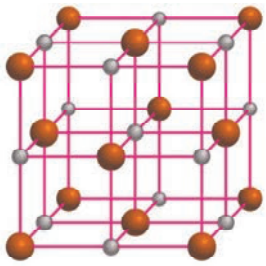
Chapter 8

Chemical Bonding



In the chapter on atomic structure, we learnt that the number of electrons in an atom of any element is fixed. We also learnt that the number of electrons in a shell and the electronic configuration is also fixed. The number of electrons in an atom is equal to the number of protons in its nucleus. Since the charge on a proton is equal but opposite to that on an electron, therefore the atom is electrically neutral.

It is observed that some elements found in nature are reactive and others are non-reactive or inert. The difference in reactivity can be explained if we look at the electronic configurations of elements. It is interesting to note that the chemical properties of an element are dependent on the number of electrons present in its outermost shell (valence electrons). It is seen that elements that have eight electrons in their outermost shell (except helium, which has two electrons) generally do not form compounds. These elements are helium, neon, argon, krypton and xenon and they exist as monoatomic gases. Since these gases do not react they are known as inert (noble) gases. Except for helium all other inert gases have eight electrons (octet) in their outermost shell.

8.1 Ionic Bonds

Those elements (except hydrogen) that have less than eight electrons in the outermost shell of their atoms try to complete the octet, that is, they try to attain inert gas configuration by reacting with other atoms. The other atom can be of the same element or from a different element.

Let us try to understand the above statement by looking at sodium chloride, which you may know as common salt. Sodium chloride is formed by the elements, sodium and chlorine. We know that the atomic numbers of sodium and chlorine are 11 and 17 respectively. Let us write their electronic configurations:

$_{11}Na$ - 2, 8, 1

$_{17}Cl$ - 2, 8, 7

By looking at the electronic configurations of the two elements, tell –

- How many electrons are present in the outermost (valence) shell of each atom?
- In how many ways can the sodium atom complete its octet? In how many ways can the chlorine atom attain inert gas configuration?

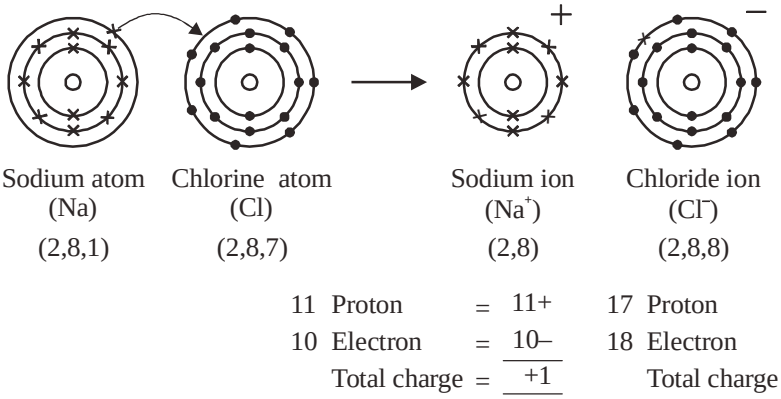


Fig. 1 : (a) Formation of sodium chloride

We saw that the sodium atom has 2 electrons in its K shell, 8 in the L shell and 1 electron in the M shell. One possibility to attain the octet configuration is that the sodium electron loses the one electron present in its M shell and then it will be left with 2 electrons in the K shell and 8 in the L shell. In this case, it attains the configuration of the inert gas neon (2,8).

The second possibility is that the sodium atom accepts 7 electrons so that it has 2 electrons in its K shell, 8 in the L shell and 8 in the M shell. In this case also it attains inert gas configuration (argon 2,8,8).

The atomic number of sodium is 11 which means that its atom has 11 protons in the nucleus and 11 electrons in shells. Can you tell what will be the charge on the sodium atom if it loses an electron or gains 7 electrons?

An atom is electrically neutral because the number of positively charged particles (protons) in its nucleus is equal to the number of negatively charged particles (electrons) in its shells. If the atom gains an electron it becomes a negatively charged ion or anion. If the atom loses electrons it becomes positively charged ion or cation. The charge on an ion is equal to the number of electrons gained or lost.

Now, we will consider the chlorine atom. Chlorine can also achieve inert gas configuration in two ways, either by gaining one electron or by losing seven electrons. If chlorine accepts an electron then it will have 2 electrons in the K shell, 8 in the L shell and 8 in the M shell and it will form chloride ion (Cl^-). If it loses 7 electrons, then it will have 2 electrons in the K shell and 8 in the L shell and it forms Cl^{7+} ion.

The nucleus of the sodium atom is not capable of holding on to seven extra electrons. Similarly, it is difficult for the chlorine atom to lose seven electrons and form Cl^{7+} ion. This means that it is easier for the sodium atom to lose an electron and for the chlorine atom to gain one electron. Therefore, sodium forms Na^+ ion by losing an electron and chlorine forms Cl^- ion by accepting an electron.

Due to opposite charges, sodium and chloride ions are attracted to each other and are held together by strong electrostatic forces of attraction to form sodium chloride.

The type of bond formed in this way is called ionic bond or electrostatic bond. The compounds formed in this manner are called electrovalent or ionic compounds. It should be noted that sodium chloride does not exist as a single molecule but as an aggregate of oppositely charged ions.

Here, the bond is not formed between one sodium ion and one chloride ion. Instead, a three dimensional crystal is formed in which each positively charged sodium ion is surrounded by negatively charged chloride ions and similarly each chloride ion is surrounded by positively charged sodium ions. The number of sodium ions, in the crystal, is equal to the number of chloride ions.

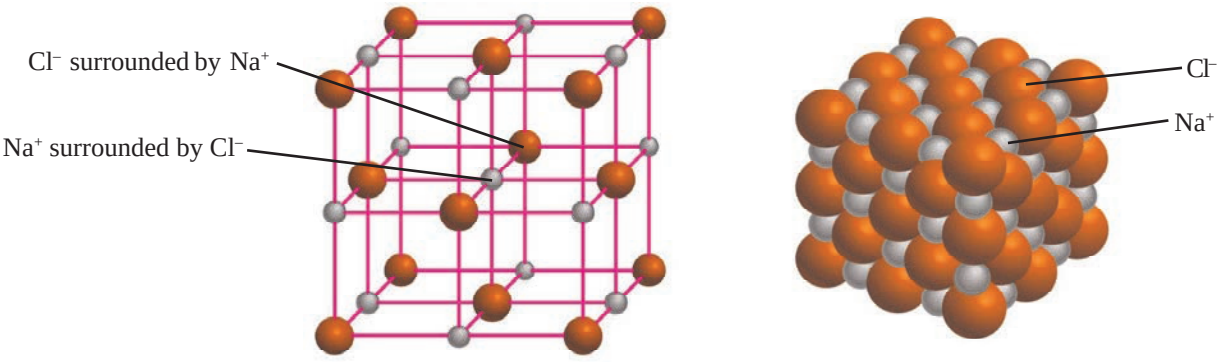


Fig. 1 (b) :Three dimensional structure of sodium chloride

The American chemist Gilbert Newton Lewis used electron dot configurations, also called Lewis symbols, to show the number of bonding electrons in an atom. In this method, the electrons in the outermost shell of an atom are shown by putting an equal number of dots around the symbol of the element.

Now, we will look at some more ionic compounds. Ionic bonds are also formed between magnesium and chloride ions. The atomic number of magnesium is 12. Write its electronic configuration and think of how it will attain inert gas configuration?

We know that for magnesium (2,8,2) to attain inert gas configuration (2,8), it will have to lose two electrons but the chlorine atom needs only one electron to complete its octet. Think, how will the two electrons lost by magnesium be accommodated? Here, two chlorine atoms will take part in bond formation with one magnesium atom. Therefore, each chlorine atom will accept one of the two electrons lost by the magnesium atom and attain inert gas (2,8,8) configuration. This is why the formula of the compound is $MgCl_2$.Can you tell the value of the charge on the magnesium ion?

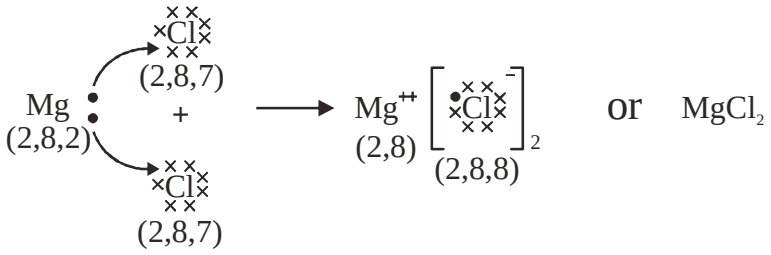


Fig. 2 : Formation of magnesium chloride

Now, let's look at another ionic compound which is formed by calcium and oxygen. The atomic numbers of calcium and oxygen are 20 and 8 respectively. Write down their electronic configurations and think of how they will attain inert gas configuration?

We can see that calcium has two electrons in its outermost shell and oxygen has 6 electrons in its outermost shell. Therefore, it is easy for calcium to lose two electrons and for oxygen to gain two electrons. In this way, oxygen accepts the two electrons lost by calcium and forms an ionic bond. What will be the charges on calcium ion and oxide ion, respectively, in calcium oxide?

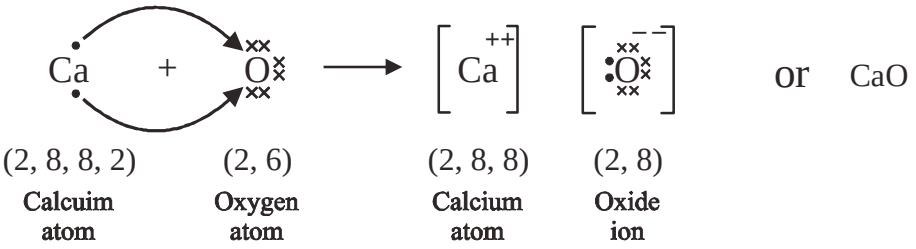


Fig. 3 : Formation of Calcium oxide

So far, we have seen that during bond formation between elements, one or two electrons are lost by one atom and accepted by the other atom or atoms. Now we will look at a compound formed by the element aluminium.

The atomic numbers of aluminium and chloride are 13 and 17 respectively. $AlCl_3$ is formed by the transfer of electrons between Al and Cl. Can you show the electronic structure of $AlCl_3$ to complete the equation given below?

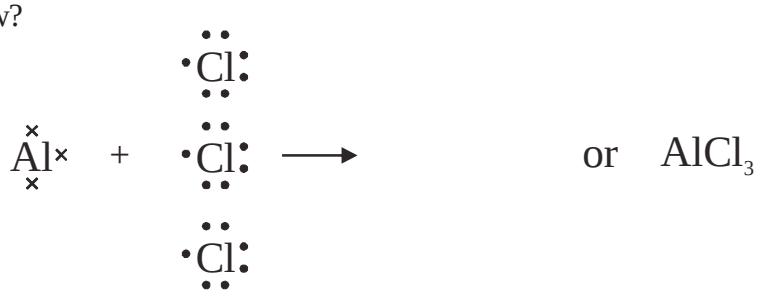


Fig. 4 : Formation of aluminium chloride

Through the examples seen so far, we now know that sodium needs to lose one electron to form bonds and oxygen gains or accepts two electrons. In this way the number of electrons in the outermost shells of both atoms becomes eight. Think, what will be the formula of the compound formed by bonding between sodium and oxygen? How will they form ionic bonds? Complete the figure below by showing electron transfer between sodium and oxygen.

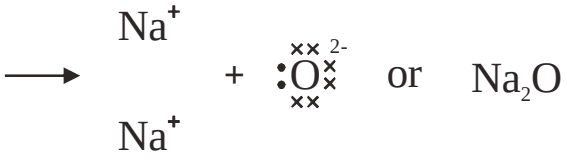


Fig. 5 : Formation of sodium oxide

8.2 Valency

We saw many different examples of how atoms of different elements lose or accept electrons to achieve inert gas configuration. Therefore, we can understand valency in the following ways:

- Sodium has one electron in its valence shell which it loses to achieve inert gas configuration, therefore, the valency of sodium is one.
- Calcium loses two electrons from its valence shell so its valency is two.
- Chlorine has 7 electrons in its valence shell and it gains an electron to complete its octet, therefore, the valency of chlorine is one.

Valency tells us how many electrons will be lost or accepted by the atom of any element to achieve inert gas configuration. In this way, we find that atoms of some elements lose atoms from their valence shell and atoms of some other elements gain electrons to complete their octet. So far, we have identified metals and non-metals based on their physical properties. Now, we can say that during ionic bond formation, the elements that lose electrons are called metals and the elements that gain electrons are called non-metals.

Questions

1. The atomic numbers of potassium and chlorine are 19 and 17 respectively:
   (a) Write their electronic configuration.
   (b) In how many ways can the two elements achieve inert gas configuration? Describe.
   (c) Depict the ionic bond in potassium chloride using Lewis symbols.
   (d) What will be the charges on potassium and chloride ions in potassium chloride?
2. The atomic numbers of lithium and fluorine are 3 and 9 respectively. Use electron dot structures to show the ionic bond formation between lithium and fluorine.

3. What is the valency of oxygen? What is the valency of potassium? Explain.

4. The number of electrons in the M shell of an element is 7 and its valency is 1. What will be the electronic configuration of the ion of this element?

You know that aluminium has three electrons in its valence shell which it loses to form Al^{3+}. Can you name the element that has four electrons in its outermost shell?

8.3 Covalent bonds

We will now consider the element carbon whose atomic number is 6 and electronic configuration is 2,4. If carbon loses 4 electrons to attain inert gas configuration similar to helium (2) then it will form C^{4+} ion. On the other hand, if it gains four electrons to attain inert gas configuration similar to neon (2,8) then it will form C^{4-}.

In both cases the ions formed are unstable so both are not possible. Then, how does carbon form bonds? Let us see.

One alternative is that carbon shares its electrons with other elements. What does sharing mean? Let us take the example of carbon tetrachloride to understand this better. Carbon tetrachloride is formed by one carbon and 4 chlorine atoms. We already know that a chlorine atom needs one electron to complete its octet. In this case, each chlorine contributes one of its electrons to one atom of carbon and similarly carbon also shares one of its four electrons with each of the chlorine atoms to form bonds. In this way, carbon and each of the chlorine atoms attain inert gas configuration (2,8 and 2,8,8). Both shared electrons are owned equally by both the atoms therefore, they are included in the octets of both atoms.

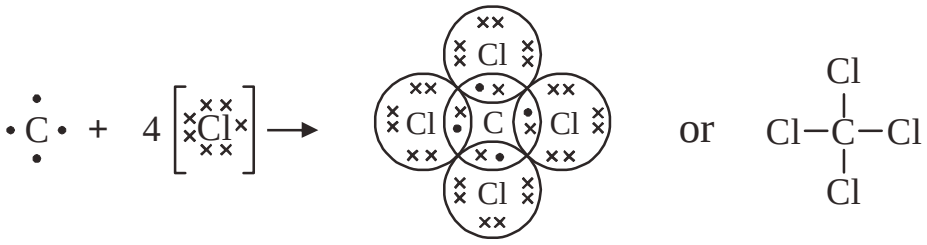


Fig. 6 : Covalent bond in carbon tetrachloride

Now we will look at the compound methane formed by carbon and hydrogen. We have seen that it is easier for the carbon atom to share its valence electrons rather than losing them or gaining additional electrons. What about the hydrogen atom? The atomic number of hydrogen is one which means that it has one proton in its nucleus and one electron in the K shell. The nearest rare gas is helium which has two electrons in its K shell. When a bond is formed between carbon and hydrogen, the carbon atom needs to share four electrons but the hydrogen atom needs to share only one. So, one atom of carbon and four atoms of hydrogen share electrons to form CH_4 molecule.

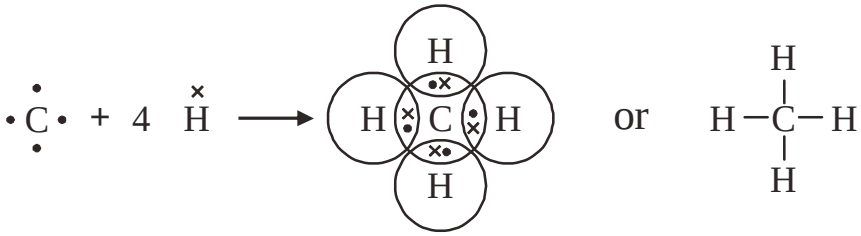


Fig. 7 : Covalent bonding in methane

Now, we will look at another carbon compound, carbon dioxide. It is clear from the name itself that the molecule has two oxygen atoms (di- is a suffix that stands for two so dioxide implies two atoms of oxygen). Previously, we have seen that usually oxygen accepts two electrons to form the divalent ion, O^{2-} but at the same time carbon prefers to share electrons to form bonds. Can you tell how carbon and oxygen will share electrons to form the stable compound carbon dioxide? It is possible only when each oxygen atom shares its two valence electrons with two-two electrons of carbon (fig.8).

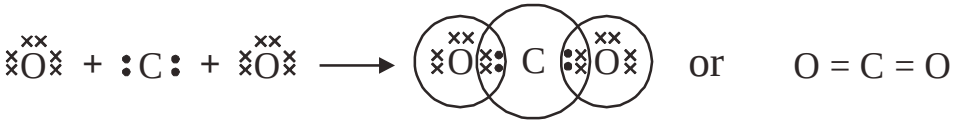


Fig. 8 : Covalent bonding in carbon dioxide

By looking at the given structure, can you tell how many bonds are formed between the carbon atom and the oxygen atom? In this compound, two pairs of (four) electrons of carbon combines with one pair of electrons of each oxygen atom to form a double bond. In the previous example, carbon formed CCl_4 with chlorine and CH_4 with hydrogen by sharing one-one electron to form single bonds. But in carbon dioxide molecule, a double bond is present between the oxygen and carbon atoms. Single and double bonds between two atoms are shown by a single dash (–) or a double dash (=) respectively.

Such compounds where electrons are shared between atoms to form bonds are called covalent compounds. It should be noted here that two or more atoms attain the nearest inert gas configuration by sharing of electrons. Such groups of atoms are known as molecules or we can say that the molecules of covalent compounds are made up of two or more atoms.

Water is a compound which is formed by combination of hydrogen and oxygen. We know that hydrogen needs to share one electron and oxygen needs to share two electrons to complete their octet. Try to make a structure of water that satisfies the valence of both hydrogen and oxygen (figure-9).

Fig. 9 : Covalent bonding in water

The molecular formula of the compound ammonia is NH_3. It is formed by nitrogen and hydrogen. Hydrogen needs to share one electron and nitrogen needs to share three electrons to attain inert gas configuration (fig.10).Can you draw the electron dot structure of ammonia?

Fig. 10 : Covalent bonding in ammonia

We will now consider bonding in hydrogen. You may know that hydrogen is the lightest gas. If we look at its electronic configuration we can see that its outermost shell (in this case, K) has only one electron and we also know that the hydrogen molecule exists. Two atoms of hydrogen shares an electron each with each other to form hydrogen molecule. We can show this by electron dot structures (figure-11).

Fig. 11 : Covalent bonding in hydrogen

So we see that molecules are formed not just by atoms of different elements but also by atoms of the same element.

The element hydrogen exists as a diatomic molecule having single bonds (we know that di- stands for two and therefore diatomic means two atoms).

Is there any element that exists as a molecule having double bonds? Let us consider the element oxygen. We already know that the atomic number of oxygen is 2, its electronic configuration is 2,6 and therefore it needs two electrons to attain the nearest inert gas configuration. So, two atoms of oxygen each contribute two electrons to form a doubly bonded oxygen molecule (fig.12).

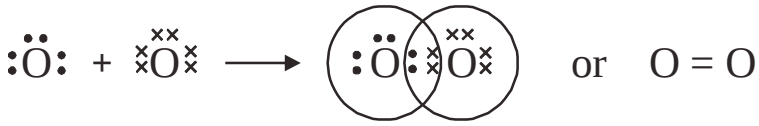


Fig. 12 : Covalent bonding in oxygen

You will be astonished to learn that carbon atoms can be linked to each other not just by single bonds but even by double and triple bonds.

Let us take C_2H_4 (or $H_2C=CH_2$) as an example.Here, one atom of carbon shares two electrons with another carbon atom to satisfy two valencies and the remaining two are satisfied by other atoms (fig.13).

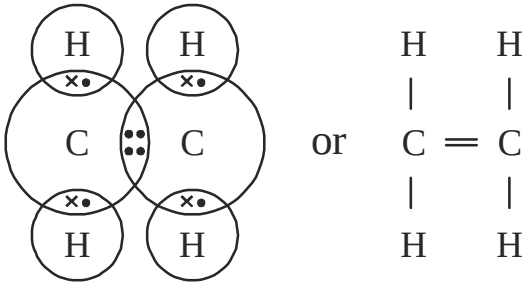


Fig. 13 : Covalent bonding in ethene

Similarly, we can also understand triple bond formation through sharing of electrons between two atoms.

Now we will consider nitrogen in which each nitrogen atom shares three-three electrons because the atomic number of nitrogen is 7 and its electronic configuration is 2,5. Since two atoms of nitrogen combine to form a molecule therefore nitrogen exists as a diatomic gas (fig.14).

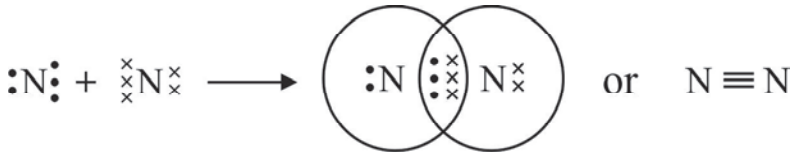


Fig. 14 : Covalent bonding in nitrogen

We have already seen how single and double bonds are formed between two carbon atoms. Similarly, triple bonds are also found between two carbon atoms. For example, a molecule of C_2H_2 (or CH≡CH) has the following structure (fig.15).

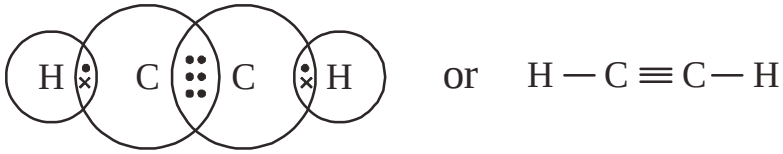


Fig. 15 : Covalent bonding in ethyne

In this chapter, we saw that the valency of an element depends on how many electrons it accepts or loses from its valence shell in order to attain the nearest inert gas configuration. We also saw that elements can also complete their octet by sharing of electrons between its own atoms or with atoms of another element. Therefore, we can understand valency as the number of electrons shared by the atoms of an element in order to complete their octet. If we take the example of carbon, since the carbon atom shares four electrons to complete its octet, its valency is four. The oxygen atom in calcium oxide accepts two

electrons from the calcium atom but in carbon dioxide, an oxygen atom shares two electrons with the carbon atom. What is the valency of oxygen in the twocases? Thus, the valency of an element is the number of electrons it loses, accepts or shares in order to form bonds.

Questions

1. Draw the electron dot structure of ethane (C_2H_6).
2. Draw the electron dot structure of any molecule which has a double bond.
3. The atomic number of chlorine is 17.
   (a) Write its electronic configuration.
   (b) Explain the formation of chlorine molecule using electron dot structures.

8.4 Ionic and covalent bonds

We saw that covalent bonds are formed by sharing of electrons between atoms and ionic bonds are formed when the valence shells of atoms gain or lose electrons.The compounds having ionic bonds are known as ionic or electrovalent compounds and the compounds that have covalent bonds are known as covalent compounds. Now, let us look at the properties of the two types of compounds.

8.4.1 Properties of ionic compounds

1. Usually, ionic compounds are soluble in water.
2. Ionic compounds have high melting and boiling points because the oppositely charged ions in them are held together by strong electrostatic forces of attraction. More energy is required to break the bonds formed by the string electrostatic forces.
3. Ionic compounds ionize when dissolved in water or on melting and therefore, can conduct electricity.

8.4.2 Properties of covalent compounds

1. Usually, covalent compounds are not soluble in water.
2. Their melting and boiling points are low as compared to ionic compounds.
3. Covalent compounds do not conduct electricity because they do not form ions.

We will now examine whether different ionic and covalent compounds conduct electricity or not.

Activity-1

Take four beakers and label them ‘A’, ‘B’, ‘C’ and ‘D’. Take 100-150 ml water in each beaker and prepare separate solutions as described below:

1. Dissolve 2 spoonfuls common salt in beaker ‘A’.
2. Dissolve 2 spoonfuls calcium chloride in beaker ‘B’.

3. Dissolve 2 spoonfuls sugar in beaker 'C'.

4. Dissolve 2 spoonfuls glucose in beaker 'D'.

First, insert two graphite rods in beaker 'A' (fig.16). The graphite rods act as electrodes. Connect these rods to a bulb and a 9 V battery as shown in the figure to complete the circuit. Take care that the two rods do not touch each other or come in contact.

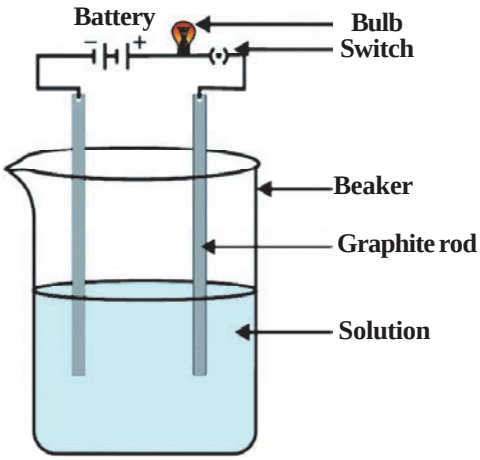


Fig. 16 : Testing if solutions of compounds conduct electricity

- Did the bulb light up?
- Repeat this experiment with the other three beakers and note your observations.

Now answer the following questions:

- Why did the bulb light up in case of beaker 'A' and beaker 'B'?
- Why did the bulb light up in case of beaker 'C' and beaker 'D'?
- You must have understood now that electricity is conducted by salt and calcium chloride because of electrovalent bonds but not in glucose and sugar because they have covalent bonds.

Questions

- Write down the differences between ionic and covalent compounds.
- Explain why ionic compounds have high melting and boiling points.

Keywords

Ion, cation, anion, ionic bond, covalent bond, sharing, valency, ionic compound, covalent compound, noble or inert gas, valence shell, octet, electrostatic attraction, electron dot or Lewis structures

What we have learnt

- During ionic bond formation, one atom loses electrons to form cations and another atom accepts electrons to form anions. The oppositely charged ions are bound together by strong electrostatic forces of attraction to form ionic bonds.
- Covalent bonds are formed by sharing of electrons between atoms.

- When one-one electron is shared between two atoms a single bond is formed. Double bond is formed by sharing of two-two electrons between two atoms and triple bonds are formed by sharing of three-three electrons between two atoms.
- The number of electrons in the outermost shell that are shared, accepted or lost in order to attain inert gas configuration is called the valency of the element.
- Ionic compounds are soluble in water, have high boiling and melting points and conduct electricity when ionized in solutions or melts.
- Covalent compounds do not dissolve in water, have lower melting and boiling points and do not conduct electricity.

Exercises

1. Choose the correct option

   (i) When sodium reacts with chlorine

   (a) Each sodium atom accepts an electron

   (b) Each chlorine atom accepts an electron

   (c) Each sodium atom loses seven electrons

   (d) Each chlorine atom loses seven electrons

   (ii) A sodium atom and a sodium ion:

   (a) Are chemically same

   (b) Have the same number of protons

   (c) Form covalent bonds

   (d) Have the same number of electrons

   (iii) An ionic bond is formed when

   (a) The combining atoms accept electrons

   (b) The combining atoms lose electrons

   (c) One atom loses and the second gains electrons

   (d) When two metals react

(iv) Which of the following elements loses two electrons in order to attain inert gas configuration similar to argon?

(a) magnesium (b) sodium

(c) calcium (d) sulphur

(v) double bonds are found in which of the following molecules:

(a) N_2 (b) C_2H_2

(c) Cl_2 (d) CCl_4

2. Fill in the blanks

(i) Sodium atom ..... an electron to attain the electronic configuration of the element .....

(ii) Two atoms of nitrogen share ..... pairs of electrons to form a nitrogen molecule.

(iii) The number of electrons in the outermost shells of inert gases is ..... but in case of helium it is .....

(iv) Chlorine molecule has ..... bond but magnesium chloride has ..... bond.

(v) Ionic compounds are usually ..... in water but covalent compounds are ..... in water.

3. What type of bond is formed when electrons are transferred from one atom to another? Explain.

4. Draw the electron dot structure of a molecule that has a triple bond.

5. Argon atoms does not form Ar_2 molecule by covalent bonding. Why?

6. The electronic configuration of elements X and Y are:

X = 2,8,8,2 Y = 2,6

Explain the type of bonding seen when X and Y combine. Show through electron dot structures.

7. What is the role of valence electrons in the formation of chemical compunds? Explain.

8. (i) Give the number of covalent bonds in one molecule of ammonia.

(ii) 'Sodium chloride is a molecule'. Explain why this statement is not true.

9. Draw the electron dot structures of the given compounds and write the type of bonding seen in each.

(i) Water (ii) nitrogen

(iii) magnesium oxide (iv) calcium oxide

10. Write down the properties of ionic and covalent compounds.

11. Explain how the valency of an element is related to its electronic configuration.

12. The atomic numbers of three elements are 6,7 and 8 respectively.

    (i) Write the electronic configuration of each element and give their valency.

    (ii) What type of compounds (ionic/covalent) will be formed by each of the elements? Explain.

13. Separate ionic compounds and covalent compounds in the given group. Give reasons for your choice.

14. Which of the following are possible? Give reasons for your answer.

    (i) Mg_2 (ii) $MgCl_2$ (iii) Cl_2