# Chemical Bonds

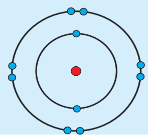
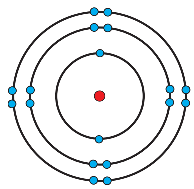
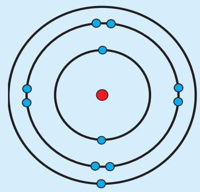
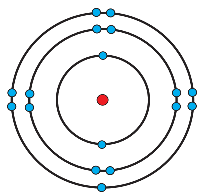
Chemistry 10

The English alphabet contains 26 letters. Yet, the combination of them forms a large number of words. There is only a limited number of elements. In spite of that, millions of compounds are formed by their chemical combination.

Though most of the elements form chemical compounds, there are some elements which do not form compounds under normal conditions. Helium, neon and argon are examples. These elements occurring as single atoms in nature exist as gases. They are known as noble gases.

What is the reason why many elements form compounds but not the noble gases? This can be explained by taking into consideration the electronic configuration of elements.

Table10.1

| Element | Electronic configuration | Distribution of electrons among the energy levels |
|---|---|---|
| Neon (Ne) | 2, 8 |  |
| Argon (Ar) | 2, 8, 8 |  |
| Sodium (Na) | 2, 8, 1 |  |
| Chorine (Cl) | 2, 8, 7 |  |

The outermost shell carrying electrons in an atom of an element is known as its valence shell.The valence shell of the atoms of neon and argon has eight electrons each. This electronic structure has been identified as a stable electronic configuration. Because of this stable configuration their reactivity is very low, so they are referred to as noble gases. But, the state of sodium and chlorine atoms is different. In order to have the stable noble gas configuration, a sodium atom has to either lose the electron in the last shell or gain seven electrons. Similarly a chlorine atom can attain the stable electronic configuration by receiving a single electron or by removing seven electrons. In the atoms of these element, electrons in the valence shell reorganise to acquire the stable electronic configuration. That means, loss, gain or sharing of electrons occurs.

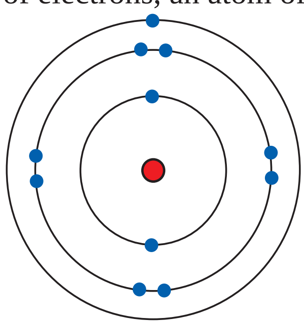
**The attractive forces or binding among the atoms or ions resulted by the rearrangement of electrons in the valence shell for stabilising the atoms of elements as described above are called chemical bonds.**

According to the way the participating atoms behave when they chemically bind together, the chemical bonds can be divided into two types.

1. Ionic bonds
2. Covalent bonds

## 10.1 Ionic Bonds

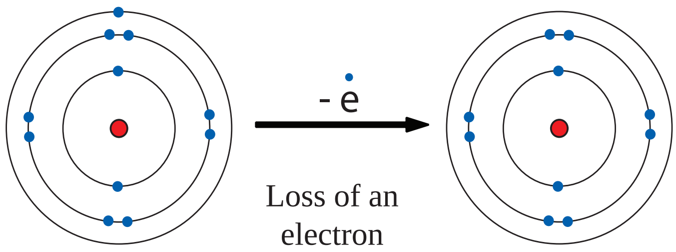
The electronic configuration of the sodium atom is 2, 8, 1. Sodium is an element with low electronegativity. As the number of protons in a sodium atom is equal to the number of electrons, an atom of sodium is electrically neutral (Fig. 10.1).



| | |
|---|---|
| Number of electrons | 11 (-11) |
| Number of protons | 11 (+11) |
| Total charge | 0 |

A sodium atom
Fig. 10.1

The atom after losing its electron in the outer energy level becomes a sodium ion ($Na^+$) with a charge of +1 (Fig.10.2). An atom after receiving a charge is known as an ion. Since this ion has a positive charge it is called a positive ion or a cation. The chemical properties of an ion is different from that of an atom.




The Na atom

| | |
|---|---|
| Number of electrons | 11(-11) |
| Electronic configuration | 2, 8, 1 |
| Number of protons | 11(+11) |
| Total charge | 0 |

The $Na^{+}$ ion

| | |
|---|---|
| Number of electrons | 10(-10) |
| Electronic configuration | 2, 8, |
| Number of protons | 11(+11) |
| Total charge | +1 |

$$\mathbf{Na} \longrightarrow \mathbf{Na^{+} + e}$$

$$\textbf{Atom} \longrightarrow \textbf{Positive ion} + \mathbf{e}$$

Fig 10.2 Formation of a $Na^{+}$ ion form a Na atom

The electronic configuration of the chlorine atom is 2, 8, 7.Chlorine is an element with a high electronegativity value. Since the opposite charges are equal, a chlorine atom is electrically neutral (Fig.10.3).

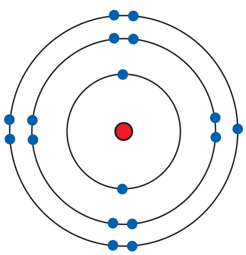
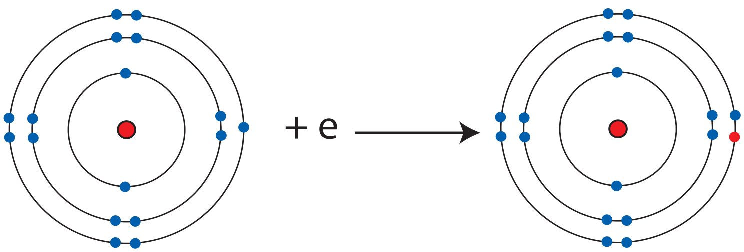


Fig. 10.3 A chlorine atom

Chlorine atom

| | |
|---|---|
| Number of electrons | 17 (-17) |
| Electronic configuration | 2, 8, 7 |
| Number of protons | 17 (+17) |
| Total charge | 0 |

Gaining one electron to the outermost energy level, a chlorine atom (Cl) forms the chloride ion ($Cl^{-}$) with a single negative charge (Fig. 10. 4). As this ion is negatively charged it is called a negative ion or an anion.




| The Cl atom | |
|---|---|
| Number of electrons | 17 (- 17) |
| Electronic configuration | 2, 8, 7 |
| Number of protons | 17 (+ 17) |
| Total charge | 0 |

| The $Cl^-$ (chloride) ion | |
|---|---|
| Number of electrons | 18 (- 18) |
| Electronic configuration | 2, 8, 8 |
| Number of protons | 17 (+ 17) |
| Total charge | - 1 |

$$Cl + e \longrightarrow Cl^-$$

$$\text{Atom} + e \longrightarrow \text{Negative ion}$$

Fig. 10.4 Formation of a $Cl^-$ ion from a $Cl^-$ atom

Neutral atoms form positively charged ions by losing electrons. Neutral atoms form negatively charged ions by gaining electrons. Some polyatomic groups too bear positive or negative charges (e.g. $NH_4^+$, $SO_4^{2-}$, $NO_3^-$). **An ion is an atom or a group of atoms with an electrical charge.**

Now let us examine how the compound sodium chloride is formed. The sodium ions formed by the sodium atoms by losing electrons and the chloride ion formed by chlorine atoms by gaining electrons are oppositely charged. These ions by virtue of their opposite charges strongly bind together by electrostatic attractive forces to form the compound sodium chloride with ionic bonds. This process is illustrated in Fig. 10.5.

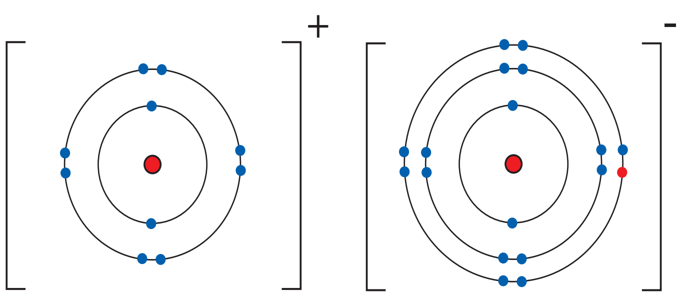



Fig.10.5 Electrostatic attraction between $Na^+$ and $Cl^-$ ions

**The bonds formed due to the strong electrostatic attractions between the positive and negative ions produced by the exchange of electrons among atoms are known as ionic bonds or electrovalent bonds. So, sodium chloride is a compound with ionic bonds. Such compounds are called ionic compounds.**

Fig 10.6 shows how electrons in the outermost energy levels of the atoms reorganise during the formation of sodium chloride.

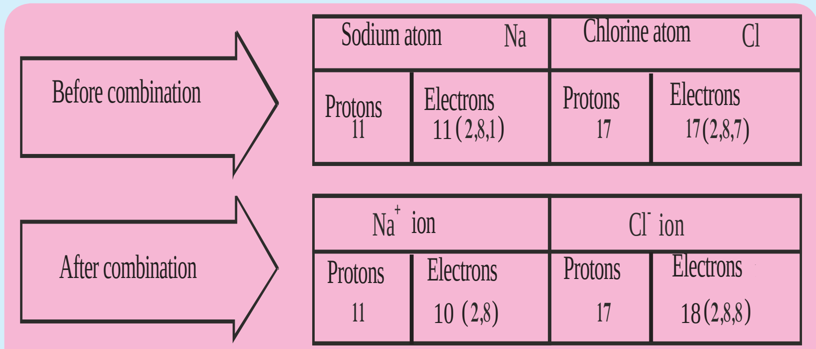
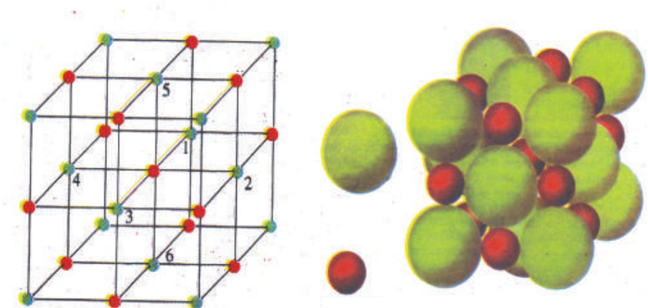



Fig 10.6

The attractions among the ions in the compound sodium chloride is not limited to a single pair of $Na^+$ and $Cl^-$ ions. Owing to the attractions, a large number of positive and negative ions arrange themselves to form a regular three dimensional array where six $Na^+$ ions surround every $Cl^-$ ion and six $Cl^-$ ions surround every $Na^+$ ion. This arrangement gives rise to the crystal lattice of sodium chloride known as an 'ionic lattice' (Fig. 10.7). In all ionic compounds the ions are organised in a three dimensional lattice.




10.7 Ionic lattice of sodium chloride

## • Ionic Compounds

Mostly the ionic bonds are formed between the positive ions produced by the atoms of low electronegativity and the negative ions formed by the atoms of high electronegativity. Table 10.2 presents some examples for such ionic compounds.

Table 10.2

| Compound | Chemical formula |
|---|---|
| Sodium chloride | $NaCl$ |
| Lithium oxide | $Li_2O$ |
| Magnesium sulphide | $MgS$ |
| Calcium chloride | $CaCl_2$ |
| Potassium fluoride | $KF$ |

In addition to the above compounds, ionic bonds are formed during the combination of ionic radicals and ions also. Presents some examples for such compounds.

Table 10.3

| Compound | Chemical formula |
|---|---|
| Copper sulphate | $CuSO_4$ |
| Calcium carbonate | $CaCO_3$ |
| Ammonium chloride | $NH_4Cl$ |
| Ammonium nitrate | $NH_4NO_3$ |

**Assignment – 10 -1**

As was done for sodium chloride, illustrate pictorially how ionic bonds are formed in the ionic compounds lithium oxide ($Li_2O$) and calcium chloride ($CaCl_2$).

**Activity - 10 - 1**

Using coloured clay or plastics balls or any other suitable materials, make a model of the sodium chloride ionic lattice.

## 10.2 Covalent Bonds

Electron sharing between atoms is another method of forming bonds among them. By sharing of electrons like this, the atoms acquire the noble gas configuration. Joining of atoms by sharing electrons between a pair of atoms is referred to as a covalent bond.

Sharing of electrons between atoms of the same kind gives rise to homoatomic molecules.

e.g. hydrogen ($H_2$), fluorine ($F_2$), oxygen ($O_2$), nitrogen ($N_2$)

Sharing of electrons between atoms of different elements gives rise to heteroatomic molecules.

e.g. water ($H_2O$), methane ($CH_4$), ammonia ($NH_3$)

### a). Fluorine molecule

The electronic configuration of a fluorine atom is 2, 7. By sharing a pair of electrons, two fluorine atoms acquire the stable electronic configuration. The result of this is the bonding of two fluorine atoms covalently to form a fluorine molecule (Fig.10.8).

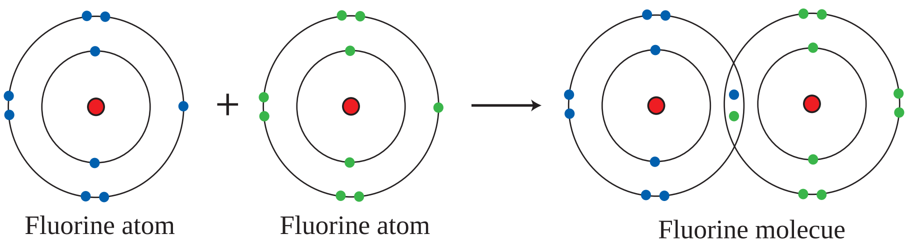



Fig.10.8 Formation of a fluorine molecule

### b). Hydrogen molecule

A hydrogen atom has one electron. Two hydrogen atoms share their electrons between them each acquiring the stable configuration of helium. This gives rise to the hydrogen molecule ($H_2$) in which the two hydrogen atoms are joined by a covalent bond (Fig. 10.9).

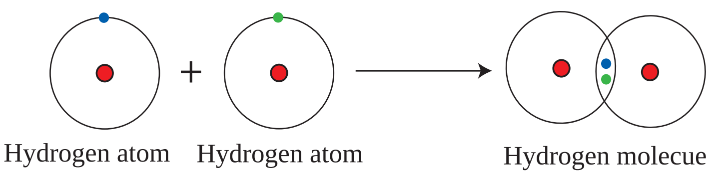
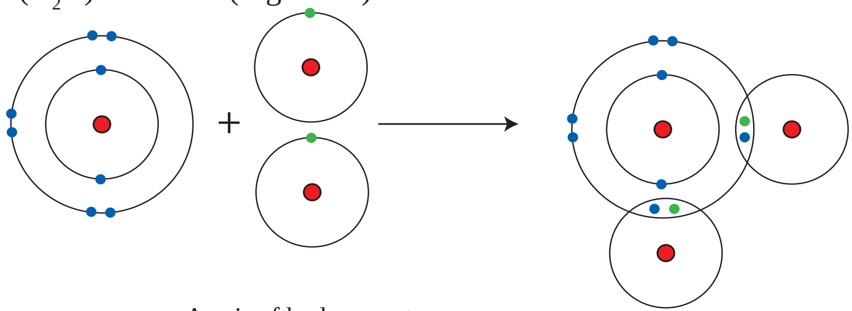



Fig. 10.9 Formation of the hydrogen molecule

## c). Water molecule

The electronic configuration of the oxygen atom is 2, 6. An oxygen atom shares two pairs of electrons with two hydrogen atoms forming two single bonds giving rise to the water ($H_2O$) molecule (Fig.10.10).

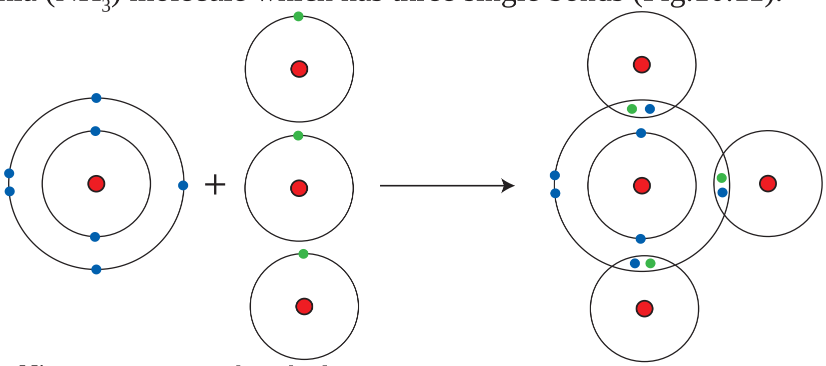


Oxygen atom A pair of hydrogen atoms Water molecue

Fig. 10.10 Formation of a water molecule

## d). Ammonia molecule

The electronic configuration of the nitrogen atom is 2, 5. Three hydrogen atoms share three pairs of electrons with a nitrogen atom. This leads to the formation of an ammonia ($NH_3$) molecule which has three single bonds (Fig.10.11).



Nitrogen atom Three hydrogen atoms Ammonia molecue

Fig. 10.11 Formation of the ammonia molecule

## e). Methane molecule

The electronic configuration of the carbon atom is 2, 4. Four hydrogen atoms share four electrons with a carbon atom forming a methane molecule ($CH_4$) with four single bonds (Fig. 10.12).

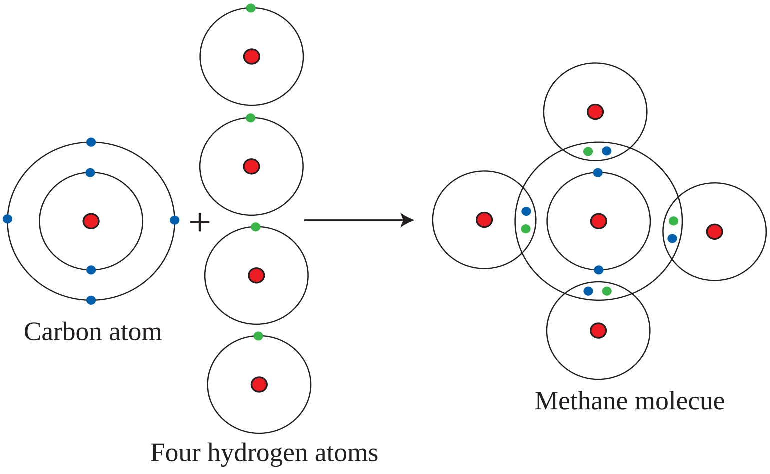



Fig.10.12 Formation of a methane molecule

## f). Hydrogen chloride molecule

The electronic configuration of a chlorine atom is 2, 8, 7. The hydrogen chloride (HCl) molecule is formed by the sharing of a pair of electrons between a chlorine atom and a hydrogen atom (Fig. 10.13).

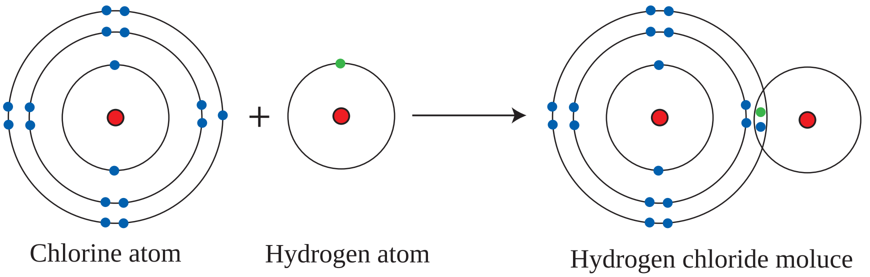



Fig. 10.13 Formation of a hydrogen chlorine molecule

## g). Carbon tetrachloride molecule

The electronic configuration of a carbon atom is 2, 4. The electronic configuration of a chlorine atom is 2, 7. The carbon tetrachloride ($CCl_4$) molecule is formed due to the sharing of four pairs of electrons between a carbon atom and four chlorine atoms (Fig.10.14).

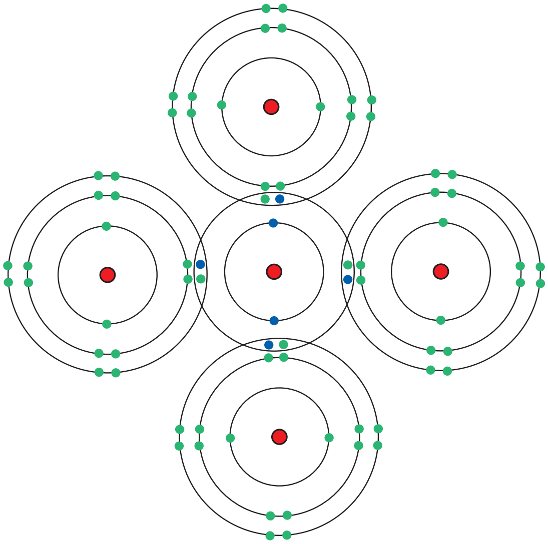


Fig.10.14 Formation of a carbon tetrachloride molecule

## h). Oxygen molecule

The oxygen atom has the electronic configuration 2, 6. When forming the oxygen ($O_2$) molecule, two oxygen atoms share two pairs of electrons between them. Since two pairs of electrons are shared, the bond is known as a double bond (Fig. 10.15).

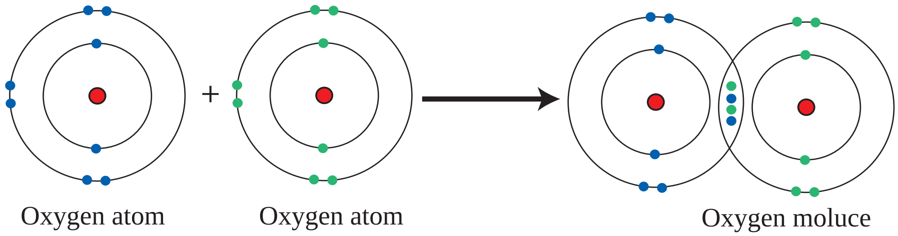



Fig.10.15 Formation of an oxygen molecule

## i). Nitrogen molecule

The electronic configuration of a nitrogen atom is 2, 5. Two nitrogen atoms form a nitrogen ($N_2$) molecule by sharing three pairs of electrons between them. Since three pairs of electrons are shared such a bond is called a triple bond (Fig. 10.16).

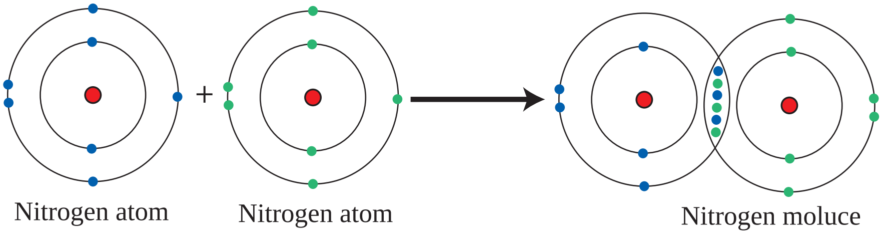



Fig 10.16- Formation of a nitrogen moluce

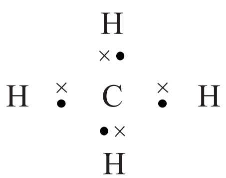
## Activity 01

### Displaying covalent bonds

**Requirement** : Styrifoam, beads of various colours, markers, glue

**Method** : Take a styrifoam sheet and draw the molecules a, b, c, d, e, f, g, h, i you studied above. Show creatively the formation of covalent bond using beads for the electrons. Display your work in the class.

- ## Dot and cross diagram

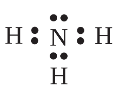



Dot and cross diagram of methane

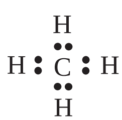
Always electrons in the valence shells of atoms participate in the formation of covalent bonds. The Lewis dot and cross diagram illurtrates how electrons exist in the covalent bond. In this diagram, electrons of one atom are represented by dots while the electrons of the other atom are shown by crosses. For example, let's take the dot and cross structure of the methane ($CH_4$) molecule. Carbon whose electronic configuration is 2, 4 has four electrons in its valence shell. These electrons are represented by dots. The electrons of hydrogen atoms which form covalent bonds with carbon are symbolised by the crosses.

## Lewis Structure

Showing covalent bonds of a molecule representing the valence shell electrons of its atoms **only by dots** is called the Lewis dot diagram.



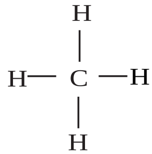

Dot diagram of ammonium



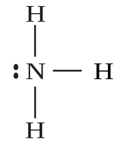

Dot diagram of methane

When a bond electron pair is represented by a short line (-) and a non – bonding lone pair by dots, it is called the Lewis structure.

Lewis structure of $H_2$



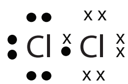
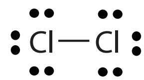
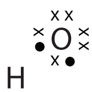
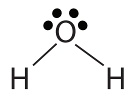
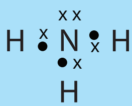
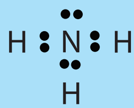
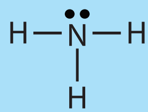
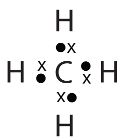
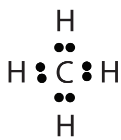
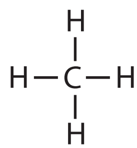
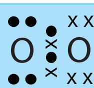
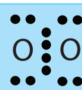
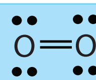
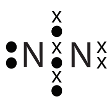
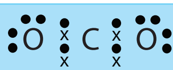
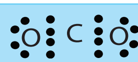
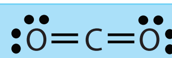
Lewis structure of $CH_4$



Lewis structure of $NH_3$

The electrons represented by dots are known as lone pairs whereas electrons pairs represented by lines are called bond pairs. The dot and cross diagrams, Lewis dot diagrams and Lewis structures of some covalent molecules are given in Table 10.3.

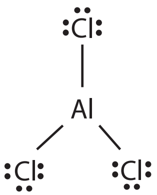
Table 10.3

| Molecule | Lewis dot and cross diagram | Lewis dot diagram | Lewis structure |
|---|---|---|---|
| $Cl_2$ |  |  |  |
| $H_2$ |  |  |  |
| $H_2O$ |  |  |  |
| $NH_3$ |  |  |  |
| $CH_4$ |  |  |  |
| $O_2$ |  |  |  |
| $N_2$ |  |  |  |
| $CO_2$ |  |  |  |

In the ammonia molecules nitrogen atom is the central atom and hydrogen atoms are the peripheral atoms. There are three bond pairs and a single lone pair in the valence shell of the ammonia molecule.

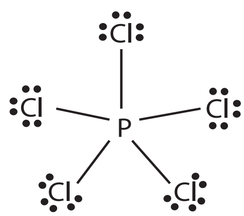
In all the molecules given above, the central atom as well as the peripheral atoms have acquired the noble gas configuration. That means, except in hydrogen, a set of eight electrons is completed in the valence shell of atoms after the formation of the bonds. Those are known as the compounds in which the octet of electrons is complete.

Nevertheless, there are exceptions too. Let's take aluminium chloride ($AlCl_3$) as an example. In this, the electronic configuration of the aluminium atom is 2, 8, 3. The electronic configuration of a chlorine atom is 2, 8, 7. Three chlorine atoms share three pairs of electrons with an aluminium atom to form an $AlCl_3$ molecule.




In this molecule, the valence shell of the aluminium atom contains six electrons. In the case of a chlorine atom, the octet is complete.

In contrast, there are instances where the octet of electrons in the valence shell is expanded. Phosphorus penta chloride ($PCl_5$) is an example. The electronic configuration of phosphorus is 2, 8, 5. The electronic configuration of chlorine is 2, 8, 7. A phosphorus atom and five chlorine atoms share five pairs of electrons to form the $PCl_5$ molecule.Then there are10 electrons around the central phosphorus atom. In each chlorine atom, the octet is completed.

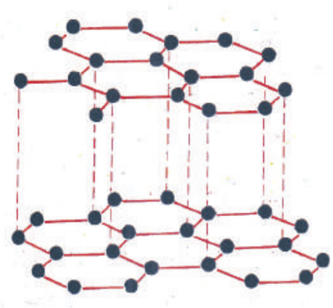



- ## Atomic Lattice

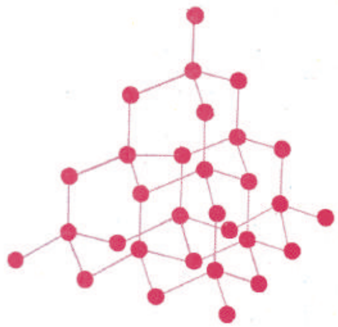
In some elements the atoms are organised as a lattice. Such lattices in which the atoms are covalently bonded are known as atomic lattices. Carbon naturally occurs as two forms of atomic lattices, graphite and diamond. They are known as the allotropic forms of carbon. These two forms differ in the way the carbon atoms form covalent bonds with one another. Generally the melting points and boiling points of covalent compounds are low. But in diamond and graphite, the melting point and boiling point are high due to their atomic lattice structure.

- Graphite

Graphite consists of layers of carbon atoms formed by the joining of one carbon atom with three other carbon atoms by single bonds. These layers are superimposed on one other. The forces holding these layers are weak. Thus one layer can easily slide over the other. Because of this structure, graphite behaves as a lubricant.



Atomic lattice of diamond



Atomic lattice of graphite

## Diamond

Diamond is a three dimensional lattice in which every carbon atom forms four single bonds with four other carbon atoms. Diamond is the hardest substance found in nature.

# 10.3 Polarity of Bonds

Electronegativity is the tendency of an atom to attract electrons of a chemical bond towards itself. It takes different values for different atoms. Then hydrogen molecule is formed by the joining of two hydrogen atoms of equal electronegativity by a covalent bond. The distribution of electrons in the bond pair of this molecule is symmetrical. Therefore, the hydrogen is a non – polar molecule. But when two atoms of different electronegativities are joined by a covalent bond, the attraction imposed by the two atoms on the bond pair is different. Let us take hydrogen fluoride molecule as an example. Since fluorine is more electronegative than hydrogen, the bond pair is more displaced towards the fluorine atom. So, the electron distribution is not symmetrical. Consequently the fluorine atom bears a small negative charge. This is known as polarization. However the molecule HF as a whole is a neutral molecule.

$$H^{\delta^+} — F^{\delta^-}$$

Fig. 10.18 - Polarization of the hydrogen fluoride molecule

When two atoms of unequal electronegativities are joined by a covalent bond, it gets polarized due to asymmetric distribution of electrons. Such bonds are called polar covalent bonds.

In case where two atoms of similar or slightly different electronegativities are joined by a covalent bond, the bonding electrons between those two atoms distribute symmetrically. Such covalent bonds are referred to as non – polar covalent bonds.

In the water molecule, there are four pairs of electrons in the valence shell of its oxygen atom. Of them two pairs are bond pairs and two pairs are lone pairs.

When an O – H bond of a water molecule is considered, the bond pair shifts more towards the more electronegative oxygen atom. Thus the molecule is polarized so that the oxygen atom bears a partial negative charge while the hydrogen atom carries a partial positive charge. Hence water is a compound with polar covalent bonds.

In three dimensional space water molecule is disposed as follows. It assumes an angular shape (Fig. 10.19).

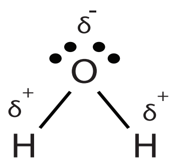



Fig. 10.19 Shape of the water molecule

## 10.4 Intermolecular Bonds

In water molecules the hydrogen atoms which bear a very small positive partial charge forms attractive forces with oxygen atoms bearing a very small negative charge of the neighbouring water molecules. This kind of attractions among the molecules are known as intermolecular forces or intermolecular bonds.

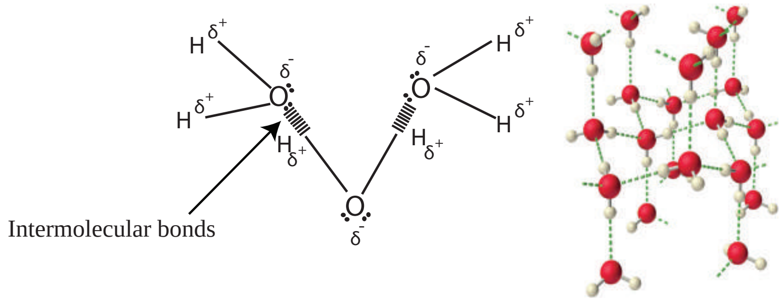



Fig. 10.20 - Intermolecular bonds in water

These intermolecular forces are not as strong as the covalent bonds between the oxygen atoms and the hydrogen atoms in a water molecule. Yet, these intermolecular forces impart many special properties to water.

Because of these intermolecular forces, water exists as a liquid at room temperature. In case that there were no intermolecular forces among the water molecules, water is a gas at room temperature.

Some special properties possessed by water due to attractive forces among the water molecule are as follows.

- High boiling point
- High specific heat capacity
- Having a higher density than that of ice

## 10.5 Properties of Ionic and Covalent Compounds

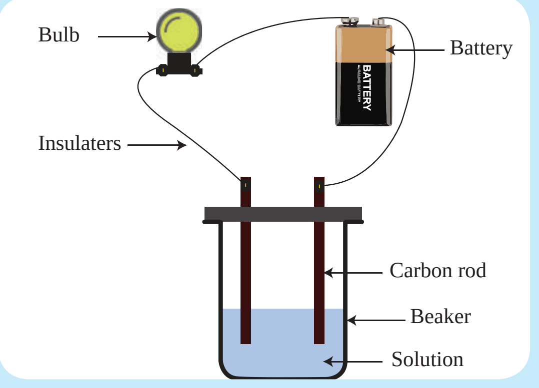
**Activity 3**

**Examining the electrical conductivity of the solutions of ionic and covalent compounds**

**Requirement:** Four beakers, two carbon rods, two bulbs, two batteries (Six dry cells), conducting wires, a salt solution (common salt), sugar solution, copper sulphate solution, distilled water

**Method:**

- Take four equal beakers and label them A, B, C, D.
- Add salt solution to A, copper sulphate solution to B, sugar solution to C and distilled water to D.
- Dip two carbon rods in each solution, complete the circuit as shown in fig. 10.21 and see whether the bulb lights. The carbon rods should be washed well before using in the other solution.




Examining the electrical conductivity of the solution of ionic and covalent compound
Fig. 10.21

The bulb lights in the circuits with common salt and copper sulphate solutions. It doesn't light in the circuits with the sugar solution and distilled water. Common salt and copper sulphate are compounds with ionic bonds. Hence, aqueous solutions of ionic compounds conduct electricity. Sugar and water are covalent compounds. Electricity does not flow through them. Experiment shows that even common salt in the fused state conducts electricity. This confirms that electricity flows through ionic compounds in aqueous solution and fused state. However electricity does not flow through ionic compound in solid state.

## Melting Points and Boiling Points of some Compounds

Table 10.5

| Compound | Melting / $^0$C | Boiling point / $^0$C | Bond type |
|---|---|---|---|
| Sodium chloride | 801 | 1413 | Ionic |
| Potassium chloride | 776 | 1500 | Ionic |
| Water | 0 | 100 | Covalent |
| Ammonia | -78 | -33 | Covalent |
| Oxygen | -218 | -183 | Covalent |
| Ethyl alcohol | -117 | 79 | Covalent |
| Calcium oxide | 2580 | 2850 | Ionic |
| Sulphur dioxide | -73 | -10 | Covalent |

Form Table 10.5 it is clear that melting points and boiling points of ionic compound are relatively high. Mostly they exist as solids at room temperature. The above Table also affirms that the melting points and boiling points of covalent compounds are low. Generally they are liquids or gases at room temperature.

### Characteristics of Ionic Compounds

- Ionic compounds are composed of oppositely charged (+ and -) ions.
- Most of the compounds have a solid crystalline form at room temperature.
- They have high melting points and boiling points.
- They conduct electricity in the fused (molten) state and in aqueous solution.
- Most of the ionic compounds are soluble in water.

### Characteristics of Covalent Compounds

01. They mostly exist as molecules composed of several atoms.
02. Most of the covalent compounds are in the liquid or gaseous state at room temperature.
03. Generally the melting points and boiling points of covalent compound are low (However the lattice compounds have high melting points and boiling points).
04. The aqueous solutions of covalent compounds do not conduct electricity.
05. Some covalent compounds are soluble in water.

**For further exploration**

Collect information about the unique characteristics of water caused by the intermolecular forces.

## Summary

- Compounds are formed by bonding two or more atoms of different elements chemically.
- When forming compounds, electrons in the valence shells of atoms rearrange.
- Positive ions are formed by the loss of electrons from an atom; negateve ions are formed by the gain of electrons by an atom.
- Electrostatic attractions between the oppositely charged ions are called ionic bonds.
- The bonds formed by sharing of electrons between pairs of atoms are named covalent bonds.
- Solid crystalline ionic lattice of an ionic compounds is formed by the orderly arrangement of ions in space.
- An atomic lattice is created by the orderly arrangement of atoms in space.
- According to the nature of bonding, ionic and covalent compounds show characteristic properties.
- A bond with partial positive and negative charges is called a polar covalent bonds. Water is a compound with polar covalent bonds.
- The attractive forces among the molecules are known as intermolecular forces.
- The intermolecular forces give specific characteristics to compounds.
- Water has special properties due to intermolecular attractions among the water molecules.

## Exercises

01. Define an ion.

02. Write the electronic configurations of the following ions and illustrate them by diagrams.

    (a) $Na^{+}$ (b) $Mg^{2+}$ (c) $O^{2-}$ (d) $N^{3-}$

03. What is meant by an ionic bond?

04. Illustrate by diagrams how the compound calcium oxide is formed.

05. Draw the dot and cross diagrams of the following molecules.

    (a) Chlorine (b) Oxygen (c) Water

    (d) Methane (e) Ammonia

06. What is meant by a covalent bond?

07. Give two properties of ionic compounds and covalent compounds.

08. Carbon is an element in Group IV. Why carbon has a high melting point and a high boiling point.

09. Explain scientifically why common salt is readily soluble in water.

10. Why water which is a covalent compound has a boiling point of 100 $^{o}$C.

## Technical terms

| | | | | |
|---|---|---|---|---|
| Chemical bonds | - | රසායනික බන්ධන | - | இரசாயனப் பிணைப்பு |
| Cation | - | කැටායනය | - | கற்றயன் |
| Anion | - | ඇනායනය | - | அனயன் |
| Ionic bonds | - | අයනික බන්ධන | - | அயன் பிணைப்பு |
| Covalent bonds | - | සහසංයුජ බන්ධන | - | பங்கீட்டுவலுப்பிணைப்பு |
| Polarity | - | ධ්‍රැවීයතාව | - | முனைவுத்தன்மை |
| Inter molecular bond | - | අන්තර් අණුක බල | - | மூலக்கூற்றிடை விசை |
| Hydrogen bond | - | හයිඩ්‍රජන් බන්ධන | - | ஐதரசன் பிணைப்பு |