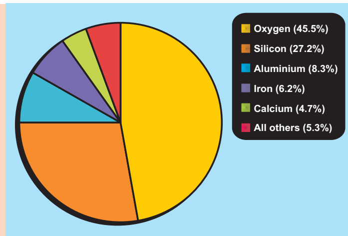
UNIT 5



Some Elements in Chemistry and Industry

Unit Outcomes

After completing this unit, you will be able to:

- *describe the occurrence and abundance of the elements in nature;*
- *explain how carbon, nitrogen and phosphorus cycles in nature;*
- *understand metallurgical processes;*
- *understand the occurrence, extraction, chemical properties and uses of sodium, calcium, tin, lead, zinc and chromium;*
- *describe the occurrence, extraction, chemical properties and main uses of silicon;*
- *explain the major steps in the industrial production of ammonia, nitric acid, sulphuric acid and diammonium monohydrogen phosphate; and*
- *demonstrate scientific enquiry skills: classifying, communicating, asking questions, relating cause and effect and making generalizations.*

MAIN CONTENTS

5.1 SOME ELEMENTS IN NATURE

After completing this subunit, you will be able to:

- define the terms mineral and ore;
- describe the forms of occurrences of metals;
- discuss the distribution and relative amounts of the elements in the earth's crust;
- define the term fixation; and
- discuss the carbon cycle, the nitrogen cycle and the phosphorus cycle.

Start up Activity

1. Collect pieces of metals and non-metals from your neighbourhood. Explain how you classified these samples as metals and non-metals to the class.
2. Refer to chemistry books available in your school library, or to any other sources and;
   a identify three man-made elements and describe two physical properties for each element.
   b based on their positions in the periodic table, predict their chemical properties. Present your investigation to the class.

There are 113 elements known at present. 92 elements occur in nature, while the rest are man-made. All the materials on the earth are made of the naturally occurring elements. The elements are classified as metals, non-metals and metalloids.

A solid substance that occurs naturally in the earth's crust is called mineral. All minerals are not suitable for the extraction of elements. Minerals from which elements can be extracted easily and economically are called ores. Thus, all ores are minerals, but all minerals are not ores, because a mineral may not contain sufficient percentage of an element for economic extraction. In economic extraction, the cost of obtaining the element out of the ore is significantly less than the amount of money to be made by selling the element.

5.1.1 Occurrence of Elements

Activity 5.1

Try to find out:

a various gaseous elements around you;

b different metallic elements in your home and school;

c physical states in which the elements exist; and

d different non-metallic elements present in your body.

Make a list of metallic elements which you come across in your daily life, and discuss their importance with your friends.

Are all elements found free in nature?

The twelve most abundant elements that constitute 99.7% by mass of the earth's crust are, in decreasing order of abundance: oxygen (O), silicon (Si), aluminium (Al), iron (Fe), calcium (Ca), magnesium (Mg), sodium (Na), potassium (K), titanium (Ti), hydrogen (H), phosphorous (P), and manganese (Mn).

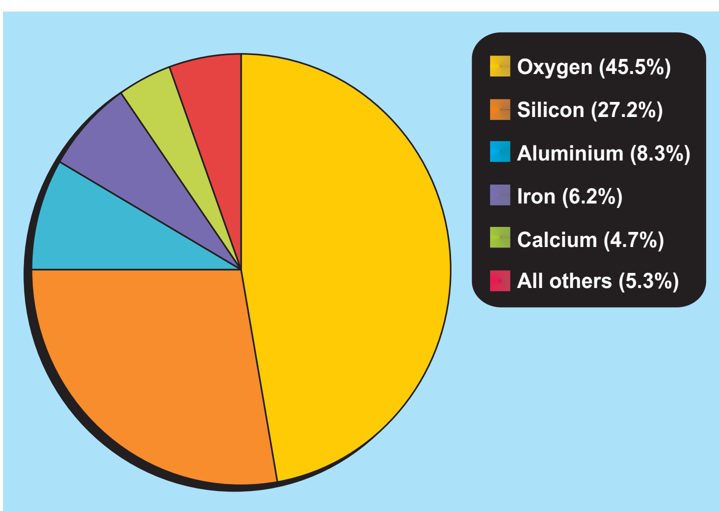


Figure 5.1 Abundance of elements in the Earth's crust.

The earth's atmosphere contains mainly nitrogen (78%), oxygen (21%), argon, carbon dioxide, and other trace gases.

Very few elements exist in the free or native state. The most unreactive metals, i.e., those that are not affected by air and water, such as silver, gold, platinum, palladium, ruthenium and osmium, are generally found in the native state. Most metals, however, occur in combined form as compounds such as oxides, carbonates, sulphides, sulphates, silicates, chlorides, nitrates and phosphates etc. A variety of physical and chemical methods can be applied to separate the pure forms of elements from their ores. However, the financial cost of mining, separating and purifying an element is the major consideration before a process is chosen for implementation.

Metals at the top of the reactivity series (K, Na, Ca, Mg, and Al) are so reactive that they are never found in nature as free elements. The metals in the middle of the reactivity series (Zn, Fe, Sn, and Pb) are moderately reactive and also exist in the combined state. Copper and silver are the two metals that occur in free as well as in combined states, such as as sulphide, oxide or halide ores.

Table 5.1 Reactivity series of elements (the most reactive is at the top and the least reactive is at the bottom).

Elements	Symbol
Potassium	K
Sodium	Na
Lithium	Li
Calcium	Ca
Magnesium	Mg
Aluminium	Al
Carbon	C
Zinc	Zn
Iron	Fe
Tin	Sn
Lead	Pb
Hydrogen	H
Copper	Cu
Silver	Ag
Gold	Au
Platinum	Pt

Table 5.2 Main type of minerals.

Type	Minerals
Uncombined metals	Ag, Au, Cu, Pd, Pt, Ru, Os
Carbonates	$BaCO_3$ (witherite), $CaCO_3$ (calcite, limestone), $MgCO_3$ (magnesite), $CaCO_3.MgCO_3$ (dolomite),
Halides	CaF_2 (fluorite), NaCl (halite), KCl (sylvine or silvite), Na_3AlF_6 (cryolite)
Oxides	$Al_2O_3.2H_2O$ (bauxite), Al_2O_3 (corundum), Fe_2O_3 (hematite), Fe_3O_4 (magnetite), Cu_2O (cuprite), SnO_2 (Cassiterite), TiO_2 (rutile), ZnO (zincite).
Phosphates	$Ca_3(PO_4)_2$ (phosphate rock), $Ca_5(PO_4)_3OH$ (hydroxylapatite)
Sulphides	Ag_2S (argentite), CdS (greenockite), Cu_2S (chalcocite), FeS_2 (pyrites), HgS(cinnaber), PbS (galena), ZnS (sphalerite)
Sulphates	$BaSO_4$ (barite), $CaSO_4$ (anhydrite), $PbSO_4$ (anglesite), $CaSO_4 . 2H_2O$ (gypsum), $MgSO_4 . 7H_2O$ (epsomite)

Exercise 5.1

1. Explain why some elements exist free in nature while others exist in the form of compounds.
2. List, in order, the six most abundant elements in the earth's crust and classify them as metals, non-metals and metalloids.
3. What is the distinction between a mineral and an ore?
4. Write the names of the minerals containing:

a	PbS	e	Fe_2O_3
b	FeS_2	d	HgS
c	$MgSO_4.7H_2O$	f	$CaCO_3.MgCO_3$

5.1.2 The Recycling of Elements in Nature

How do elements recycle in nature?

Living organisms interact with the environment. The key part of this interaction is the cycling of nutrients in the ecosystem.

An ecosystem consists of all organisms living in a community as well as the abiotic (non-living) factors with which they interact.

Nutrients provide substances to organisms that help them to grow, but nutrients can be very limited in the environment. It is through this exchange of necessary elements between the living and non-living world that sustains life. The major cycles that you will study are the carbon cycle, nitrogen cycle and phosphorus cycle. Note that the law of conservation of mass is obeyed in the recycling of substances.

Activity 5.2

Form a group, and discuss the following question. After the discussion, share your ideas with your classmates.

What are the impacts of afforestation, deforestation and the building of large numbers of cement factories, on global warming?

1. *The Carbon Cycle*

The Earth's atmosphere contains 0.035% carbon dioxide (CO_2), and the biological environment depends upon plants to convert carbon dioxide into sugars, proteins and fats.

As shown in Figure 5.2, green plants convert atmospheric carbon dioxide and water into glucose and oxygen in a process called photosynthesis.

$$6CO_2(g) + 6H_2O(l) \rightarrow C_6H_{12}O_6\,(aq) + 6O_2(g);\ \Delta H = +2803\ kJ\ mol^{-1}$$

Photosynthesis is an endothermic reaction. Solar energy from the sun provides the necessary energy for the above reaction to proceed.

Animals (including humans) eat plants, or eat other animals that have eaten plants, and incorporate the plants' carbon atoms into their cells.

Carbon returns to the physical environment in a number of ways. Both plants and animals respire, and they release carbon dioxide during respiration.

$$C_6H_{12}O_6(aq) + 6O_2(g) \rightarrow 6CO_2(g) + 6H_2O(l);\ \Delta H = -2803\ kJ\ mol^{-1}$$

Respiration is an exothermic reaction, releasing 2803 kJ/mol of energy.

The process of decomposition of organic matter also releases carbon dioxide back into the atmosphere.

Over a very long period of time, dead organisms under high pressure and in the absence of air can be converted into fossil fuels such as coal, oil and gas. Humans combust these fossil fuels as energy sources which releases carbon dioxide back into the atmosphere. The complete combustion of coal, oil, or natural gas results in the formation of carbon dioxide gas:

$$C(s) + O_2(g) \rightarrow CO_2(g)$$

The combustion of fossil fuels is exothermic, and therefore, releases energy in the form of heat.

According to law of conservation of mass, the total number of carbon atoms (in the atmosphere) is always constant; but there is a growing concern over the amount of carbon that exists as carbon dioxide, because carbon dioxide is a greenhouse gas and is a major contributor to global warming.

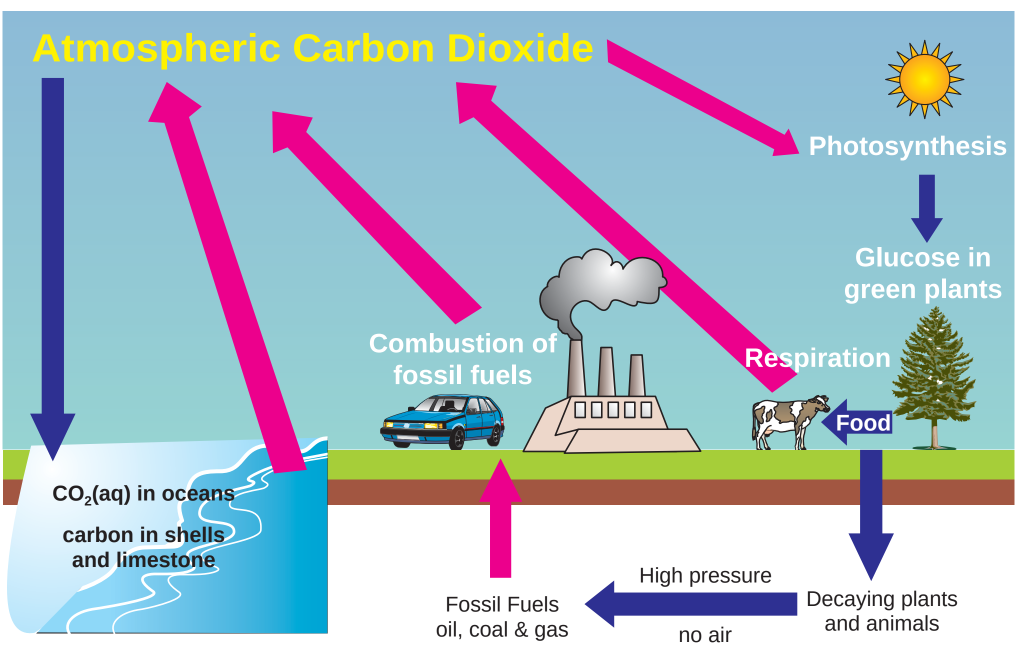


Figure 5.2 Carbon cycle.

Exercise 5.2

1. a Discuss how green plants and animals incorporate carbon atoms from atmospheric carbon dioxide gas.

   b Describe how carbon returns to the atmosphere.

2. One of the possible consequences of global warming is an increase in the temperature of ocean water. The oceans serve as a "sink" for CO_2 by dissolving a large amount of the substance. How would the solubility of CO_2 in the oceans be affected by an increase in the temperature of water?

Activity 5.3

In your group, discuss each of the following questions. After the discussion, share your ideas with the rest of the class.

1. Why are fertilisers like urea and diammonium monohydrogen phosphate extensively used in agriculture?
2. What role do the nitrogen-fixing bacteria play in legumes in the nitrogen cycle?

2. *The Nitrogen Cycle*

Proteins and nucleic acids contain nitrogen, so nitrogen is a very important atom in biological organisms. Nitrogen makes up 78% of the earth's atmosphere, but most organisms cannot use nitrogen (N_2). This is because the N≡N triple bond has large dissociation energy (945 kJ mol^{-1}), and N_2 is quite inert.

Nitrogen fixation refers to the conversion of nitrogen gas into nitrogen compounds.

Natural fixation reactions can be initiated by lightning, which breaks nitrogen molecules and enables their atoms to combine with oxygen in the air, forming nitrogen oxides. These compounds are then washed into the soil by rain.

Bacteria found in nodules in the roots of leguminous plants, such as beans, lentils, and peas, can convert atmospheric nitrogen gas into nitrates (NO_3^-), which plants use to make plant proteins. Generally, soluble nitrogen compounds in the soil can be taken up by plants to make plant proteins.

Animals eat plants and convert plant proteins into animal proteins. Animals excrete nitrogenous wastes, partially as urea or uric acid, which is returned to the soil.

Industrial chemical processes involving the fixation of atmospheric nitrogen include the Haber's process for the manufacture of ammonia, and the formation of calcium cyanamide, which involves the use of high temperatures and pressures. Bacteria can fix atmospheric nitrogen easily at room temperature and atmospheric pressure, yet man requires expensive industrial plants with high temperatures and pressures to do the same thing.

Once atmospheric nitrogen is fixed by chemical industries, it can be converted to nitrogen-containing fertilisers, which can be used by plants for their metabolism.

When plants and animals die, specialized decomposing bacteria will start to convert them back into ammonia and water-soluble ammonium salts. After the nutrients are converted back into ammonia, anaerobic bacteria will convert it back into nitrogen gas. This process is known as denitrification.

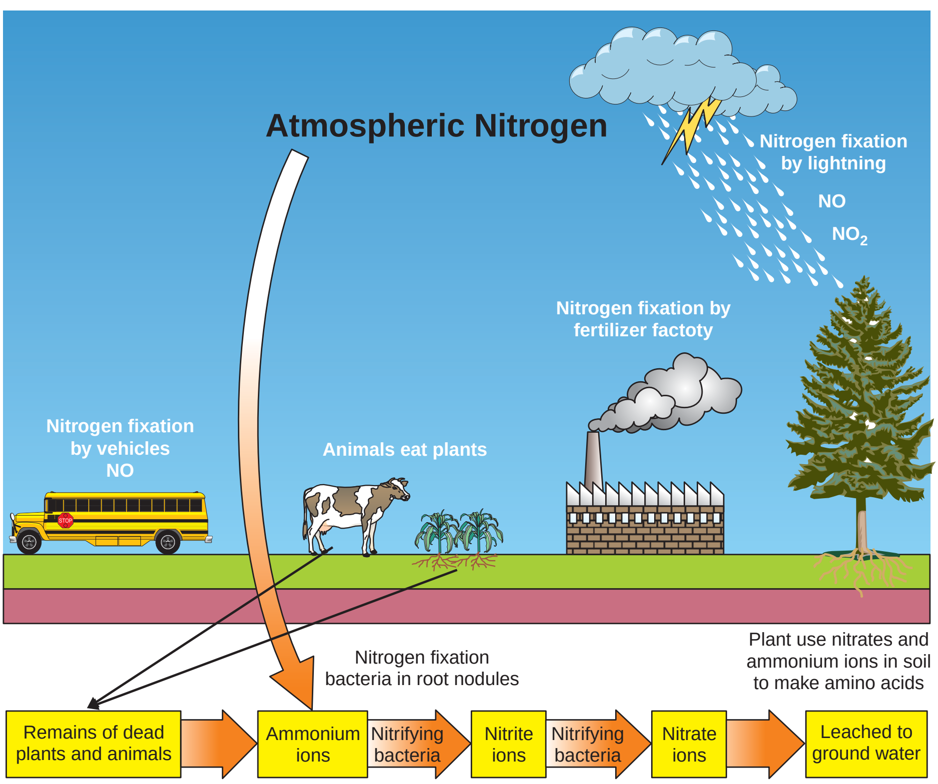


Figure 5.3 Nitrogen cycle.

Exercise 5.3

1. For what purpose do plants and animals need nitrogen?
2. Why is atmospheric nitrogen less reactive?
3. What is the difference between nitrogen fixation and denitrification? Use examples to explain your answer.
4. How is nitrogen fixed naturally and synthetically?

3. *The Phosphorus Cycle*

The phosphorus cycle differs from the nitrogen and carbon cycles primarily in that phosphorus is not found in the atmosphere in the gaseous state.

Phosphorus is mainly found in water, soil and sediments. It is an essential nutrient for plants and animals in the form of PO_4^{3-} and HPO_4^{2-} ions. It is part of DNA (deoxyribo nucleic acid) molecules, molecules that store energy-rich ATP (adenosine triphosphate) and fats of cell membranes. Phosphorus is a building block of certain parts of the human and animal body, such as bones and teeth.

Phosphate salts are released when phosphate rocks are eroded by rainfall, weathering and runoff. The release of phosphate salts into the soil results in a constant phosphorus supply for plants. Phosphate salts are absorbed through the roots of plants and are used to make organic compounds. Animals absorb phosphates by eating plants or plant-eating animals. When plants and animals die, they decompose and return phosphorus into the soil or water and complete the cycle.

In comparison to the nitrogen and carbon cycles, the rate at which phosphate salts are released is extremely slow. Phosphorus can remain in rocks or sediments for millions of years. As a result, the need of phosphate salts for plant growth outweighs the amount of phosphate salts being released. To alleviate the phosphate demand, the addition of phosphate fertilisers has been devised by humans to maintain and increase crop production.

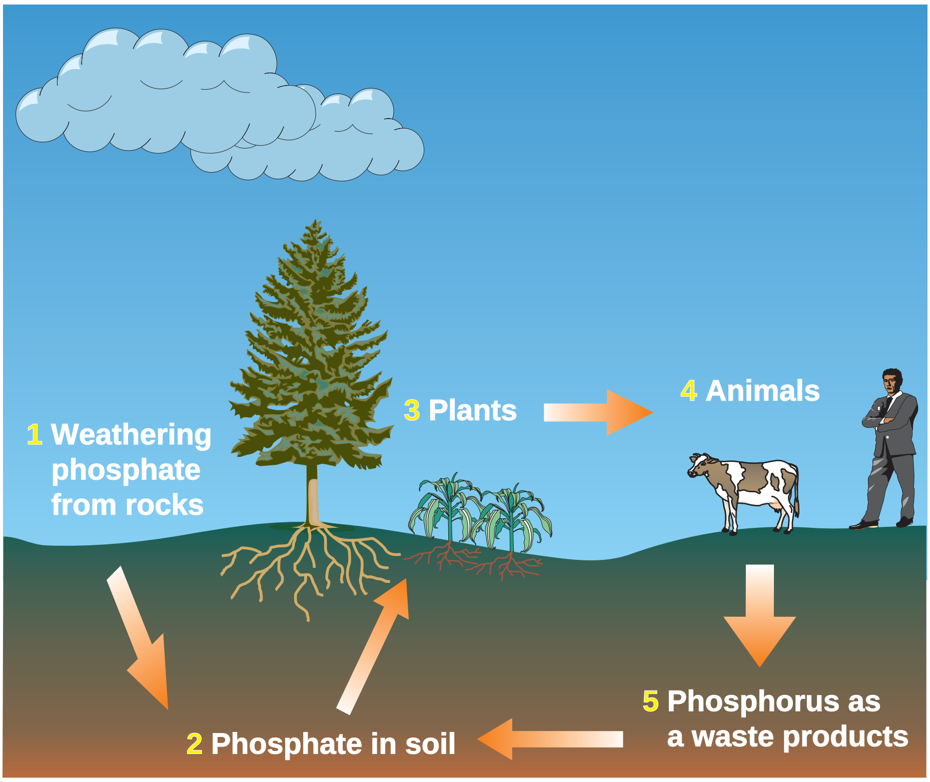


Figure 5.4 Phosphorus cycle.

Exercise 5.4

1. What are the effects of using phosphate fertilisers on the environment?
2. What makes the phosphorus cycle different from the carbon and nitrogen cycles?
3. What are the major uses of phosphorus in living organism?

5.2 Some Elements in Industry

After completing this subunit, you will be able to:

- define metallurgy;
- explain the major steps in metallurgical processes;
- describe the manufacture of sodium by Down's cells;

- explain the chemical properties of sodium;
- describe the uses of sodium;
- describe the manufacture of calcium;
- explain the chemical properties of calcium;
- describe the uses of calcium;
- describe the manufacture of tin;
- explain the chemical properties of tin;
- describe the uses of tin;
- describe the manufacture of lead;
- explain the chemical properties of lead;
- describe the uses of lead;
- describe the manufacture of zinc;
- explain the chemical properties of zinc;
- describe the uses of zinc;
- describe the manufacture of chromium;
- explain the chemical properties of chromium;
- describe the uses of chromium;
- describe the production of silicon;
- explain the chemical properties of silicon;
- describe the uses of silicon;
- explain the steps in the Haber process in the industrial production of ammonia and describe the uses of ammonia;
- explain the steps in the Ostwald's process in the industrial production of nitric acid and describe the uses of nitric acid;
- explain the steps in the Contact process in the industrial production of sulphuric acid and describe the uses of sulphuric acid; and
- explain the steps in the industrial production of diammonium monohydrogen phosphate and describe its uses.

Activity 5.4

Discuss each of the following questions in your group; after the discussion, share your ideas with the rest of the class.

1. How are metals extracted from their ores?
2. What property determines the application of chemical or electrolytic reduction?
3. Why are some elements extracted by electrolysis and others by chemical reduction? Give examples for each type.

5.2.1 Metallurgy

Metallurgy is the science and technology of extracting metals from their natural sources and preparing them for practical use.

The principal steps that are carried out to obtain a metal from its ore are: concentrating the ore, pre-treatment, extracting the metal and refining (*purifying*) the crude metal.

1. *Concentrating the Ore*

What physical and chemical methods are employed to concentrate an ore?

Concentrating an ore increases the fraction of metal-bearing ore by eliminating most of the accompanying rock and soil, called gangue. A gangue is undesired material or impurity, which is found together with the ore.

The ore must first be finely divided by crushing and grinding, and then the gangue can be removed in a number of ways.

i) Gravity Separation

Gravity separation depends on the difference in density between the mineral and the gangue. For example, since gold has a very large density (19.3 g/mL), it can be separated from its gangue by this method.

ii) Magnetic Separation

Magnetic separation can be used for separating ferromagnetic minerals from their impurities.

For example, the mineral magnetite (Fe_3O_4) can be separated from gangue by using a strong electromagnet.

iii) Froth Floatation

In this process, the ore is finely ground and added to water containing oil and detergent. Because of the differences in the surface characteristics of mineral particles and the silicate rock particles, the oil wets only the mineral particles. A stream of air blown through the mixture causes tiny bubbles to form on the oil-covered pieces, which then float to the surface in the form of froth or foam, while the gangue settles to the bottom. The froth is skimmed off, allowed to collapse, and then is dried to recover the mineral particles. For example, sulphide ores are concentrated by froth flotation.

iv) Amalgamation

An amalgam is an alloy of mercury with another metal or metals.

How are metals recovered from an amalgam?

Mercury forms amalgams with a number of metals and can be used to extract these metals from their ores. For example, mercury dissolves silver and gold in an ore to form a liquid amalgam, which is easily separated from the remaining ore. The gold or silver is recovered by distilling off the mercury.

v) Leaching

How does leaching differ from other methods of concentrating ore?

The methods we have seen so far are physical methods of concentrating ore. In contrast, leaching is a chemical process of concentrating ore. In this method, the ore is treated with a reagent that dissolves the target substance, leaving the impurities undissolved. For example, aluminium oxide, Al_2O_3, is separated from bauxite ($Al_2O_3{\cdot}2H_2O$) and oxides of iron and silicon impurities. When the crushed ore is treated with hot 30% aqueous solution of sodium hydroxide, the amphoteric aluminium oxide dissolves.

$$Al_2O_3(s) + 2NaOH\ (aq\ 30\%) + 3H_2O \xrightarrow{150°C\ to\ 220°C} 2Na^+(aq) + 2Al(OH)_4^-(aq)$$

Why is aluminium oxide soluble in excess strong bases like NaOH?

Iron oxide and other basic oxides are not affected by the base, and the silicate impurities are converted to insoluble aluminosilicates. The solution is filtered, cooled, and diluted to reduce the OH^- concentration. Aluminium hydroxide then precipitates and the anhydrous oxide is obtained by heating.

$$Al(OH)_4^-\ (aq) \longrightarrow Al(OH)_3(s) + OH^-\ (aq)$$

$$2Al(OH)_3(s) \xrightarrow{heat} Al_2O_3(s) + 3H_2O(g)$$

Gold is sometimes found in ores in the elemental state, but it usually occurs in relatively small concentrations. A process called cyanidation treats the crushed ore with an aqueous cyanide solution in the presence of air. This process dissolves the gold by forming the complex ion $Au(CN)_2^-$.

$$4Au(s) + 8CN^-(aq) + O_2(g) + 2H_2O(l) \longrightarrow 4Au(CN)_2^-(aq) + 4OH^-(aq)$$

Pure gold is then recovered by reacting the solution of $Au(CN)_2^-$ with zinc powder to reduce Au^+ in the complex to Au.

$$2Au(CN)_2^-(aq) + Zn(s) \longrightarrow 2Au(s) + Zn(CN)_4^-(aq)$$

Activity 5.5

Discuss the following in your group; after the discussion, share your ideas with the rest of the class.

1. Which elements can form amalgam with mercury?
2. Can non-metals form amalgam; if not why?
3. What are the uses of amalgams in our daily life?

Exercise 5.5

1. Define metallurgy.
2. Describe and give an example of each of the following methods of concentrating ores.

   a Gravity separation
   b Magnetic separation
   c Froth flotation
   d Amalgamation
   e Leaching

2. *Pre-treatment*

Pre-treatment converts a mineral to a form that is easy to reduce. For example, sulfides are converted to reducible oxides by heating them in dry air, a process called roasting:

$$2PbS(s) + 3O_2(g) \xrightarrow{\text{heat}} 2PbO(s) + 2SO_2(g)$$

If a metal is to be obtained by electrolytic reduction, its oxide, hydroxide, or carbonate is often treated with HCl to convert it to chloride. Chlorides are preferred for electrolytic reductions because they usually melt at low temperatures, except for aluminium chloride, to form conductive liquids. Molten aluminium chloride is a poor conductor of electricity. This pre-treatment method is used in the Dow process for obtaining magnesium metal from seawater.

Seawater contains about 1.3 g of magnesium ions per litre. These ions are first precipitated as magnesium hydroxide and then converted to magnesium chloride.

The chemical equations are:

$$CaCO_3(s) \xrightarrow{\text{heat}} \underset{\text{Lime}}{CaO(s)} + CO_2(g)$$

$$CaO(s) + H_2O(l) \longrightarrow \underset{\text{Saturated solution}}{Ca(OH)_2(aq)}$$

$$\underset{\text{Seawater}}{Mg^{2+}(aq)} + Ca(OH)_2(aq) \longrightarrow Mg(OH)_2(s) + Ca^{2+}(aq)$$

The magnesium hydroxide is filtered and converted to magnesium chloride with HCl.

$$Mg(OH)_2(s) + 2HCl(aq) \longrightarrow MgCl_2(aq) + 2H_2O(l)$$

Pure $MgCl_2$, for electrolysis, is recovered by evaporating the water.

3. *Production of Metals*

By what methods are metals extracted from their pre-treated ores?

Because metals in their combined form always have positive oxidation numbers, the production of a free metal usually involves a reduction process. How a particular pure metal is obtained by reduction from its combined form depends on the standard reduction potential of the metal. The production of metals by reduction may be accomplished either chemically or electrolytically.

a Chemical Reduction

A more electropositive metal can be used as a reducing agent to separate a less electropositive metal from its compound at high temperatures.

For example:

$$V_2O_5(s) + 5Ca(l) \longrightarrow 2V(l) + 5CaO(s)$$

$$TiCl_4(s) + 2Mg(l) \longrightarrow Ti(s) + 2MgCl_2(l)$$

$$Cr_2O_3(s) + 2Al(s) \longrightarrow 2Cr(l) + Al_2O_3(s)$$

The less electropositive metals like copper, tin, lead, zinc, manganese, cobalt, nickel and iron are obtained by reducing their oxides with coke (carbon) at high temperature.

$$ZnO(s) + C(s) \xrightarrow{\text{heat}} Zn(l) + CO(g)$$

Carbon is used as a reducing agent because it is readily available and is cheap. However, it can not be used to reduce all the metal oxides.

Hydrogen may also be used to reduce metals that are lower than itself in the reactivity series. But since hydrogen is more expensive than carbon, it is only used on a large scale for the extraction of tungsten because this process avoids the formation of tungsten carbide.

$$WO_3(s) + 3H_2(g) \longrightarrow W(s) + 3H_2O(g)$$

b Electrolytic Reduction

How can we prepare metals by electrolysis?

Electrolytic reduction is suitable for highly electropositive metals, such as sodium, magnesium and aluminium. Aluminium is extracted by the electrolysis of molten aluminium oxide (Al_2O_3) with cryolite (Na_3AlF_6). Cryolite is added to aluminium oxide to enhance electrical conductivity and to lower the melting point. However, the many metals are extracted by the electrolysis of anhydrous molten halides. At the cathode, metal ions are reduced and at the anode, anions are oxidized.

4. *Refining and Alloying*

Metals prepared by reduction usually need further treatment to remove impurities. The extent of purification, of course, depends on how the metal will be used. The three common purification procedures are distillation, electrolysis, and zone refining.

a Distillation

What kind of metals can be separated by distillation?

Metals that have low boiling points, such as mercury, magnesium, and zinc, can be separated from other metals by fractional distillation.

b Electrolysis

Electrolysis is another important purification technique. For example, the copper metal obtained by roasting copper sulphide usually contains impurities such as zinc, iron, silver, and gold. The more electropositive metals are removed by an electrolysis process in which the impure copper acts as anode and pure copper acts as the cathode. (Refer to the electrolysis of copper sulphate, using copper electrodes, in Unit 4).

c Zone Refining

Another method of obtaining pure metals is zone refining. In this process, a metal rod containing a few impurities is drawn through an electrical heating coil that melts the metal in the metal rod. Most impurities dissolve in the molten metal. As the metal rod comes out from the heating coil, it cools and the pure metal crystallizes, leaving the impurities in the molten metal portion that is still in the heating coil.

Purification of the metal occurs because as the crystal reforms, the metal ions are likely to fit much better in the crystal lattice than are atoms of impurities. Several repetitions of this process give a very pure metal.

High purity of metals is not always required, because pure metals possess undesirable properties for most practical applications. For instance, as you learned in Unit 4, iron deteriorates by corrosion. Therefore, iron is generally more useful when it is alloyed or coated with other metals.

To make alloys, metals are melted together to form a molten solution, and the solution is cooled to the solid state. The resulting alloy possesses the same general characteristics as the parent metals. However, because the alloy is a mixture in the form of a solid solutions, it is stronger than its parent metals.

Activity 5.6

Form a group. Discuss the following questions in your group. After the discussion, share your ideas with the rest of class.

1. Make a list of various elements present in sea water and river water.
2. Are carbonates and bicarbonates also present in sea water?
3. Which elements are economically recovered from sea water by electrolysis?

Exercise 5.6

1. Discuss the main steps in obtaining a pure metal from its ore.
2. What is meant by pre-treatment of an ore? Give some examples of pre-treatment.
3. Describe, with examples, the chemical and electrolytic reduction processes used in the production of metals.
4. Describe the process by which a metal is purified by zone refining.
5. A copper sample containing gold, lead, silver, and zinc as impurities, is refined electrolytically using a copper sulphate as electrolyte. Use Table 4.2 and state which substances will be found in the anode sludge.

5.2.2 Extraction, Properties and Uses of Some Selected Metals

1. *Sodium*

Activity 5.7

Form a group. Discuss the following questions in your group. After the discussion, share your ideas with the rest of class.

1. What are the main ores of sodium?
2. Which of the ores you listed in question (1) are found in Lake Afdera and Lake Abiyata?
3. Which regions in Ethiopia are the potential sources of table salt?
4. Why is sodium metal kept under kerosene or paraffin oil?
5. For the electrolysis of molten sodium chloride, write a balanced chemical equation for:

   a anode reaction   b cathode reaction   c overall reaction

Extraction of Sodium

How is sodium metal extracted from sodium chloride?

Sodium is a very reactive metal and is not found free in nature. It exists in the form of compounds. It is a strong reducing agent and cannot be reduced by carbon. Sodium is obtained by the electrolysis of a molten mixture of about 40% $NaCl$ and 60% $CaCl_2$ in a Downs cell as shown in Figure 5.5. Calcium chloride ($CaCl_2$) is added to lower the melting point of $NaCl$ from 800°C to 600°C.

The sodium metal formed at the cathode is in liquid state. Because sodium metal is less dense than molten NaCl, the sodium floats to the surface and is collected. Chlorine gas forms at the anode and is collected at the top of the Downs cell.

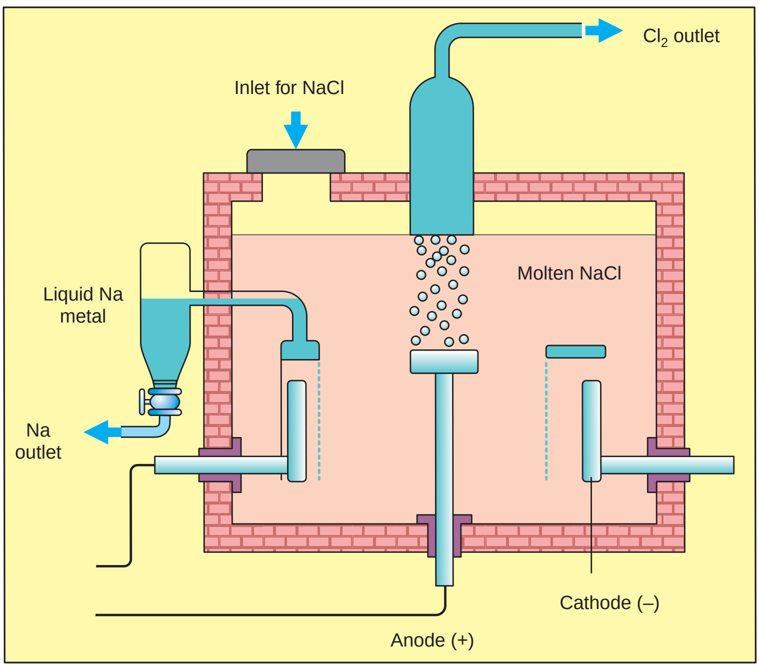


Figure 5.5 Downs cell for electrolysis of molten NaCl.

Chemical Properties of Sodium

a Reaction with water

Sodium reacts with water, liberating hydrogen and forming sodium hydroxide solution.

$$2Na(s) + 2H_2O(l) \longrightarrow 2NaOH(aq) + H_2(g)$$

b Reaction with air

Sodium tarnishes readily in dry air to form sodium peroxide and sodium oxide.

$$6Na(s) + 2O_2(g) \longrightarrow \underset{\text{major product}}{Na_2O_2(s)} + \underset{\text{minor product}}{2Na_2O(s)}$$

c Reaction with hydrogen

Sodium reacts with hydrogen to form sodium hydride.

$$2Na(s) + H_2(g) \longrightarrow 2NaH(s)$$

d Reaction with halogens (F_2, Cl_2, Br_2 and I_2)

Sodium reacts with halogens to form sodium halides.

$$2Na(s) + F_2(g) \longrightarrow 2NaF(s)$$

Uses of Sodium

The largest use of sodium is to make a Na/Pb alloy needed to make tetraethyl lead ($PbEt_4$) and tetramethyl lead ($PbMe_4$). These compounds are used as anti-knock additives to petrol. Another important use is to reduce $TiCl_4$ and $ZnCl_4$ to the metals. Liquid sodium metal is used as a coolant in nuclear reactors. It is also used to make Na_2O_2 and NaH, and for street lights.

Exercise 5.7

1. Write the chemical formulas of the following ore:

   a borax   b trona   c rock salt

2. Why is calcium chloride added in the electrolysis of molten sodium chloride?
3. Assume that a piece of sodium catches a fire in the laboratory. Why shouldn't you try to extinguish with water?
4. Write balanced chemical reactions for the reaction of sodium with:

   a chlorine   b bromine   c iodine

5. State the uses of sodium metal.

2. *Calcium*

Occurrence of Calcium

Calcium is the 5th most abundant element in the earth's crust. The main ores of calcium are: limestone, chalk, and marble ($CaCO_3$), dolomite ($CaCO_3.MgCO_3$), gypsum ($CaSO_4.2H_2O$), fluorite (CaF_2), and hydroxylapatite, $Ca_5(PO_4)_3OH$. In Ethiopia, gypsum deposits are found in the Danakil depression.

Extraction of Calcium

Explain why sodium and calcium cannot be extracted by using carbon as a reducing agent?

Calcium is prepared by the electrolysis of molten calcium chloride ($CaCl_2$).

Anode (oxidation) : $2Cl^-(l) \longrightarrow Cl_2(g) + 2e^-$

Cathode (reduction) : $Ca^{2+}(l) + 2e^- \longrightarrow Ca(l)$

Overall reaction : $Ca^{2+}(l) + 2Cl^-(l) \longrightarrow Ca(l) + Cl_2(g)$

Calcium can also be prepared by the reduction of CaO by aluminium in vacuum, where the calcium produced distills off.

Based on the above information, write an equation that shows the reaction between calcium oxide and aluminium metal.

Chemical properties of Calcium

a Reaction with water

Calcium reacts with cold water quite readily, liberating hydrogen gas and forming calcium hydroxide.

$$Ca(s) + 2H_2O(l) \longrightarrow Ca(OH)_2(aq) + H_2(g)$$

b Reaction with oxygen

Calcium reacts with oxygen to form calcium oxide.

$$2Ca(s) + O_2(g) \longrightarrow 2CaO(s)$$

c Reaction with nitrogen

Calcium reacts with nitrogen at high temperatures to form calcium nitride.

$$3Ca(s) + N_2(g) \xrightarrow{\text{high temperature}} Ca_3N_2(s)$$

d Reaction with halogens

Calcium reacts with F_2, Cl_2, Br_2 and I_2 to form CaF_2, $CaCl_2$, $CaBr_2$ and CaI_2 respectively.

$$Ca(s) + F_2(g) \longrightarrow CaF_2(s)$$

e Reaction with hydrogen

Calcium combines with hydrogen to form calcium hydride.

$$Ca(s) + H_2(g) \longrightarrow CaH_2(s)$$

Uses of Calcium

Calcium is an essential element in living matter. It is the major component of bones and teeth. A characteristic function of Ca^{2+} ions in living systems is in the activation of a variety of metabolic processes. For example, calcium plays a vital role in heart action, blood clotting, muscle contraction, and nerve-impulse transmission.

Exercise 5.8

1. List the common ores of calcium.
2. When exposed to air, calcium first forms calcium oxide, which is then converted to calcium hydroxide, and finally to calcium carbonate. Write a balanced chemical equation for each step.
3. Write a balanced chemical equation to show the reaction between calcium and:

   a chlorine   c iodine

   b bromine   d nitrogen
4. Describe the uses of calcium metal.

3. *Tin*

Occurrence

The only important ore of tin is cassiterite, SnO_2.

Extraction of Tin

Activity 5.8

Refer to chemistry books available in your school library, or to any other sources, and write a report how tin occurs in nature and how it is extracted from cassiterite. After discussing it with your teacher, present your report to the class.

Chemical Properties of Tin

a Reaction with water

Tin does not react with cold water, but it reacts with steam to form SnO_2 and H_2.

$$Sn(s) + 2H_2O(g) \xrightarrow{heat} SnO_2(s) + 2H_2(g)$$

b Reaction with acids

Tin reacts with dilute and concentrated acids.

$$Sn(s) + \textit{dil.}\ 2HCl(aq) \longrightarrow SnCl_2(aq) + H_2\ (g)$$

$$Sn(s) + \textit{conc.}\ 4HNO_3(aq) \longrightarrow Sn(NO_3)_2(aq) + 2NO_2(g) + 2H_2O(l)$$

c Reaction with halogens

Tin reacts with Cl_2 and Br_2 in the cold and with F_2 and I_2 on warming, forming the corresponding tin tetrahalide.

$$Sn(s) + 2Cl_2(g) \xrightarrow{\text{cold}} SnCl_4(s)$$

$$Sn(s) + 2F_2\ (g) \xrightarrow{\text{warm}} SnF_4(s)$$

Uses of Tin

The main uses of tin are for electroplating steel, to make tin-plate, and alloys. Tin-plate is extensively used for making cans for food. Tin is a constituent of many alloys, including type metal (Sn, Sb and Pb), bronze (Sn and Cu), and solder (Sn and Pb).

Exercise 5.9

1. Write balanced chemical equation to show the extraction of tin from cassiterite.
2. Write the reactions of tin with steam and dilute HNO_3.
3. Write the reactions of tin with chlorine, bromine and iodine.
4. Describe the uses of tin metal.

4. *Lead*

Occurrence of Lead

The main ore of lead is galena, PbS. It is black, shiny and very dense.

Extraction of Lead

Galena is mined and separated from its impurities by froth flotation. There are two methods of extracting the element:

According to first method, the ore is roasted in air to give PbO, which is then reduced with coke or carbon monoxide in a furnace.

$$2PbS(s) + 3O_2(g) \longrightarrow 2PbO(s) + 2SO_2(g)$$

$$2PbO(s) + C(s) \xrightarrow{\Delta} 2Pb(l) + CO_2(g)$$

In second method, PbS is partially oxidized by heating and blowing air through it. After some time the air is turned off and heating is continued, and the mixture undergoes self–reduction.

$$3PbS(s) + O_2(g) \xrightarrow{\text{heated in air}} PbS(s) + 2PbO(s) \xrightarrow[\text{of air}]{\text{heated in absence}} 3Pb(l) + SO_2(g)$$

Chemical Properties of Lead

Lead is not affected by water because the metal is covered by a thin oxide film. It dissolves slowly in dilute HCl, forming the sparingly soluble $PbCl_2$ and quite readily in dilute HNO_3, forming $Pb(NO_3)_2$ and oxides of nitrogen. However, it does not dissolve in dilute H_2SO_4 because a surface coating of $PbSO_4$ is formed. Lead is slowly attacked by cold alkali, and rapidly by hot alkali, giving the plumbates $Na_2Pb(OH)_6$. Thus, lead is amphoteric. It also reacts with F_2 in the cold, forming PbF_2, and with Cl_2 on heating, giving $PbCl_2$.

Uses of Lead

The major use of lead is to make lead-acid storage batteries. It is also used in the manufacture of $PbEt_4$ as an additive for petrol, in paints and pigments. In addition, lead is used for the production of lead sheets, lead pipes and solder.

Exercise 5.10

1. Show the extraction of lead from galena, using chemical equations.
2. Write balanced chemical equations to show the reaction between lead and

   a H_2O b HCl c HNO_3
3. Describe the uses of lead metal.

5. *Zinc*

Occurrence of Zinc

Zinc is the 24th most abundant element in the earth's crust. The most important ore of zinc is zinc blende (ZnS).

Extraction of Zinc

How is zinc metal extracted from zinc blende?

ZnS is concentrated by froth flotation and then roasted in air to give ZnO and SO_2. The SO_2 is used to make H_2SO_4. Zn is extracted from the oxide by two different processes.

1. ZnO may be reduced by carbon monoxide at 1200°C

$$ZnO(s) + CO(g) \longrightarrow Zn(g) + CO_2(g)$$

2. ZnS is heated in air at a lower temperature, yielding ZnO and $ZnSO_4$. These are dissolved in H_2SO_4. Zinc dust is added to precipitate Cd, and then the $ZnSO_4$ solution is electrolyzed to give pure zinc. This method is more expensive than the first.

Chemical Properties of Zinc

Zinc is a silvery solid that tarnishes rapidly in moist air. It dissolves in dilute HCl and liberates hydrogen gas.

$$Zn(s) + HCl(aq) \longrightarrow ZnCl_2(aq) + H_2(g)$$

Zinc also reacts with aqueous solution of sodium hydroxide and forms sodium zincate, $Na_2Zn(OH)_4$. Hence, zinc shows amphoteric properties.

On heating, it reacts with oxygen to form zinc oxide.

$$2Zn(s) + O_2(g) \xrightarrow{\text{heating}} 2ZnO(s)$$

Uses of Zinc

Zinc is used in large amounts for coating iron to prevent it from rusting. A thin coating of zinc may be applied electrolytically. This process is called galvanizing. A thicker layer may be applied by dipping a metal in molten zinc. Large amounts of Zn are used to make alloys. The most common alloy is brass, which is an alloy of copper and zinc.

Can you list the other alloys of zinc?

Zinc is also used as the negative electrode (anode) in sealed 'dry' batteries such as Le clanche' cells, mercury cells and alkaline manganese cells. Zinc oxide is sometimes used as a white pigment in paint. It is particularly bright as it absorbs UV light and re-emits it as white light.

Exercise 5.11

1. Describe the extraction of zinc from zinc blende.
2. Explain the amphoteric properties of zinc.
3. State the uses of zinc metal.

Experiment 5.1

Studying Chemical Properties of Some Metals

Objective: To study some chemical properties of sodium, calcium, lead, tin and zinc metals.

Chemicals: Na, Ca, Sn, Pb, and Zn metals; 2 M HCl, water.

Apparatus: Test tubes and beakers.

1. *Reaction of cold water with sodium*

   Take about 5 mL of water in a test tube and place a small piece of sodium metal to the water. Check the basicity of the solution using litmus paper.

2. *Reaction of cold water with calcium*

   Take about 50 mL of water in a beaker and add a small piece of calcium metal in the water. Check the basicity of the solution by using litmus paper.

3. Reaction of tin, lead and zinc with 2M HCl

   Place 1 mL of 2M HCl in three test tubes and then add a small piece of tin metal in the first test tube, lead metal in the second test tube, and zinc metal in the third test tube. What do you observe?

Results and Discussion:

1. What is the gas liberated? How do you confirm it?
2. Write a chemical equation that shows:

   a the burning of hydrogen gas.

   b the reaction between zinc and dilute hydrochloric acid.

6. *Chromium*

Occurrence

Chromium is the 21st most abundant element, by weight, in the Earth's crust. The most important ore of chromium is chromite ($FeCr_2O_4$).

Extraction

Chromium is produced in two forms which are ferrochrome and pure chromium metal. Ferrochrome is mainly an alloy of chromium and iron. It is prepared by reducing chromite with carbon.

$$FeCr_2O_4(s) + 4C(s) \xrightarrow[\text{furnance}]{\text{electric}} \underbrace{Fe + 2Cr}_{\text{ferrochrome}} + 4CO$$

Four basic steps are followed to get pure chromium.

Step 1: When chromite is fused with NaOH in air, chromium (III) is oxidized to chromium (VI).

$$4FeCr_2O_4(s)+16NaOH(s)+7O_2(g) \xrightarrow{1100°C} 8Na_2CrO_4(s)+2Fe_2O_3(s)+8H_2O(l)$$

Step 2: Ferric oxide (Fe_2O_3) is insoluble, but sodium chromate (Na_2CrO_4) is soluble in water. Thus the sodium chromate is separated from ferric oxide by dissolving with water, followed by decantation or filtration. The sodium chromate solution is acidified to convert it to a less soluble sodium dichromate.

$$2Na_2CrO_4(aq) + 2HCl(aq) \longrightarrow Na_2Cr_2O_7(s) + 2NaCl(aq) + H_2O(l)$$

Step 3: The sodium dichromate is reduced to Cr_2O_3 by heating with carbon.

$$Na_2Cr_2O_7(s) + 2C(s) \longrightarrow Cr_2O_3(s) + Na_2CO_3(s) + CO(g)$$

Step 4: Finally, Cr_2O_3 is reduced to the metal by Al.

$$Cr_2O_3(s) + 2Al(s) \longrightarrow 2Cr(s) + Al_2O_3(s)$$

Chemical Properties

Chromium is an active metal but it is protected from corrosion by a very thin transparent oxide film.

$$4Cr(s) + 3O_2(g) \longrightarrow 2Cr_2O_3(s)$$

Concentrated nitric acid and other oxidizing agents build up the oxide film to the point where chromium becomes passive, that is, it no longer dissolves in the acid solution.

Chromium dissolves in HCl and dilute H_2SO_4 to form blue chromium (II) ions, which are stable only in the absence of air.

$$Cr(s) + 2H^+(aq) \longrightarrow Cr^{2+}(aq) + H_2(g)$$

The unstable chromium (II) state is readily oxidized to the chromium (III) state.

It can remove traces of oxygen by bubbling the gas through a solution containing chromium (II) ions.

$$4Cr^{2+}(aq) + O_2(g) + 4H^+(aq) \longrightarrow 4Cr^{3+}(aq) + 2H_2O(l)$$

Uses

Nichrome wire, commonly used in chemistry laboratories for flame tests, is an alloy of nickel and chromium. Ferrochrome, iron–chromium alloy, is used in the production of stainless steel. Cr_2O_3 is dissolved in H_2SO_4 and deposited electrolytically (*electroplating*) on the surface of a metal. This protects the metal from corrosion and gives it a shiny appearance.

Sodium and potassium chromates and dichromates are used as pigments and corrosion inhibitors in heating systems and air-conditioning systems.

Chromium (VI) oxide, CrO_3, appears as a bright-red precipitate when saturated potassium dichromate is treated with excess of concentrated sulphuric acid.

$$Cr_2O_7^{2-}(aq) + 2H^+(aq) \longrightarrow 2CrO_3(s) + H_2O(l)$$

$$CrO_3(s) + H_2O(l) \rightleftharpoons H_2CrO_4$$

The resulting acid mixture (also known as chromic acid) is a powerful oxidizing agent. It can oxidize grease and was used as a cleaning solution for laboratory glassware.

Exercise 5.12

1. Write equations for the reduction of chromite ore with carbon, and Cr_2O_3 with aluminium.
2. Pure chromium can also be prepared from chromite by the following steps. Write the equations for each step.

Step 1: The ore is fused with sodium carbonate in the presence of air, yielding sodium chromate, iron (III) oxide, and carbon dioxide gas.

Step 2: The sodium chromate is converted to sodium dichromate by the addition of acid.

Step 3: The sodium dichromate is recrystallised, dried and reduced to chromium (III) oxide with carbon.

Step 4: The chromium (III) oxide is reduced to chromium metal with aluminium.

5.2.3 Silicon

Occurrence

Silicon is the second most abundant element, after oxygen, in the Earth's crust. It occurs as silica (SiO_2) and silicate compounds containing the silicate ion, (SiO_4^{4-}). Quartz is a pure crystalline form of silica, and flint is a hard amorphous form.

Extraction

Silicon is prepared by heating silica with coke to approximately 3000°C in an electric furnace:

$$SiO_2(s) + 2C(s) \longrightarrow Si(l) + 2CO(g)$$

The molten silicon is taken from the bottom of the furnace and allowed to cool producing a shiny blue-gray solid.

Extremely high-purity silicon is needed for the electronics industry. Purifying raw silicon requires additional steps. First, the silicon in the impure sample is allowed to react with chlorine to convert the silicon to liquid silicon tetrachloride.

$$Si(s) + 2Cl_2(g) \longrightarrow SiCl_4(l)$$

Silicon tetrachloride (*boiling point* 57.6°C) is carefully purified by distillation and then reduced to silicon, using magnesium:

$$SiCl_4(g) + 2Mg(s) \longrightarrow 2MgCl_2(s) + Si(s)$$

The magnesium chloride is washed out with water, and the silicon is remelted and cast into bars. A final purification is carried out by zone refining.

Chemical Properties

Silica is resistant to attack by all acids except HF, with which it reacts to give SiF_4 and H_2O. This chemical attack is involved in the etching of glass. It also dissolves slowly in hot, molten NaOH or Na_2CO_3 to give Na_4SiO_4:

$$SiO_2(s) + 4HF(l) \longrightarrow SiF_4(g) + 2H_2O(l)$$

$$SiO_2(s) + 2Na_2CO_3(l) \longrightarrow Na_4SiO_4(s) + 2CO_2(g)$$

Silicon and methyl chloride (CH_3Cl) react at 300°C in the presence of copper powder as a catalyst. The main product of this reaction is $(CH_3)_2SiCl_2$.

$$Si(s) + 2CH_3Cl\,(g) \longrightarrow (CH_3)_2SiCl_2(l)$$

When it reacts with water, initially it produces $(CH_3)_2Si(OH)_2$, and the reaction continues to form a polymer.

$$(CH_3)_2SiCl_2(l) + 2H_2O(l) \longrightarrow (CH_3)_2Si(OH)_2(l) + 2HCl(g)$$

$$n(CH_3)_2Si(OH)_2(l) \longrightarrow [(CH_3)_2SiO]_n(s) + nH_2O(l)$$

Silicone polymers are non-toxic and have good stability to heat, light, moisture, and oxygen.

Uses

Silicon is a semiconductor and is used in the construction of transistors and microprocessors. Quartz crystals are used to control the frequency of radio and television transmissions. Silicone polymers are used in making lubricants, lipstick, car polish and other materials.

Activity 5.9

Form a group. Discuss the following question. After the discussion, share your ideas with the rest of the class.

Explain why elements like tin, lead, zinc, chromium and silicon can be extracted from their ores using carbon as a reducing agent, but sodium and calcium cannot.

Exercise 5.13

1. Describe how ultra pure silicon can be produced from silica.
2. State major uses of silicon and its compounds.

Activity 5.10

Have a look at the Periodic Table of elements and make a list of various metals, which at room temperature:

1. do not react with acids, bases or air;
2. vigorously react with water;

3. react with air and water, and hence are stored under kerosene; and
4. react with chlorine.

Discuss your findings with your teacher and share them with your classmates.

5.2.4 Some Important Compounds of Selected Non-metals

1. *Ammonia* (NH_3)

Historical Note

Haber, Fritz (1868-1934), was a German chemist and Nobel laureate. He is best known for his development of an economical method of ammonia synthesis. Haber was born in Breslau (now Wroclaw, Poland) and educated at the Technische Hochschule in Berlin. He was appointed as professor of physical chemistry at the University of Berlin in 1911. Subsequently, he became director of the Kaiser Wilhelm Institute for Physical Chemistry in Berlin. During World War I, Haber was chief of the German chemical warfare service, and he directed the chlorine gas attack at the Second Battle of Ypres. In 1933, because of anti-Semitic policies in Germany, Haber resigned and went to Switzerland, where he died the following year. Haber's greatest achievement was his discovery, in 1913, of a process for synthesizing ammonia by the direct combination of nitrogen and hydrogen. The method was adapted to commercial use in the 1930s by the German chemist Karl Bosch. The Haber-Bosch process is used in the manufacture of explosives and in the production of fertilizers. Haber also made fundamental contributions to the field of electrochemistry. He was awarded the 1918 Nobel Prize in chemistry.

Haber Fritz

Activity 5.11

In your group, discuss each of the following questions. After the discussion, share your ideas with the rest of the class.

1. Write a balanced chemical equation for the formation of ammonia by Haber process.
2. What is the purpose of adding finely divided iron in the Haber process?
3. Why is ammonia highly soluble in water?

4. What conditions are required to get high yield of ammonia using Le Chatelier's principle?
5. What conditions are required to get economically feasible yields of ammonia?
6. Discuss the uses of ammonia.

2. *Nitric Acid (HNO_3)*

Pure nitric acid is a colourless liquid, but on exposure to light it turns brown because of slight decomposition into NO_2 (*brown*) and O_2.

$$4HNO_3(l) \longrightarrow \underset{\text{brown}}{4NO_2(g)} + O_2(g) + 2H_2O(l)$$

Nitric acid is a strong acid and dissociates completely to give H_3O^+ and NO_3^- in dilute aqueous solution.

Nitric acid forms a large number of salts, called nitrates, which are typically very soluble in water.

Nitric acid is a strong oxidizing agent, particularly when it is hot and concentrated. Nitric acid is produced industrially from ammonia by the three-step Ostwald process:

Step 1: Ammonia is burned in excess oxygen over a platinum catalyst to form nitric oxide (NO):

$$4NH_3(g) + 5O_2(g) \xrightarrow[\text{Pt}]{850\ °C,\ 5\ atm} 4NO(g) + 6H_2O(g)$$

Step 2: Additional air is added to cool the mixture and oxidize NO to NO_2:

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

Step 3: The NO_2 gas is bubbled into warm water where it reacts to give nitric acid and nitric oxide:

$$3NO_2(g) + H_2O(l) \longrightarrow 2HNO_3(aq) + \underset{\text{recycled}}{NO(g)}$$

The nitric oxide (NO) is recycled in Step 2.

The largest percentage of nitric acid is used to synthesize ammonium nitrate, a water soluble fertiliser. Large quantities are also used to make plastics, drugs, and explosives such as trinitrotoluene (TNT) and nitroglycerine.

Exercise 5.14

1. Describe the properties of nitric acid.
2. Show the preparation of nitric acid by the Ostwald process.
3. What are the main uses of nitric acid?

3. *Sulphuric Acid (H_2SO_4)*

Sulphuric acid is the world's most important industrial chemical, and the rate of consumption of sulphuric acid is a measure of a country's industrialization. Pure H_2SO_4 melts at 10.5°C and boils at 338°C. Anhydrous H_2SO_4 and concentrated H_2SO_4 mix with water in all proportions and release large amounts of heat energy (880 kJ/mol).

If water is poured into concentrated acid, the heat evolved leads to boiling of the water and causes violent splashing. The safe way to dilute strong acids is to carefully pour the acid into the water while stirring. Concentrated H_2SO_4 has strong oxidizing properties.

Do you know where sulphuric acid is manufactured in Ethiopia?

Sulphuric acid is prepared industrially by the contact process, using four steps:

Step 1: Burning sulphur in air:

$$S(s) + O_2(g) \longrightarrow SO_2(g)$$

Step 2: Converting SO_2 to SO_3

$$2SO_2(g) + O_2(g) \xrightarrow[400°C]{V_2O_5 \text{ catalyst}} 2SO_3(g)$$

The conversion of SO_2 to SO_3 is slow, but it is increased by heating the reaction mixture to 400ºC in the presence of V_2O_5 catalyst. Because the SO_2 and O_2 molecules react on contact with the surface of V_2O_5, the process is called Contact process.

Step 3: Passing SO_3 into concentrated H_2SO_4:

$$SO_3(g) + H_2SO_4(l) \longrightarrow H_2S_2O_7(l)$$

Pyrosulphuric acid
(oleum or fuming sulphuric acid)

Step 4: Addition of water to pyrosulphuric acid

$$H_2S_2O_7(l) + H_2O(l) \longrightarrow 2H_2SO_4(aq)$$

Uses of sulphuric acid

Sulphuric acid is used in the production of fertilisers, detergents, plastics and paints. It is used in the production of a number of explosives. Sulphuric acid is an oxidizing agent and a good dehydrating agent. It is often used to dry neutral and acidic gases such as nitrogen, oxygen, and carbon dioxide. It is also used as electrolyte in car batteries. It is also used as a catalyst in the manufacture of many chemicals.

Exercise 5.15

1. Describe the industrial production of H_2SO_4. Write the equations and state the conditions of each step.
2. State the properties and major uses of sulphuric acid.

Activity 5.12

Form a group and discuss each of the following questions:

1. What are some of the indications that the soil in which plants grow, is deficient in:
   a nitrogen? b phosphorus ? c potassium?
2. Why the large-scale use of synthetic fertilizers can be harmful to the environment?

After the discussion, share your ideas with the rest of the class.

4. *Diammonium monohydrogen phosphate (DAP), $(NH_4)_2HPO_4$*

Diammonium monohydrogen phosphate (DAP) is a white crystalline compound that is completely soluble in water. *How is DAP produced industrially*? It can be produced when ammonia reacts with phosphoric acid by the following two steps:

Step 1: Anhydrous ammonia reacts with phosphoric acid to form monoammonium dihydrogen phosphate and diammonium monohydrogen phosphate

$$3NH_3(g) + 2H_3PO_4(l) \longrightarrow NH_4H_2PO_4(s) + (NH_4)_2HPO_4(s)$$

Step 2: Recycling monoammonium dihydrogen phosphate for further reaction with anhydrous ammonia yields DAP:

$$NH_4H_2PO_4(s) + NH_3(g) \longrightarrow (NH_4)_2HPO_4(s)$$

DAP is used as a fertiliser. When applied as plant food, it temporarily increases soil acidity, but over the long term, the soil becomes more acidic than before upon nitrification of the ammonium. DAP has the advantage of having both nitrogen and phosphorus, which are essential for plant growth.

DAP can be used as fire retardant. It lowers the combustion temperature of the material, decreases weight-loss rates, and causes an increase in the production of residue or char.

DAP is also used as a yeast nutrient in wine making and beer brewing.

Exercise 5.16

1. Describe the industrial production of DAP. Write the chemical equations.
2. State properties and major uses of DAP.
3. Calculate the percentage composition of phosphorus and nitrogen in diammonium monohydrogen phosphate.

Unit Summary

- *There are 113 elements in the periodic table. Of these, 92 elements occur in nature, and the others are man-made.*
- *Minerals that are suitable for the extraction of elements are called ores.*
- *All ores are minerals, but not all minerals are ores.*
- *The twelve most abundant elements in the earth's crust, in decreasing order of abundance, are: oxygen, silicon, aluminium, iron, calcium, magnesium, sodium, potassium, titanium, hydrogen, phosphorus and manganese.*
- *Metals found in the Earth's crust are in the form of oxides, carbonates, sulphides, halides, sulphates and phosphates.*
- *Nutrients are limited in nature, and they are exchanged between living and nonliving things.*
- *In the carbon cycle, atmospheric carbon dioxide is converted to glucose by green plants. Animals incorporate carbon by eating plants or other animals. Carbon returns to the physical environment during respiration, the burning of wood or fossil fuels, and the decomposition of plants and animals.*
- *In the nitrogen cycle, atmospheric nitrogen is converted to nitrogen compounds by lightning, through the Haber process or by bacteria on*

root nodules of leguminous plants. Plants use these compounds to prepare their proteins and nucleic acids. Animals also prepare their proteins and nucleic acids through eating plants or other animals. Nitrogen returns to the atmosphere during the decomposition of plants and animals through the action of denitrifying bacteria.

- *The phosphorus cycle differs from the nitrogen and carbon cycles primarily because phosphorus cannot exist in gaseous form in the atmosphere. Plants absorb phosphates, using their roots, and make DNA, and ATP. Animals get phosphates by eating plants or other animals. When plants and animals die, they decompose and return phosphates into the soil or water.*
- *Metallurgy is the science and technology of extracting metals from their natural sources and preparing them for practical use. This process has three main steps: concentrating the ore, extracting the metal and purifying the crude metal.*
- *Sodium is the 7th most abundant element in the Earth's crust and is extracted from molten sodium chloride using Downs cell.*
- *Calcium is the 5th most abundant element in the Earth's crust and is extracted from molten calcium chloride. It is a major component in bones and teeth.*
- *Tin is mainly extracted from cassiterite (SnO_2), using coke as reducing agent. It is used to make alloys.*
- *Lead can be extracted from galena (PbS) by partially oxidizing galena and self-reduction. It is used to make lead /acid storage batteries.*
- *Zinc is extracted from zinc blende (ZnS) by roasting, followed by reduction with carbon monoxide. Large amounts of zinc are used for coating iron.*
- *Chromium is extracted from chromite ore ($FeCr_2O_4$): First it is oxidized to sodium chromate (Na_2CrO_4). Then sodium chromate is converted to sodium dichromate by the addition of acids. Next the sodium dichromate is reduced to chromium (III) oxide, using carbon. Finally, Cr_2O_3 is reduced to chromium metal by aluminium. Chromium is used to make alloys.*

- *Silicon is the 2nd most abundant element in the Earth's crust and is extracted from silica, using carbon as reducing agent. Silicon is used in the construction of transistors and microprocessors.*
- *Ammonia is prepared by the Haber process and is mainly used to make fertilisers.*
- *Nitric acid is prepared by the Ostwald process, and is used to make fertilizers, plastics and explosives.*
- *Sulphuric acid is produced by the Contact process, and is mainly used to make fertilizers, detergents and paints.*
- *Diammonium monohydrogen phosphate (DAP) is prepared by reacting anhydrous ammonia with phosphoric acid in two steps. DAP is mainly used as a fertilizer.*

Check list

Key terms of the unit

- *Amalgamation*
- *Borax*
- *Carbon cycle*
- *Cassiterite*
- *Chemical reduction*
- *Chromite*
- *Concentrating ore*
- *Contact process*
- *Denitrification*
- *Dolomite*
- *Downs cell*
- *Economic extraction*
- *Electrolysis*
- *Electrolytic reduction*
- *Extraction of metals*
- *Fixation*
- *Froth flotation*
- *Galena*
- *Gravity separation*
- *Gypsum*
- *Haber process*
- *Leaching*
- *Magnetic separation*
- *Marble*
- *Metallurgy*
- *Mineral*
- *Nitrogen cycle*
- *Ore*
- *Ostwald process*
- *Phosphorus cycle*
- *Pretreatment*
- *Purification of metals*
- *Reactivity series*
- *Silica*
- *Trona*
- *Zinc blende*
- *Zone refining*

REVIEW EXERCISE FOR UNIT 5

Part I: Multiple Choice Questions

1. Which of the following statements is incorrect?
   a all the materials on earth are made of the 92 naturally-occurring elements.
   b all minerals are ores.
   c most metals are solids at 25°C.
   d None of the above.
2. The four most abundant elements, in increasing order of abundance, are:
   a silicon, oxygen, iron and aluminium
   b oxygen, silicon, aluminium, and iron
   c iron, aluminium, silicon, and oxygen
   d aluminium, iron, silicon, and oxygen
3. Which of the following elements does not exist in native state in nature?
   a platinium c silver
   b gold d sodium
4. The element that is a liquid at 25°C is:
   a oxygen c chlorine
   b bromine d nitrogen
5. Which of the following ores contains carbonates?
   a dolomite c epsomite
   b bauxite d cassiterite
6. Which of the following processes fix atmospheric carbon dioxide?
   a Photosynthesis c Burning of fossil fuels
   b Respiration d b and c
7. Which one of the following statements is incorrect about the nitrogen cycle?
   a nitrogen is the most abundant gas in the atmosphere
   b atmospheric nitrogen is less reactive
   c the process of releasing nitrogen gas back into the atmosphere is called nitrogen fixation
   d lightning converts atmospheric nitrogen into nitrogen oxides

8. What makes the phosphorus cycle different from the nitrogen and carbon cycles?
   a The phosphorus cycle is very slow
   b Phosphorus cannot be found in the atmosphere in the gaseous state
   c It is not an essential element for plants and animals
   d a and b
9. If a mineral is denser than its gangue, the appropriate method of separation is:
   a magnetic separation
   b froth floatation
   c amalgamation
   d gravity separation
10. If a metal is to be obtained by electrolytic reduction, its oxide, hydroxide or carbonate is often treated with HCl to convert it to the chloride. The reason for doing this conversion is that:
   a most chlorides usually melt at high temperatures to form conductive liquids
   b most chlorides usually melt at low temperatures to form conductive liquids
   c only aluminium chloride melts at low temperatures to form a conductive liquid
   d all of the above
11. Metals that have low melting points, such as mercury, magnesium, and zinc can be purified from other metals that have high melting points by:
   a zone refining
   b electrolysis
   c distillation
   d leaching
12. Which of the following statements is incorrect about sodium?
   a It is the 7th most-abundant element in the earth's crust
   b Its main ores are borax, trona and rock salt
   c It is obtained by reducing molten sodium chloride by coke
   d It reacts with both air and water
13. Which of the following statements is incorrect about calcium?
   a It is extracted by the electrolysis of molten calcium chloride
   b It reacts with both oxygen and water
   c It reacts with nitrogen at high temperature to form calcium nitride
   d None of the above
14. Tin does not react with:
   a cold water
   b dilute hydrochloric acid
   c concentrated nitric acid
   d chlorine

15. Which element is extracted from its ore by self-reduction?
    a tin
    b lead
    c chromium
    d zinc
16. Which one of the following statements is false about zinc?
    a It is mainly extracted from galena
    b It reacts with dilute hydrochloric acid to give zinc chloride and hydrogen gas
    c It shows amphoteric property
    d It is used for coating iron to prevent the iron from corrosion
17. Which of the following statements is incorrect about chromium?
    a Ferrochrome contains chromium and cobalt
    b It is passive towards oxidizing acids like concentrated nitric acid
    c It is produced by reducing chromium (III) oxide with aluminium metal
    d It is used for electroplating
18. Which of the following statements is incorrect about silicon and its compounds?
    a It is extracted by heating silica and coke at very high temperatures
    b It is a semiconductor and extensively used by the electronics industry to produce computer chips
    c Silicone polymers are used in making lubricants
    d None of the above

Part II: Short Answer Questions

19. Define each of the following terms:
    a Mineral
    b Ore
    c Metallurgy
    d Roasting
20. List the twelve most abundant elements in the Earth's crust.
21. Explain the carbon, nitrogen and phosphorus cycles using diagrams.
22. Explain the three major steps that are carried out to obtain a metal from its ore.
23. Describe the occurrence of:
    a sodium
    b calcium
    c tin
    d lead
    e chromium
    f silicon

24. Describe the extraction of each of the following elements from their respective ore:

a sodium	d lead
b calcium	e chromium
c tin	f silicon

25. Describe the chemical properties of:

a sodium	d lead
b calcium	e chromium
c tin	f silicon

26. Describe the major uses of:

a sodium	d lead
b calcium	e chromium
c tin	f silicon

27. Using chemical equations, describe the manufacturing process of:
    a ammonia, by the Haber process
    b nitric acid, by the Ostwald process
    c sulphuric acid, by the Contact process
    d diammonium monohydrogen phosphate

28. Describe the major uses of:

a ammonia	c sulphuric acid
b nitric acid	d diammonium monohydrogen phosphate