4. Chemical Bonding

4.1 Introduction

Atoms undergo chemical bonding in order to attain a complete outermost electronic configuration similar to that of the noble gases. We have seen in Chapter 2 that with the exception of the noble gases which have a duplet (two) or octet (eight) of electrons in their outermost shells, all other atoms have less than the octet number of electrons in their outermost shells. Helium has two electrons while the other noble gases have eight electrons in their outermost shells as shown in Table 2.4. This type of electronic configuration makes the element very stable.

4.2 Electronic configuration of atoms and the Periodic Table of elements

The periodic table of elements, Figure 2.11, shows a systematic arrangement of elements in increasing order of their atomic numbers. The vertical arrangement of elements into **groups** in the periodic table corresponds to the number of electrons in their outermost shells. The group number is equal to the number of electrons in the outermost shell of each member. For example sodium and potassium which have one electron in their outermost shells are in Group 1; magnesium and calcium which have two electrons in their outermost shells are in group 2; (see Table 4.1).

TABLE 4.1 Arrangement of Elements in Groups

	Group 1	Group 2	Group 3	Group 4	Group 5	Group 6	Group 7	Group 8
	H Li Na K	 Be Mg Ca	 B Al	 C Si	 N P	 O S	 F Cl	He Ne Ar
Number of electrons in outermost shell →	1	2	3	4	5	6	7	8

Except for helium which has two electrons in its outermost shell all the elements in group 8 have eight electrons. Helium is placed in group 8 because it also has a complete outermost electronic configuration for its outermost shell, the K shell.

The arrangement of the elements in the horizontal rows called **periods** corresponds to the order in the filling of a particular shell or energy level as illustrated in Table 4.2. There are seven periods in the complete periodic Table. Each period begins with an element in which the first electron enters a new outermost shell (a group 1 element), and ends with an element in which the shell is filled with a stable duplet or octet number of electrons (a group 8 element).

TABLE 4.2 Arrangement of Elements in Periods

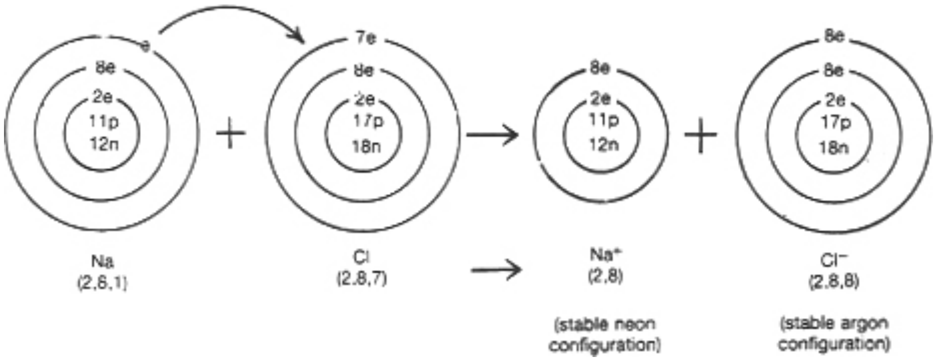
Period	Atomic Number	Symbol	Electronic configuration K	L	M	N
1	1	H	1			
	2	He	2			
2	3	Li	2.	1		
	4	Be	2.	2		
	5	B	2.	3		
	6	C	2.	4		
	7	N	2.	5		
	8	O	2.	6		
	9	F	2.	7		
	10	Ne	2.	8		
3	11	Na	2.	8.	1	
	12	Mg	2.	8.	2	
	13	Al	2.	8.	3	
	14	Si	2.	8.	4	
	15	P	2.	8.	5	
	16	S	2.	8.	6	
	17	Cl	2.	8.	7	
	18	Ar	2.	8.	8	
4	19	K	2.	8.	8.	1
	20	Ca	2.	8.	8.	2

When an outer shell is filled with eight electrons. (Helium is filled with two) the next electron is added to the next higher energy level or shell, which corresponds to the beginning of the next period.

Chemical reactions involve the making and breaking of bonds. As we learnt earlier, chemical reactions involve only electrons in the outermost shells. It therefore follows that atoms with similar outermost electronic configurations will tend to undergo similar chemical reactions. As a result, **elements in the same group of the periodic table undergo similar chemical reactions.**

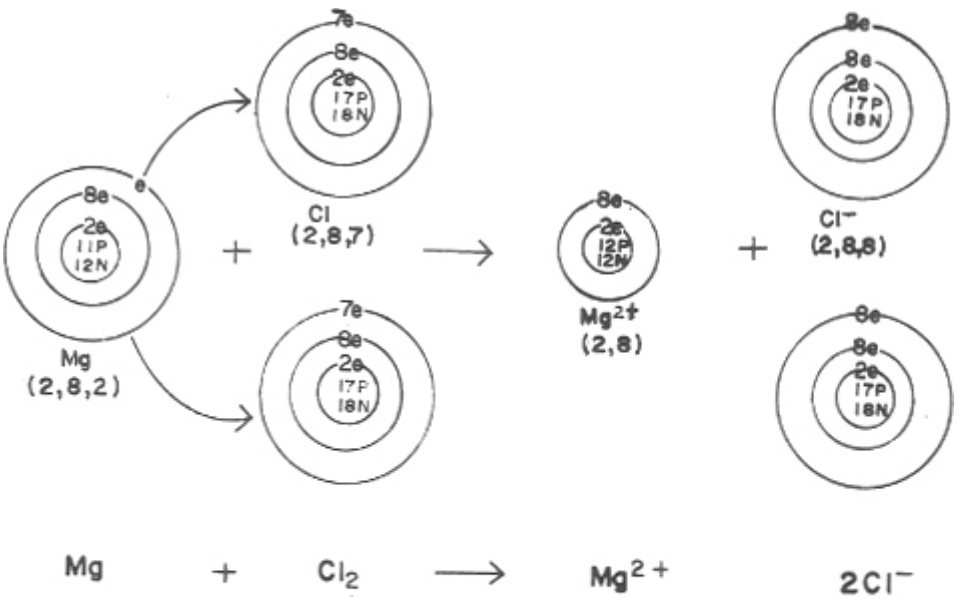
4.3 Electrovalent (ionic) bonding

Electrovalent bonds are formed when an atom gains or loses one or more electrons in a chemical reaction. For example in the reaction between sodium and chlorine to form sodium chloride, an atom of sodium loses one electron to the chlorine atom. The number of protons in the nucleus of the sodium atom is now more than the number of electrons. This gives a positively charged ion. Metals usually form such positively charged ions when they undergo ionic bonding.

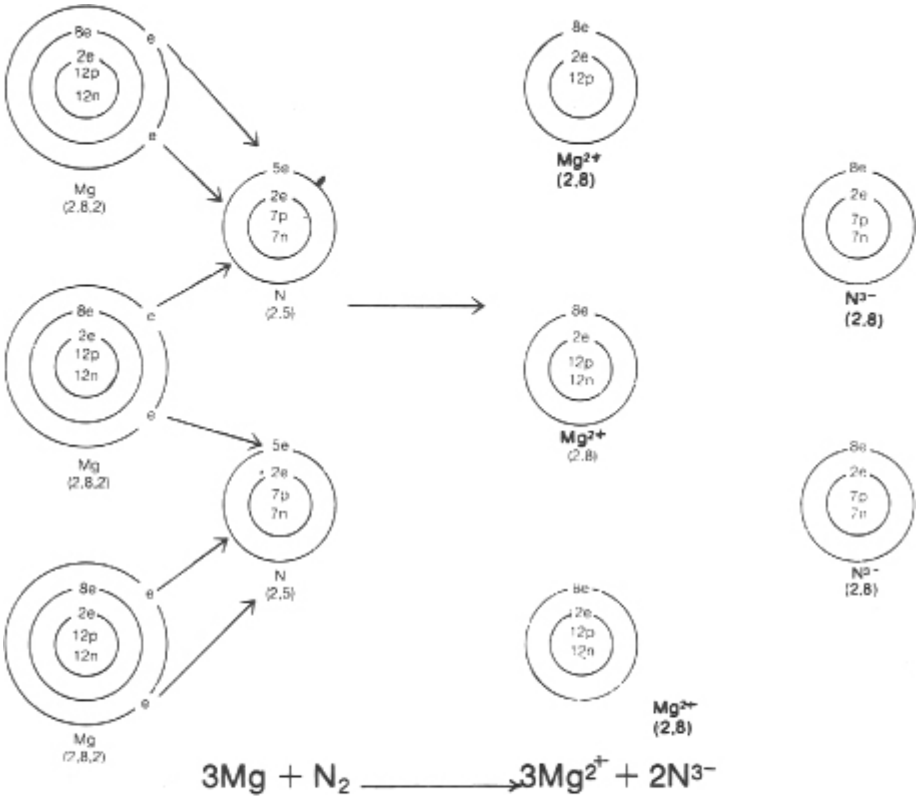


The chlorine atom gains one electron and becomes negatively charged because it has more electrons than protons. Non-metals usually form negatively charged ions in ionic bonding. The sodium ion has a charge of +1. and the chlorine (chloride) ion a charge of -1.

In general each atom involved in the bonding acquires a noble gas structure. The number of electrons lost or gained by each atom in ionic bonding is equal to the charge on the ion formed. This is illustrated with the formation of magnesium chloride and magnesium nitride.



Formation of magnesium chloride



Formation of magnesium nitride

We shall perform the following experiments to study the properties of some compounds:

Experiment 4.1 Investigating the Electrical Conductivity of the Aqueous Solutions of Different Compounds

Put 20 cm^3 of water in each of seven different 25 cm^3 or 50 cm^3 beakers. Into the separate beakers, dissolve 5g of sodium chloride, magnesium chloride, aluminium chloride, sugar, ethanol and kerosene. The seventh beaker should contain only distilled water.

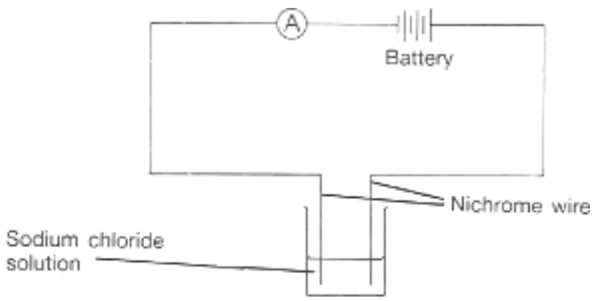


Figure 4.1 Conductivity of Solutions

Insert two nichrome wires connected to a circuit which is connected to three torch light batteries and an ammeter, into the first beaker containing sodium chloride solution as shown in Figure 4.1. Observe if the needle of the ammeter is deflected. Rinse the nichrome wires thoroughly with distilled water and repeat the experiment with the remaining six solutions.

You will observe that only the solutions of sodium chloride, magnesium chloride and aluminium chloride caused deflections. This is because these compounds conduct electricity in solution, while the others do not. From this experiment, we can classify these compounds into two categories:

(i) those that conduct electricity in solution, and

(ii) those that do not conduct electricity in solution.

This property depends on the nature of the bond in the compounds. Sodium, magnesium and aluminium chlorides which are ionic compounds conduct electricity in solution because they have ions which become mobile when dissolved in water.

Experiment 4.2 Investigating the Melting Point of Compounds

Place some iodine crystals in an evaporating dish in a fume cupboard. Heat the crystals. What do you observe? Repeat the experiment using solid calcium oxide, sodium chloride, magnesium chloride, sugar and candle. Record your observations in each case.

You will observe that solid calcium oxide, sodium chloride and magnesium chloride did not melt or evaporate, iodine sublimed, candle melted, while sugar burnt. This shows that ionic compounds have high melting points.

Experiment 4.3 Investigating the Solubility of Ionic Compounds in Different Solvents

Pour 50 cm^3 of water into each of two 250 cm^3 beakers. Put a spatula-full of sodium chloride and magnesium chloride into the separate beakers and stir well. Record your observation. Repeat the experiment with the water replaced with kerosene.

You will observe that the sodium and magnesium chlorides dissolved in water but not in kerosene. **Ionic compounds dissolve only in polar solvents** like water.

Properties of Ionic Compounds.

1. They contain ions in both the solution and molten states. When in the solution or molten state, they conduct electricity because they contain mobile ions. They are therefore called **electrolytes**.
2. They are usually ionic solids with high melting and boiling points. This is because the oppositely charged ions hold each other very firmly by electronic force of attraction.
3. They are insoluble in organic solvents like kerosene but soluble in polar solvents like water.

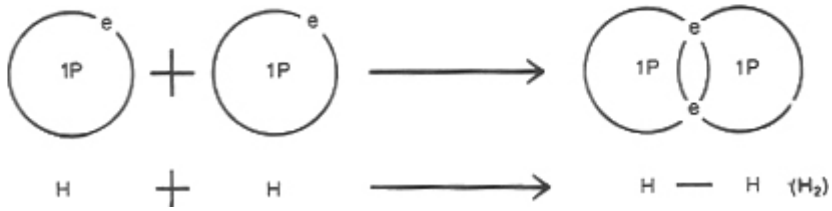
Exercise 4A

1. What is the nature of bonding in
   (a) Magnesium flouride.
   (b) Calcium oxide.
   (c) Sodium chloride?
2. Using electronic diagrams, describe the formation of magnesium oxide, sodium oxide, potassium sulphide, beryllium chloride and aluminium oxide.
3. Write the electronic configuration for an element Y with atomic number 13.
4. (a) Predict the type of bonds that will be formed between the alkali metals and the halogens.
   (b) Which of the following compounds will conduct electric current in the molten or solution state
      (i) Potassium iodide.
      (ii) Sodium flouride.
      (iii) Sugar.
      (iv) Calcium chloride.
      (v) Petrol?
5. What conditions cause two atoms to combine?
6. Explain the type of bond you expect to find in magnesium oxide and magnesium chloride.

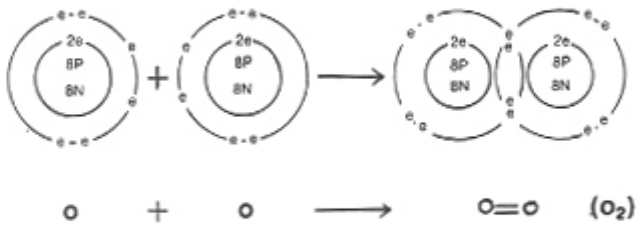
4.4 Covalent Bonding

Sugar, ethanol and kerosene do not conduct electric current because they contain no ions. Such compounds are called covalent compounds. Covalent compounds are formed between non-metallic atoms by the sharing of electrons.

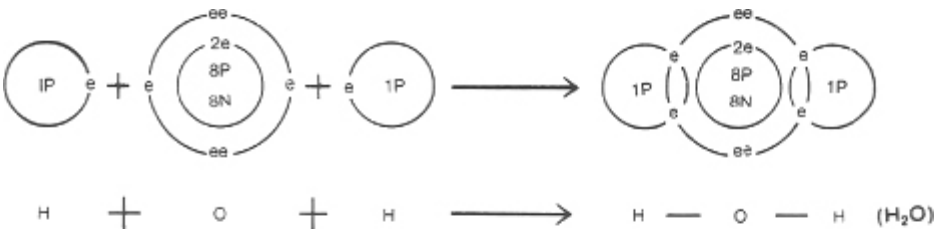
The number of electrons contributed and shared by each atom is such as to give the atom a stable duplet or octet structure as a result of the shared pairs. The compounds have no charge on them because each atom has not lost or gained any electron. Covalent compounds contain molecules. The formation of covalent molecules is here illustrated with the formation of molecules of **hydrogen, oxygen, water and hydrogen chloride**.



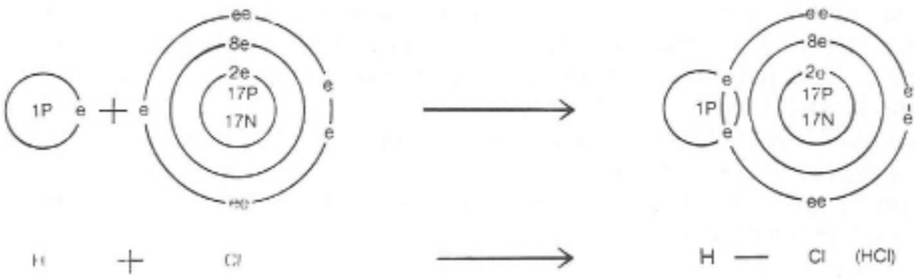
Formation of hydrogen molecules



Formation of oxygen molecule



Formation of water molecules



Formation of hydrogen chloride molecule

Experiment 4.4 To investigate the solubility of covalent compounds

Put some tetrachloromethanc in a test tube. Add a small piece of iodine crystal to it. Does it dissolve? Repeat the experiment using water in place of the solvent. Compare the quantity of iodine dissolved in both cases.

You will observe that all the iodine dissolved readily in tetrachloromethane, but just a little dissolved in water. Covalent **compounds** like iodine crystals **are soluble in non-polar organic solvents**.

Properties of Covalent Compounds

1. Covalent compounds are made up of molecules and therefore do not conduct electricity in solution or molten state. They are **non-electrolytes**.
2. They are either gases, volatile liquids or solids of low melting and boiling points. This is because the molecules are joined to one another by weak **van der Waalsâ€™ forces**. However some giant covalent molecules like diamond have high melting points.

3. Covalent compounds are usually soluble in organic solvents like kerosene, petrol, tctrachloromethane and benzene, but insoluble in polar solvents like water.
   Some covalent compounds like hydrogen chloride produce ions when dissolved in water and therefore can conduct electric current. Such covalent compounds which when dissolved in water **ionise** to produce mobile ions are called **polar covalent compounds**.

Exercise 4B

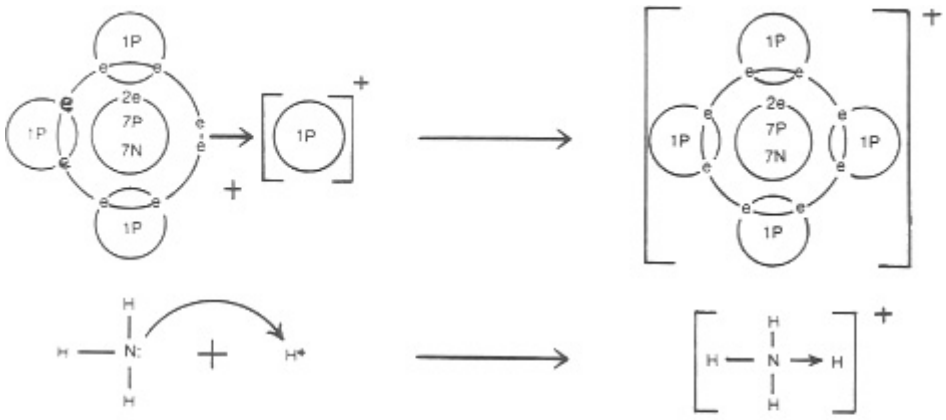
1. Using electronic diagrams, write the formation of ammonia molecule, NH_3. from nitrogen and hydrogen.
2. Do you expect candle wax to dissolve in petrol? Why?
3. Draw the electronic configuration for the nitrogen molecule.
4. Which of the following compounds will conduct electric current, benzene, aluminum chloride and iron(II) tetraoxosulphate(VI) solution? Give reasons for your answer in each case.

4.5 Co-ordinate Covalent (Dative) Bond

The word **dative** means â€˜I giveâ€™ in Latin. Co-ordinate covalent bond or dative bond is a special type of covalent bonding. It is similar to covalent bond in that atoms share electrons to form molecules. However it is different from covalent bond because the co-ordinate covalent bond is formed by one atom donating a lone pair of electrons to another atom which has a vacancy to accommodate the lone pair of electrons.

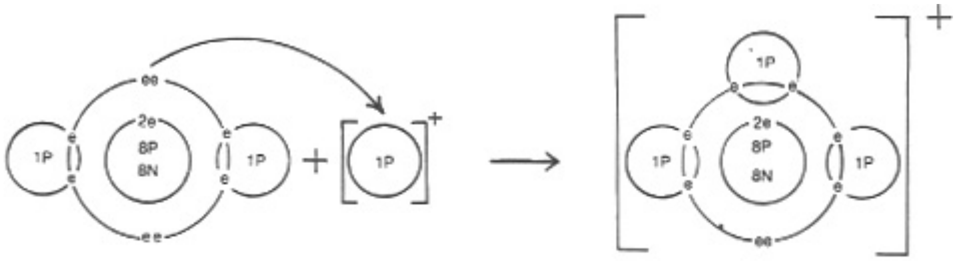
The two atoms then share the lone pair of electrons. The bond formed has the properties of covalent bond.

The formation of co-ordinate covalent bond is illustrated with the formation of ammonium and hydroxonium ions.



$$NH_3 + H^+ \longrightarrow NH_4^+$$

Formation of ammonium ion



$$H-\ddot{O}-H + H^+ \longrightarrow H_3O^+$$

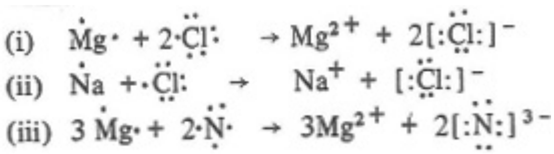
Formation of hydroxonium ion

4.6 Electron dot diagrams

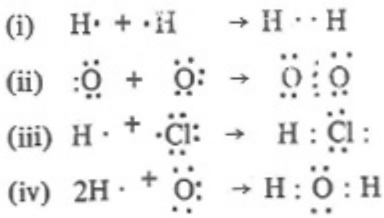
Electron dot diagrams are used to represent the electrons in the outermost shells of atoms in illustrating bond formation. This practice is economical and acceptable since only electrons in the outermost shell of an atom take part in chemical reaction.

The use of electron dot diagrams is illustrated with the use of the following reactions.

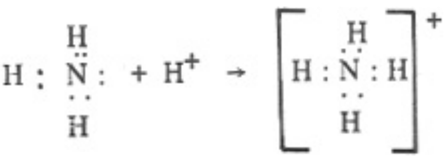
Ionic



Covalent



Co-ordinate



4.7 Metallic bonding

Metallic bonding is found only in metals. Metallic bonding involves the loosely held electrons in the outermost shells of metals and gives metals most of their characteristic properties. We shall investigate some of these properties first.

Experiment 4.5 To Investigate some Properties of Metals and Non-Metals

(a) Separately heat a piece of these substances strongly in a crucible: sulphur, iron, aluminium, phosphorus and calcium. Record your observation.

(b) Take other pieces of the same substances used in (i) and hit them hard several times with a hammer to flatten them. Record your observation.

(c) Connect a circuit as shown in Figure 4.2. Press the two terminals of the wires A and B to the two ends of each of the substances. Do not allow the two ends of the wire to touch. Record which substances cause the ammeter needle to deflect. Those that cause deflection are conductors of electricity.

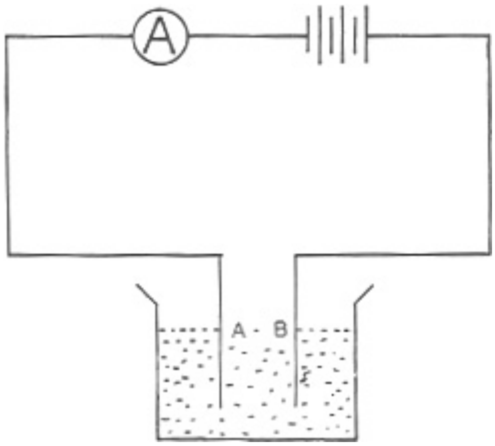


Figure 4.2 Electrical circuit for checking the conductivity of substance

You will observe in these experiments that iron, aluminium and calcium belong to a class. They do not easily melt or burn on heating, are flattened without shattering when hammered, and conduct electricity. These substances are metals in which there are metallic bonds. Sulphur and phosphorus melt on heating, shatter on hammering and are non-conductors of electricity. They are non-metals.

Metallic bonds do not have strong directional character. This is why many metals can be bent or deformed without shattering their crystal structure when subjected to strong pressure, like hammering. Metals are thus **malleable** and ductile. Metals are good conductors of heat and electricity because the electrons in the outermost shells are loosely held and are free to move throughout the solid. This is because they are far removed from the attractive force of the nucleus. It is these electrons which carry the heat energy when the metal is heated, or electric charge when a potential difference is created.

Because electrons in the outermost shells of metallic atoms are loosely held, they are easily lost during chemical reactions. This is why metals easily undergo chemical bonding by electron loss. In the metal lattice these loosely held electrons are not directly controlled by, or attached to a single atom (Figure 4.3). They are therefore described as **delocalized** or â€˜non-localizedâ€™ electrons.

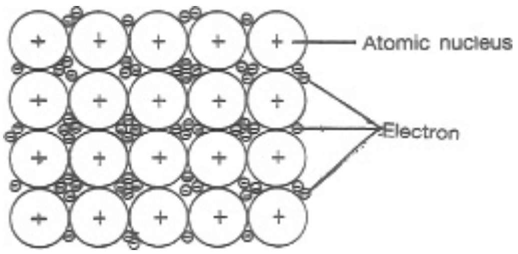


Figure 4.3 Metallic lattice

These electrons are attracted by each of the nuclei surrounding them. The electrons tend to bind the metallic atoms together. The higher the number of these delocalised electrons per atom in the lattice, the stronger the bond between the atoms and hence the higher the melting point of the metal.

Exercise 4c

(a) What are the conditions necessary for metallic bonding?

(b) Explain how you would account for the fact that metals are good conductors of heat and electricity.

TABLE 4.3 Comparison of Covalent, Electrovalent and Metallic Bonds and Compounds

Ionic	Covalent	Metallic
Crystal lattice built from ions	Crystal lattice built from molecules	Crystal lattice built from positive nuclei and delocalised electrons.
Conduct electric current in molten or solution state due to the presence of mobile ions.	Do not conduct electric current because no ions are present.	Conduct electric current because of the presence of delocalised electrons.
Soluble in polar solvents.	Insoluble in polar solvents.	Insoluble in all polar solvents.

Formed by electron transfer.	Formed by sharing of electrons.	Formed by interaction between nuclei and delocalised electrons
Reactions involving ions are spontaneous.	Reactions involving covalent bonds are slower.	Reactions take place by electron transfer.
Bonds are non-directional.	Bonds are directional.	Bonds are non-directional.
Have high melting and boiling points.	Have low melting and boiling points.	Melting and boiling,points may be low or high
Crystals are hard and brittle.	Crystals are soft.	Crystals vary widely in hardness. They are malleable and ductile.

Chapter Summary

1. Atoms are arranged in the periodic table in the order of increasing atomic numbers.
2. Atoms in a particular group of the periodic table have the same number of electrons in their outermost shells and undergo similar chemical reactions.
3. Electrovalent bonds are formed when atoms lose or gain one or more electrons. The electrovalent compounds which are formed contain ions. They are electrolytes, have high melting points and are soluble in polar solvents.
4. Covalent bonds are formed when two or more atoms contribute equal number of electrons which they share between them. The covalent compounds formed contain molecules. They are non-electrolytes, have low melting points and are soluble in non-polar solvents.
5. Co-ordinate or dative bonds are formed when an atom donates a lone pair of electrons for sharing between it ana an atom which has a vacancy to accept it. The characteristics of covalent bonds are similar to those of coordinate bonds
6. Metallic bonds occur in metals as a result of the attraction between delocalized electrons in them and positive metal atom nuclei. The bond confers the properties of malleability, ductility, as well as thermal and electrical conductivity on metals.

Assessment

1. List three properties of ionic compounds.
2. Why is it that paraffin wax is soluble in petrol but not in water?
3. Solid sodium chloride, sugar and benzene do not conduct electrical current, but a solution of sodium chloride does. Explain.
4. Which of the two compounds: sodium chloride and paraffin wax has a higher melting point? Give reason for your answer.

(WAEC).

5. Name the bond types present in each of the following compounds:
   (i) Carbon(IV) oxide.
   (ii) Calcium oxide.
   (iii) Methane.
   (iv) Ammonium chloride.

(WAEC)

6. What is the nature of bonding in
   (i) HF.
   (ii) MgF_2.
   (iii) LiF?

   Which of the two compounds CF_4 and CCl_4 contains the more polar bond? Explain.

(WAEC)

7. (a) What do you understand by
      (i) electrovalency.
      (ii) covalency.
   (b) What type of bond is present in
      (i) sodium chloride.
      (ii) calcium chloride.
      (iii) tetrachloromethane.
      (iv) copper.
      (v) carbon(IV) oxide?
8. Describe the formation of the bond type in
   (a) ammonia.
   (b) potassium chloride.
   (c) hydrogen molecule.
   (d) magnesium chloride.
   (e) chlorine molecule.

   Draw an electron-dot representation of each of the above.
9. What type of bond is present in magnesium oxide? Show the bond by electron-dot representation.
10. Which of the following compounds will conduct electric current? Give reasons.
    (a) Benzene.
    (b) Sugar.

(c) Calcium chloride solution.

11. State the combining power for each of the following:
   (a) Copper(II) ion
   (b) Fluoride ion.
   (c) Zinc ion.
   (d) Oxide ion.
   (e) Hydroxide ion.

   What will be the formula of the compound formed between an element X with a combining power of 3 and element Y with a comining power of 2?

12. What type of bond is either formed or broken in the following reactions:
   (a) dissolving copper(II) tetraoxosulphate(VI) in water.
   (b) dissolving candle wax in petrol.
   (c) dissolving fats and oils in kerosene.
   (d) burning of hydrogen in oxygen.
   (e) corrosion of iron.

13. Addition of sodium chloride solution to silver trioxonitrate(V) solution in a test tube results in the immediate precipitation of silver chloride, but the reaction between ethanol and ethanoic acid is slow. Explain the differences between the two reactions.

14. The mass number of an element X is 24. It has 12 neutrons.
   (a) What is the atomic number of X?
   (b) (i) How many atoms of an element Y, with atomic number 17, will combine with one atom of X?
   (ii) What is the molecular formula of the compound formed between X and Y?

15(a)	**Atom**	**Atomic No.**	**Mass No.**
	A	9	19
	B	10	20
	C	12	24
	D	17	35
	E	17	37

Study the data given above.
   (i) Which is the atom of a metal? Write down its electronic configuration.
   (ii) Which atoms contain 10 neutrons in their nuclei?
   (iii) Which two atoms can form ions with an electronic configuration resembling that of B?
   (iv) Which two atoms are isotopes?
   (v) Which atom is inert?

(vi) Using the letters as symbols for the atoms give the formula of the compound formed between C and D; D and hydrogen. In each case state the type of bond formed.

(b) Given that the number of atoms in 1 mole of carbon is 6 Ã— 10^{23}, calculate

(i) the number of molecules in 1.4g of nitrogen gas

(ii) the number of electrons required to convert 0.8g of oxygen atoms to oxygen ions, 0^{2-},

(iii) the number of ions in 2.4g of tetraoxosulphate(VI) ions.

(WAEC)