% silver** and the **anode** is made of **aluminium sheets**. The electrode reactions are:

Cathode

Zinc ions are discharged.



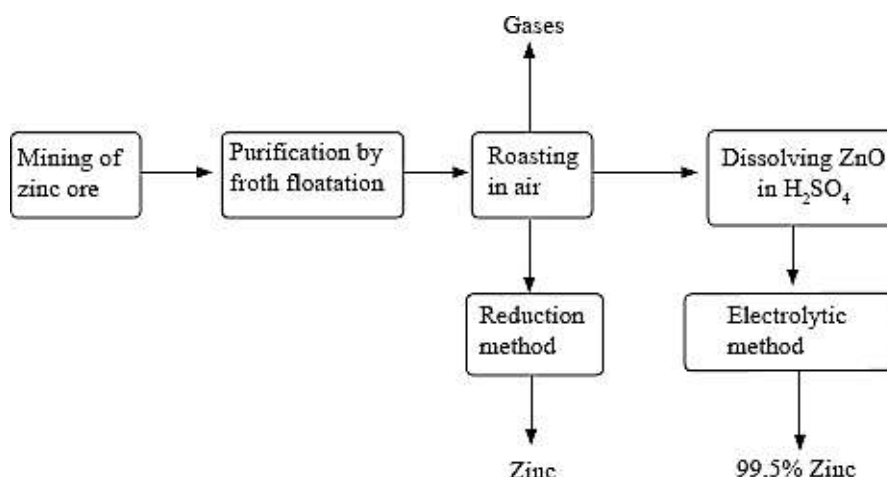
If graphite electrode were used, **hydrogen gas would have been evolved instead**. Zinc is stripped off the cathode regularly. The metal is about **99.5% pure**.

Anode

Hydroxide ions are discharged in preference to sulphate ions.



Over **80%** of zinc is extracted by the electrolytic methods.



Flow-chart to summarise the extraction of zinc

Uses of Zinc

1. Zinc is used to galvanise iron to prevent it from rusting.
2. To make brass, an alloy of copper and zinc.
3. Making of outer casing in dry batteries.

Lead

Its chief ore is **galena(PbS)**. Other ores of less industrial importance are **cerussite (PbCO₃)** and **anglesite (PbSO₄)**.

Extraction

The ore is first **ground** into a fine powder and then **concentrated through froth floatation**. The concentrated ore is then **roasted** in air to obtain **lead(II) oxide** and **sulphur(IV) oxide**.



The lead(II) oxide from the roaster is **mixed with coke** and **calcium carbonate (limestone)**. The mixture is then heated in a blast furnace.

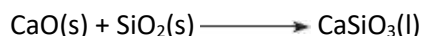
The lead(II) oxide is reduced by the coke to lead.



Iron is added to the blast furnace **to reduce any remaining lead sulphide** to lead.



Calcium oxide combine with silica to form calcium silicate.

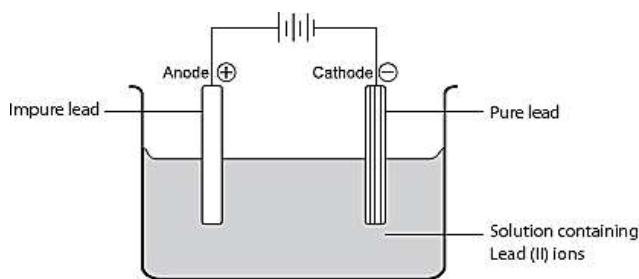


The **iron(II) sulphide** and **calcium silicate** form **slag** which is tapped off separately from the lead. The lead produced by the method is not pure.

Pure lead is obtained by **blowing a blast of air through the molten impure lead**. Oxygen in the air **oxidises** the impurities into **compounds which are less dense than lead**. These compounds **float** on the molten lead and are **skimmed off**.

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More **pure lead** can be obtained by electrolysis. The **cathode** is made of a **pure strip of lead** while the **impure lead is made the anode**. At the cathode, lead is deposited while at the anode lead dissolves.



At the **cathode**: $\text{Pb}^{2+}(\text{aq}) + 2\text{e}^- \longrightarrow \text{Pb}(\text{s})$

At the **anode**: $\text{Pb}(\text{s}) \longrightarrow \text{Pb}^{2+}(\text{aq}) + 2\text{e}^-$

Uses of Lead

1. Manufacture of storage batteries (lead acid accumulators) .
2. It is used in ammunition (shot and bullets) and as a constituent of solder, type metal, bearing alloys, fusible alloys, and pewter.
3. In heavy and industrial machinery, sheets and other parts made from lead compounds may be used to dampen noise and vibration.
4. **Lead Pipes**—Lead pipes due to its corrosion resistant properties are used for carriage of corrosive chemicals at chemical plants.
5. Lead Sheet is used in the building industry for flashings or weathering to prevent water penetration & for roofing and cladding. By virtue of its resistance to chemical corrosion, Lead Sheet also finds use for the lining of chemical treatment baths, acid plants and storage vessels.
6. Because lead effectively absorbs electromagnetic radiation of short wavelengths, it is used as a protective shielding around nuclear reactors, particle accelerators, X-ray equipment, and containers used for transporting and storing radioactive materials.

Copper

Occurrence

Copper ores include, **pyrites (CuFeS_2)**, **cuprite (Cu_2O_2)**, **chalcocite (Cu_2S)** and **malachite ($\text{CuCO}_3 \cdot \text{Cu}(\text{OH})_2$)**. It also occurs in uncombined state in various parts of the world such as Canada, USA, Zambia, Tanzania and the Democratic Republic of Congo (DRC).

Impurities in copper ores may include **traces of gold and silver**.

The chief ore of copper is **copper pyrites**.

Extraction

Copper is mostly extracted from **copper pyrites**. The ore is first **crushed** into a fine powder and **concentrated by froth flotation**. The concentrated ore is then **roasted in a limited supply of air** to obtain copper(I) sulphide and iron(II) oxide



Silica (SiO_2) is then added and the mixture is heated in the **absence of air**. The silica **reacts with iron(II) oxide to form iron(II) silicate** which separates out as a **slag** leaving behind the copper(I) sulphide.



The copper(I) sulphide is then **heated in a regulated supply of air** where some of it is converted to copper(I) oxide.



The copper(I) oxide then **reacts** with the **remaining copper(I) sulphide** to form copper metal and sulphur(VI) oxide.

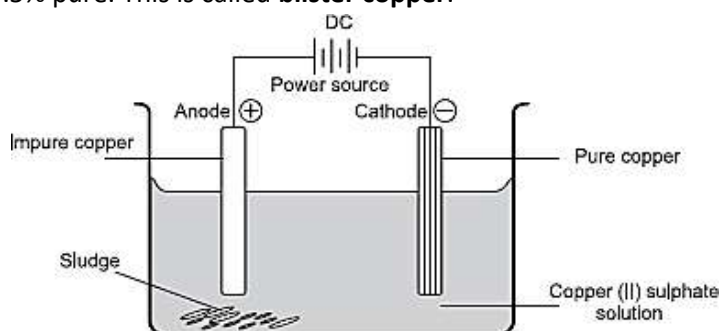


The sulphur(IV) oxide produced in the process is **either fed into adjacent sulphuric(IV) acid plant or scrubbed using calcium hydroxide.**

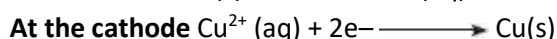


The copper obtained in this process is about 97.5% pure. This is called **blister copper**.

It is refined by electrolysis to obtain 99.8% pure copper. During the refining, stripes of pure copper are used as the cathode whereas the anode is made of the impure copper. Copper(II) sulphate solution is used as the electrolyte.



During electrolysis, the **impure copper anode goes into solution as copper ions** while **copper metal is deposited on the pure copper cathodes.**



Traces of **gold** and **silver** collect as a **sludge** at the bottom of the electrolytic cell.

Where **copper carbonate is the chief ore, it is roasted first to obtain copper(II) oxide.**



The copper(II) oxide is then reduced to copper metal using coke and carbon(II) oxide as reducing agents.



Uses of Copper

1. Making electrical wires and contacts in switches, plugs and sockets because copper is a good conductor of electricity. Pure copper is necessary for this use because impurities increase electrical resistance.
2. Making soldering instruments due to its high thermal conductivity.
3. Making alloys such as brass (Cu and Zn), bronze (Cu and Sn), German silver (Cu, Zn and Ni), etc.
4. Making coins and ornaments.

Properties of Some Metals

Physical Properties of Metals

Physical properties of metals depend on the size of the atoms, their electron arrangement and the crystal lattice.

- Metals generally have **high melting and boiling points due to strong metallic bonds.**
- They are **good conductors of both heat and electricity** due to the presence of **delocalised valence electrons** in the metallic lattice. The number of delocalised electrons and their ease of movement within the lattice account for the **difference** in electrical conductivity.

Metal	Melting point (°C)	Boiling point (°C)	Thermal & Electrical conductivity	Density (gcm ⁻³)	Malleability	Ductility
Sodium	97.8	890	Good	0.97	-	-

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Aluminium	660	2 470	Very good	2.70	Malleable	Ductile
Zinc	1 535	3 000	Good	2.86	Malleable	Ductile
Iron	420	907	Good	2.14	Malleable	Ductile
Copper	1083	2 395	Very good	8.90	Malleable	Ductile

- The metals generally have **high density**. Differences in density in metals are mainly due to different atomic masses, packing of the atoms in the metallic lattice and the size of the atoms.
- Metals can be **pressed into sheets and also drawn into wires**. These properties are referred to as **malleability** and **ductility** respectively.

Chemical Properties of Metals

Reactions with air

Freshly cut or polished surfaces of metals have a shiny appearance. Sodium rapidly tarnishes in dry air forming sodium oxide.



In moist air, both sodium metal and sodium oxide react with water vapour to form sodium hydroxide.



The resulting alkali absorbs acidic carbon(IV) oxide in the air to form sodium carbonate.



When heated in air sodium readily burns with a yellow flame to form mainly sodium peroxide.



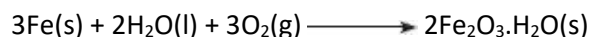
Polished aluminium is immediately coated by aluminium oxide. If heated to 800 °C, aluminium burns to form aluminium oxide and aluminium nitride.



Zinc tarnishes very slowly in air due to the formation of zinc oxide. When heated, zinc burns to form zinc oxide



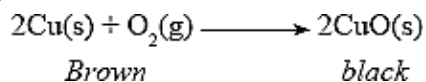
Iron rusts in the presence of moist air to form hydrated iron(III) oxide, $\text{Fe}_2\text{O}_3 \cdot \text{H}_2\text{O(s)}$.



When heated, iron reacts with oxygen to form tri-iron tetraoxide, Fe_3O_4 .



Copper forms a black coating of copper(II) oxide when heated in air. Finely divided copper burns with a blue flame to form copper(II) oxide.



Reactions with cold water and steam

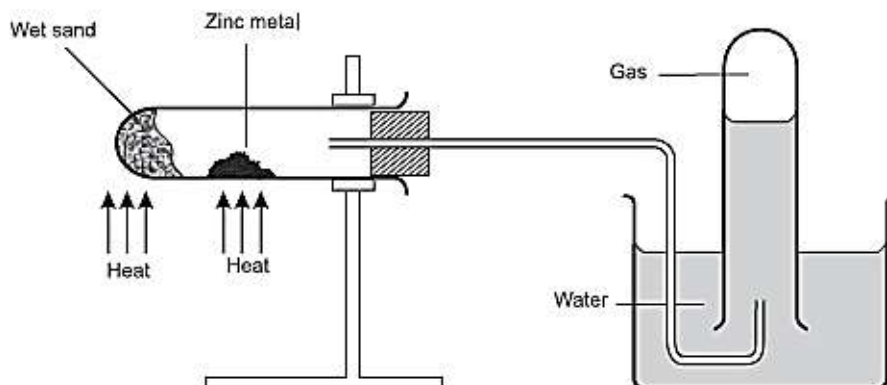
Sodium reacts **vigorously** with cold water liberating hydrogen gas. The resulting solution is alkaline(basic). The alkaline solution is **sodium hydroxide**.



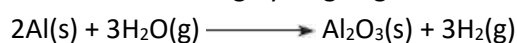
Aluminium, zinc and iron do not readily react with cold water.

Aluminium does not react with cold water **because of a thin layer of aluminium oxide on its surface**. If the thin layer of aluminium oxide is removed, aluminium reacts with cold water **very slowly** liberating hydrogen gas.

Copper does not react with cold water.



Aluminium, zinc and iron react with steam liberating hydrogen gas and forming metals oxides.



Copper **does not react with steam at all**.

Among the metals discussed, sodium is the most reactive while copper is the least reactive.

Sodium
Aluminium
Zinc
Iron
Copper



Most reactive

Decreasing order of reactivity

Least Reactive

The position of **aluminium** is **not easy to determine** in this experiment because its reaction with cold water and steam are **impaired due to the presence of an oxide coating**.

During the reaction between the metal and water, **the reactive metals displace hydrogen to form the hydroxides of the metals**.

Copper **does not** react with water because it is **low** in the reactivity series.

If hydrogen is put together with metals in order of reactivity, its position would be higher than that of copper.

Sodium
Aluminium
Zinc
Iron
Hydrogen
Copper



Most reactive

Decreasing order of reactivity

Least Reactive

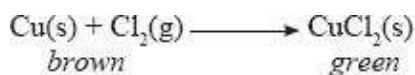
Reaction with chlorine

Hot sodium metal reacts with chlorine to form white fumes of sodium chloride.



Hot copper glows red in chlorine gas forming brown copper(II) chloride which turns green in the presence of moisture.

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Hot zinc reacts with chlorine gas to form white zinc chloride.



Hot iron **glows red** in chlorine gas. This is because the **reaction is exothermic**. During the reaction **brown** fumes are observed. The fumes solidify on the cooler parts of the tube to form black crystals of iron(III) chloride.



Hot aluminium burns in chlorine to form a white solid which sublimes and condenses on the cooler parts of the apparatus.



Both iron(III) chloride and aluminium chloride are observed to fume when exposed in damp air. This is because both chlorides are readily hydrolysed by water vapour to produce hydrogen chloride gas.



Reactions with acids

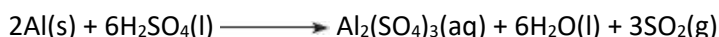
Polished aluminium reacts **very slowly** with dilute hydrochloric acid to liberate hydrogen gas and form aluminium chloride.



There is **no apparent reaction between aluminium and dilute sulphuric(VI) acid**.

There is also **no apparent** reaction between aluminium and nitric(V) acid at any concentration. This is because **nitric(V) acid is a strong oxidising agent**. A **thin layer of aluminium oxide** forms on the metal surface **immediately** it comes into contact with the acid.

Aluminium **reduces** hot concentrated **sulphuric(VI) acid** to sulphur(IV) oxide and is itself oxidized to aluminium sulphate.



Iron reacts with both dilute hydrochloric acid or sulphuric (VI) acid to liberate hydrogen gas.



Iron reduces hot concentrated sulphuric(VI) acid to sulphur(IV) oxide and is itself oxidised to iron(II) sulphate.



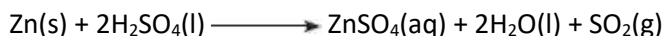
Dilute nitric(V) acid reacts with iron to form a mixture of nitrogen(I) oxide and nitrogen(II) oxide.

There is **no apparent reaction between iron and concentrated nitric(V) acid**. The concentrated acid oxidises iron and forms a thin layer of impervious tri-iron tetraoxide, Fe_3O_4 , which prevents further reaction.

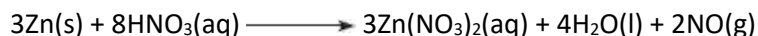
Zinc reacts with both dilute hydrochloric acid and sulphuric(VI) acid to liberate hydrogen gas.



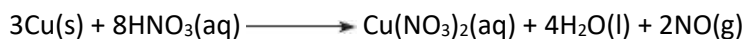
Zinc reduces concentrated sulphuric(VI) acid to sulphur(IV) oxide gas and is itself oxidised to zinc sulphate.



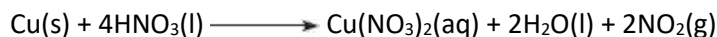
Zinc reacts with 50% concentrated nitric(V) acid to liberate nitrogen (II) oxide gas.



Copper **does not react with dilute hydrochloric acid, dilute sulphuric(VI) acid or very dilute (less than 50%) nitric(V) acid**. It however reacts with nitric(V) acid at 50% concentration to liberate nitrogen(II) oxide.



With concentrated nitric(V) acid and sulphuric(VI) acid, nitrogen(IV) oxide and sulphur(IV) oxides are produced respectively.



Effects of Extraction of Metals on the Environment

Extraction of metals leads to land pollution, air pollution and water pollution.

Mining of the ores from the ground may lead to gaping holes being left in the ground if not refilled with earth. If undesired earthy material accompanying the ores are carelessly disposed of, it may lead to serious land pollution.

Roasting of the ores, reduction of the oxide and electrolysis of chlorides leads to evolution of gaseous by-products such as sulphur(IV) oxides, carbon(IV) oxide gas and chlorine gas. These gaseous products could lead to air pollution if allowed to escape into the atmosphere. This could lead to acid rain effects.

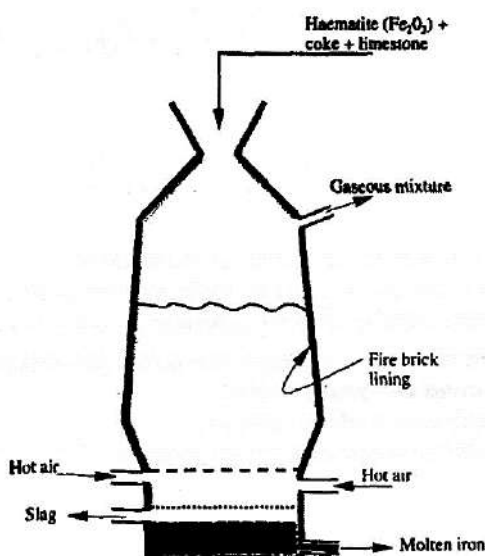
The gaseous by-products such as chlorine gas and sulphur(IV) oxide gas are fed into hydrochloric acid and sulphuric(VI) acid plants respectively.

Solid by-products such as slag could lead to land pollution if not disposed off safely. Conversely, solid by-products can be disposed off carefully by either burning them or making other uses of them. For example, slag may be used in carpeting roads.

Review Exercises

- 2006 Q 21
 - Explain why the metals magnesium and aluminium are good conductors of electricity.
(1 mark)
 - Other than cost, give two reasons why aluminium is used for making electric cables while magnesium is not
(2 marks)
- 2006 Q 6 P2

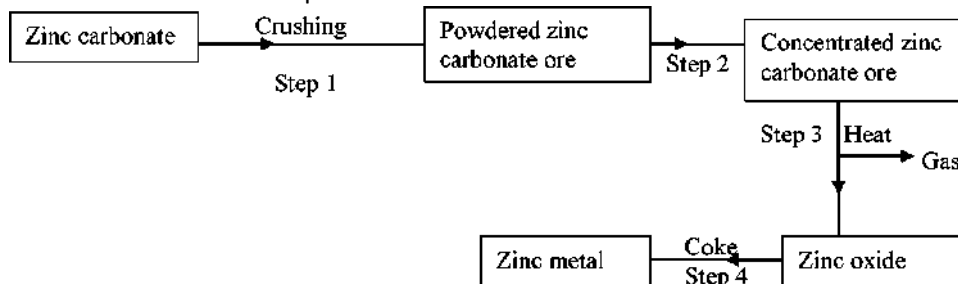
The extraction of iron from its ores takes place in the blast furnace. Study it and answer the questions that follow.



- (a) Name:
- (i) One of the substances in the slag; (1 mark)
 - (ii) Another iron ore material used in the blast furnace; (1 mark)
 - (iii) One gas which is recycled. (1 mark)
- (b) Describe the process which leads to the formation of iron in the blast furnace. (3 marks)
- (c) State the purpose of limestone in the blast furnace. (2 marks)
- (d) Give a reason why the melting point of the iron obtained from the blast furnace is 1200°C while that of pure iron is 1535°C (1 mark)
- (e) State two uses of steel (2 marks)

3. 2007 Q 19 P1

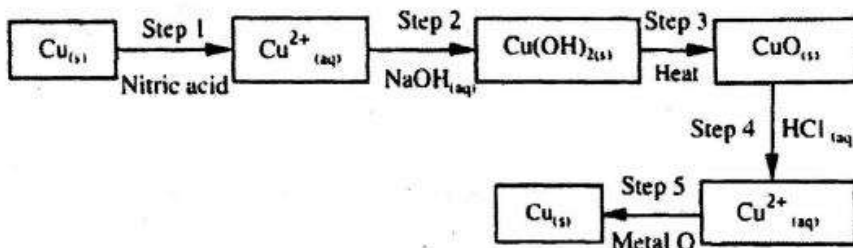
The flow chart below shows steps used in the extraction of zinc from one of its ores.



- (a) Name the process that is used in step 2 to concentrate the ore. (1 mark)
- (b) Write an equation for the reaction which takes place in step 3. (1 mark)
- (c) Name one use of zinc other than galvanizing. (1 mark)

4. 2007 Q 3 P2

The flow chart below shows a sequence of chemical reactions starting with copper study it and answer the questions that follow.



- (a) (a) In step 1, excess 3M nitric acid was added to 0.5g of copper powder.

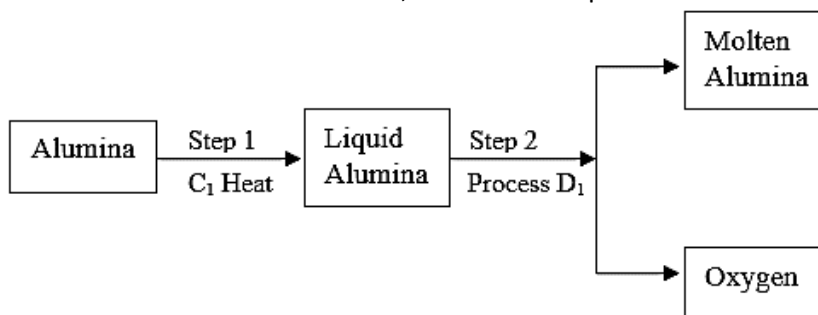
- (i) State two observations which were made when the reaction was in progress (2marks)
- (ii) Explain why dilute hydrochloric acid cannot be used in step 1 (1mark)
- (iii) I. Write the equation for the reaction that took place in step 1 (1mark)
- II. Calculate the volume of 3M nitric that was needed to react completely with 0.5g of copper powder. (Cu = 63.5) (3 marks)

(b) Give the names of the types of reactions that took place in steps 4 and 5. (1 mark)

(c) Apart from the good conductivity of electricity, state two other properties that make it possible for copper to be extensively used in the electrical industry. (2marks)

5. 2008 Q 28 P1

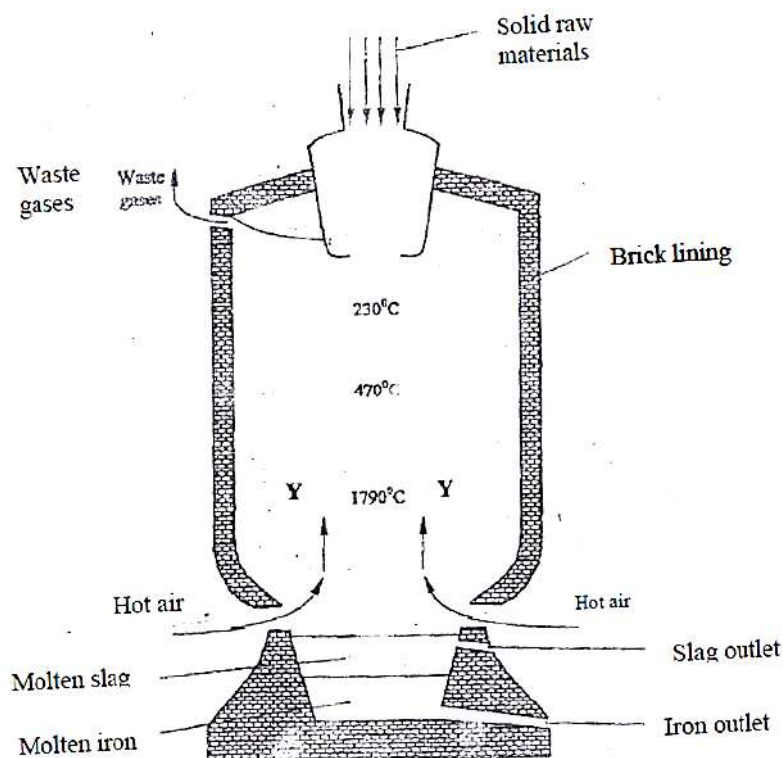
During the extraction of aluminium from its ores; the ore is first purified to obtain alumina.



- (a) Name
- (i) Substance **C₁** (1 mark)
- (ii) Process **D₁** (1 mark)
- (b) Give two reasons why aluminium is used extensively in the making of cooking pans. (1 mark)

6. 2009 Q 7 P2

Iron is obtained from hematite using a blast furnace shown in **figure 5** below.



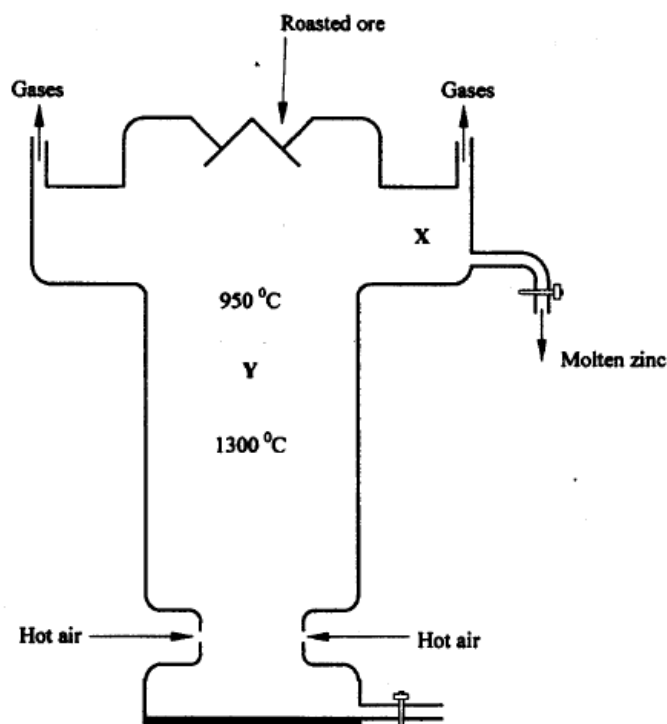
- Four raw materials are required for the production of iron. Three of these are iron oxide, hot air and limestone. Give the name of the fourth raw material. (1 mark)
- Write an equation for the reaction in which carbon (IV) oxide is converted into carbon (II) oxide. (1 mark)
- Explain why the temperature in the region marked Y is higher than of the incoming hot air. (2 marks)
- State one physical property of molten slag other than density that allows it to be separated from molten iron as shown in the figure 5. (1 mark)
- One of the components of the waste gases is Nitrogen (IV) oxide. Describe the adverse effect it has on the environment. (2 marks)
- Iron from the blast furnace contains about 5% carbon
 - Describe how the carbon content is reduced (2 marks)
 - Why is it necessary to reduce the carbon content? (1 mark)

7. 2010 Q 6 P2

The melting and boiling points of zinc are 419 °C and 907 °C respectively.

One of the ores of zinc is zinc blende. To extract zinc, the ore is first roasted in air before feeding it into a furnace.

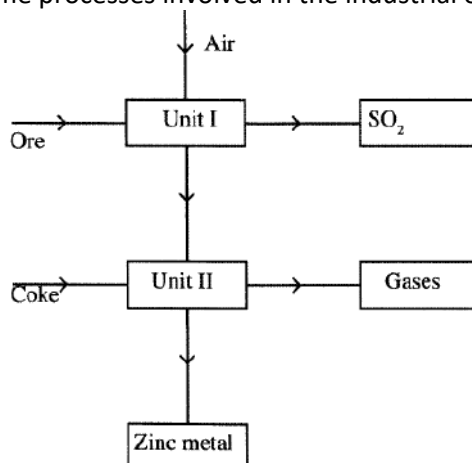
- Write the formula of the main zinc compound in zinc blende. (1 mark)
 - Explain using an equation why it is necessary to roast the ore in air before introducing it into the furnace. (2 marks)
- The diagram below shows a simplified furnace used in the extraction of zinc. Study it and answer the questions that follows:



- Name two other substances that are also introduced into the furnace together with roasted ore. (1 mark)
- The main reducing agent in the furnace is carbon (II) oxide. Write two equations showing how it is formed. (2 marks)
- In which physical state is zinc at point Y in the furnace? Give a reason. (1 mark)
- Suggest a value for the temperature at point X in the furnace. Give a reason. (1 mark)
- State and explain one environmental effect that may arise from the extraction of zinc from zinc blende (2 marks)
- Give two industrial uses of zinc. (1 mark)

8. 2011 Q 27 P1

The flow chart below shows some processes involved in the industrial extraction of zinc metal.



- Name one ore from which zinc is extracted. (1 mark)
- Write the equation of the reaction taking place in unit II. (1 mark)
- Name two uses of zinc metal. (1 mark)

9. 2012 Q22 P1

Aluminium is both malleable and ductile.

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- (a) What is meant by?
- (i) Malleable: (1 mark)
- (ii) Ductile (1 mark)
- (b) State one use of aluminium based on:
- (i) malleability (½ mark)
- (ii) ductility (½ mark)

10. 2013 Q22 P1

- (a) Name two ores from which copper is extracted. (1 mark)
- (b) During extraction of copper metal, the ore is subjected to froth flotation. Give a reason why this process is necessary. (1 mark)
- (c) Name one alloy of copper and state its use. (1 mark)

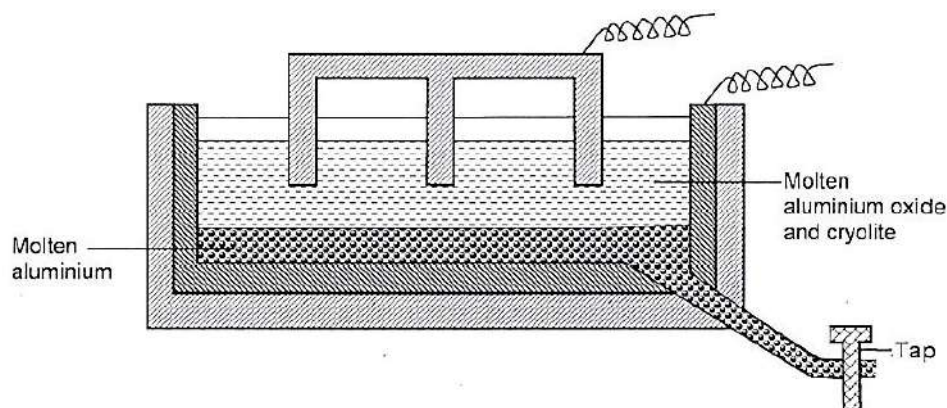
11. 2014 Q10 P1

One of the ores of copper has formula, CuFeS_2 .

- (a) Describe how iron in the ore is removed during concentration of copper metal. (1 mark)
- (b) State two environmental problems associated with extraction of copper metal. (2 marks)

12. 2014 Q6 P2, 2016 P2 Q12.

The diagram below represents a set-up of an electrolytic cell that can be used in the production of aluminium



- (a) One the diagram, label the anode. (1 mark)
- (b) Write the equation for the reaction at the anode. (1 mark)
- (c) Give a reason why the electrolytic process is not carried out below 950°C . (1 mark)
- (d) Give a reason why the production of aluminium is not carried out using reduction process. (1 mark)
- (e) Give two reasons why only the aluminium ions are discharged. (2 marks)
- (f) State two properties of duralumin that makes it suitable for use in aircraft industry. (1 mark)
- (g) Name two environmental effects caused by extraction of aluminium. (2 marks)

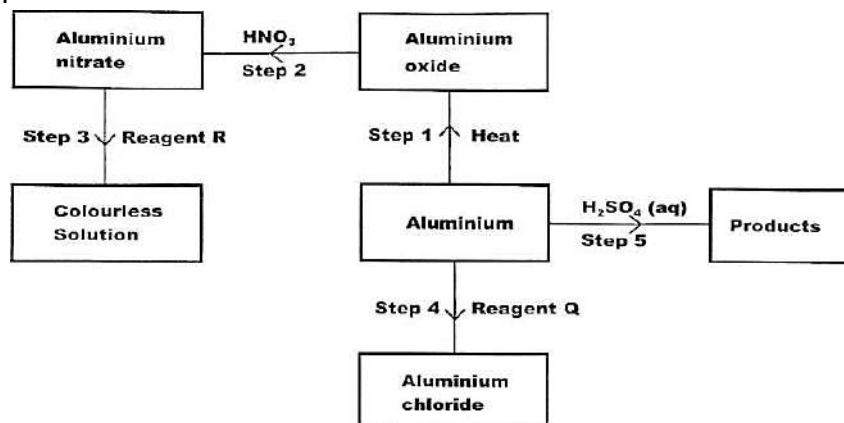
13. 2015 Q2 P1

- (a) Name the raw material from which sodium is extracted. (1 mark)
- (b) Give a reason why sodium is extracted using electrolysis. (1 mark)
- (c) Give two uses of sodium metal. (1 mark)

14. 2015 Q16 P1

The flow chart below shows various reactions of aluminium metal. Study it and answer the questions

that follow.



- (a) (i) Other than water, name another reagent that could be R. (1 mark)
 (ii) Write the formula of reagent Q. (1 mark)
 (b) Write an equation or the reaction in step 5. (1 mark)

15. 2017 P1 Q27.

- (a) Name two ores in which sodium occurs. (1 mark)
 (b) During extraction of sodium using the down's process, calcium chloride is added to the ore. Give a reason for the addition of calcium chloride. (1 mark)
 (c) State two uses of sodium. (1 mark)

16. 2017 P2 Q6.

The following steps were used to analyse a metal ore.

- (i) An ore of a metal was roasted in a stream of oxygen. A gas with a pungent smell was formed which turned acidified potassium dichromate (VI) green.
 (ii) The residue left after roasting was dissolved in hot dilute nitric(V) acid. Crystals were obtained from the solution.
 (iii) Some crystals were dried and heated. A brown acidic gas and a colourless gas were evolved and a yellow solid remained.
 (iv) The solid was yellow when cold.
 (v) The yellow solid was heated with powered charcoal. Shiny beads were formed.

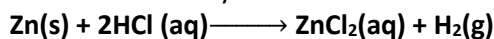
- (a) Name the:
 (i) Gas formed when the ore was roasted in air; (1 mark)
 (ii) Gases evolved when crystals in step (iii) were heated; (2 marks)
 (iii) Yellow solid formed in step (iii); (1 mark)
 (iv) Shiny beads in step (iv). (1 mark)
 (b) The yellow solid from procedure (iii) was separated, dried, melted and the melt electrolysed using graphite electrodes.
 (i) Describe the observations made at each electrode. (2 marks)
 (ii) Write the equation for the reaction that took place at the anode. (1 mark)
 (c) Some crystals formed in step (ii) were dissolved in water, and a portion of it reacted with potassium iodide solution. A yellow precipitate was formed. Write an ionic equation for this reaction. (1 mark)
 (d) To another portion of the solution from (f), sodium hydroxide solution was added drop by drop until there was no further change. Describe the observation made. (1 mark)
 (e) To a further portion of the solution from (f), a piece of zinc foil was added.

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- (i) Name the type of reaction taking place. (1 mark)
- (ii) Write an ionic equation for the above reaction. (1 mark)

17. 2018 P1 Q 20.

- (a) Zinc reacts with hydrochloric acid according to the following equation.



Identify the reducing agent. Give a reason for the answer.

(2 marks)

- (b) Iron sheets are dipped in molten zinc to prevent rusting. Name this process.

(1 mark)

18. 2018 P1 Q24.

- (a) Name two ores of iron.

(1 mark)

- (b) Describe how the amount of iron in a sample of iron(III) oxide can be determined.

(2 marks)

19. 2019 P1 Q3.

The flow chart in **Figure 1** represents some stages in the extraction of copper metal. Study it and answer the questions that follow.

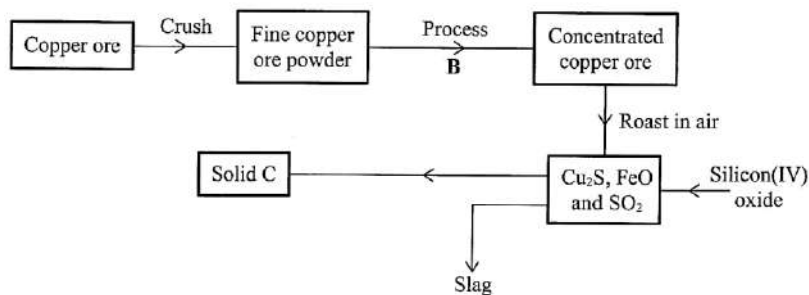


Figure 1

- (a) Identify:

(i) The copper ore;

(1 mark)

(ii) Process B;

(½ mark)

(iii) Solid C.

(½ mark)

- (b) Write an equation for the reaction that forms the slag.

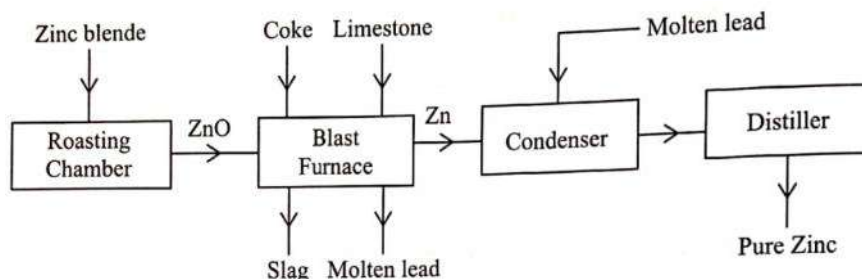
(1 mark)

20. 2019 P2 Q2.

- (a) Zinc occurs mainly as zinc blende. Name one other ore from which zinc can be extracted.

(1 mark)

- (b) The flow chart in **Figure 2** shows the various stages in the extraction of zinc metal. Study it and answer the questions that follow.



- (i) Write an equation for the reaction which occurs in the roasting chamber.

(1 mark)

- (ii) Describe the process that takes place in the blast furnace.

(3 marks)

- (iii) Explain why molten lead is added to the condenser.

(1 mark)

- (iv) State two uses of zinc.

(1 mark)

- (v) Give one reason why the extraction of zinc causes pollution to the environment.
(1 mark)
- (b) Explain the observations made when zinc metal is added to hot sodium hydroxide.
(2 marks)