STRUCTURE AND BONDING

By the end of this lesson the learner should be able to;

1. Define the bond and structure.
2. Describe the nature of chemical bond.
3. State and explain the types of bonds.

Meaning of structure and bond.

Bond:

- It is the mutual force of attraction that holds particles together with same or different atoms combines during chemical reactions.

Structure:

- It a regular pattern of particles in a substance held together by chemical bonds.

Nature of the chemical bond.

- atoms are made up of energy levels and nucleus.
- The energy levels contains electrons while the nucl eus contains protons and neutron.
- The electrons are negatively charged, protons are positively charged while neutrons are electrically neutral.

- The noble gases are chemically inert since their outer most energy levels are completely filled with the maxi mum possible number of electrons.
- Thus noble gases have either a stable duplets (2) like i n helium or stable octet configuration(2.8 or 2.8.8) as in neon and argon respectively.
- Other atoms are unstable because their outermost ener gy levels are not yet completely filled with the maximu m possible number of electrons.
- To attain the stable duplet or octet noble gases configur ation, such atoms lose, gain or share their valence electr ons.

- It is the act of losing, gaining or sharing valence electrons that lead to chemical bonding.
- When atoms gain or lose valence electron (s) they become charged forming anions and cations respectively.
- Particles of the same charge repel each other while particles of different charges attract one another.

Types of bonds

- There are three main types of chemical bonds.
  - Ionic bond
  - Covalent bond
  - Metallic bond

Ionic bonds/ Electrovalent bond

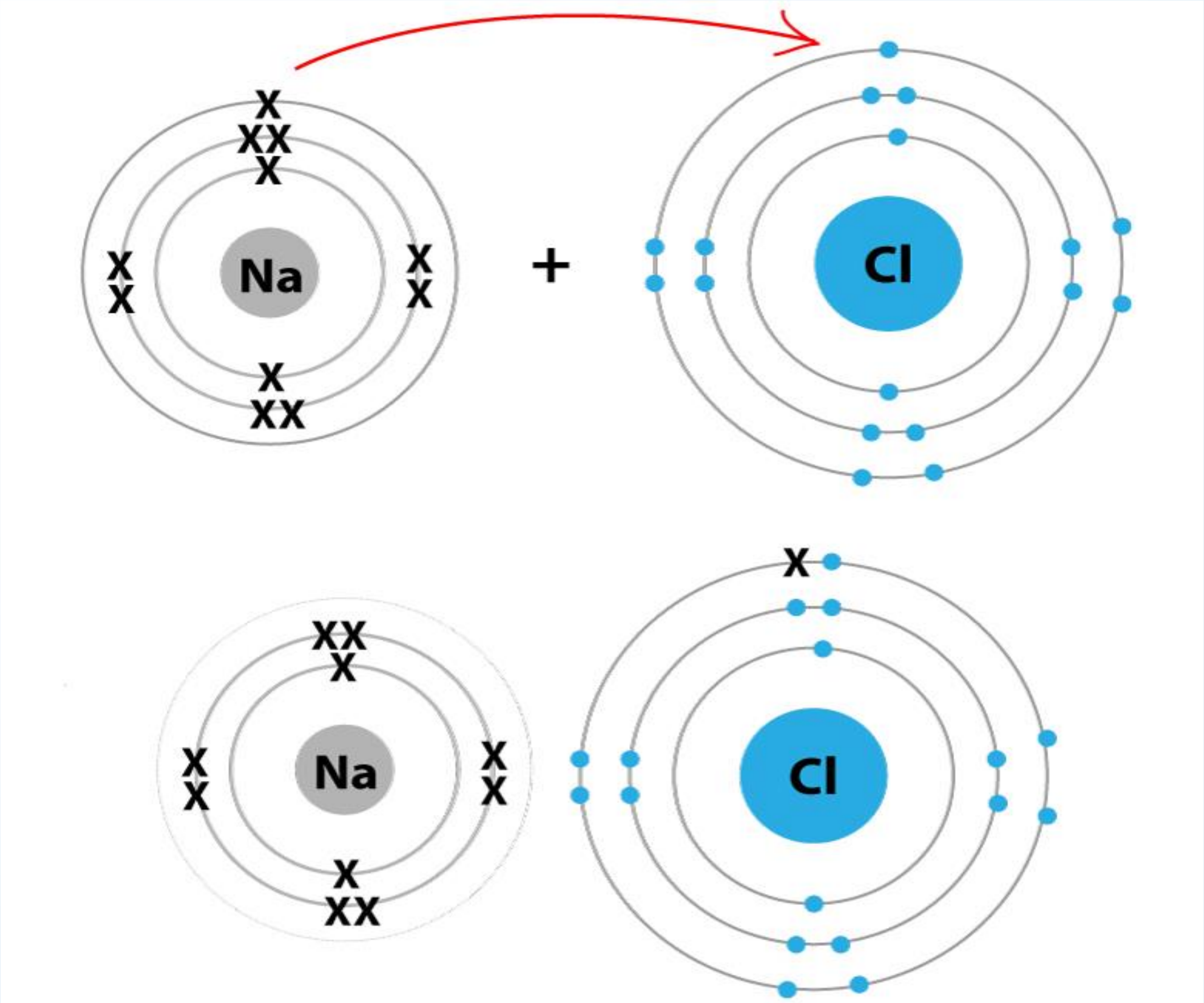
- is a bond formed due to complete transfer of electrons from one atom to another resulting into two opposite charged ions.

Formation of an ionic bond.

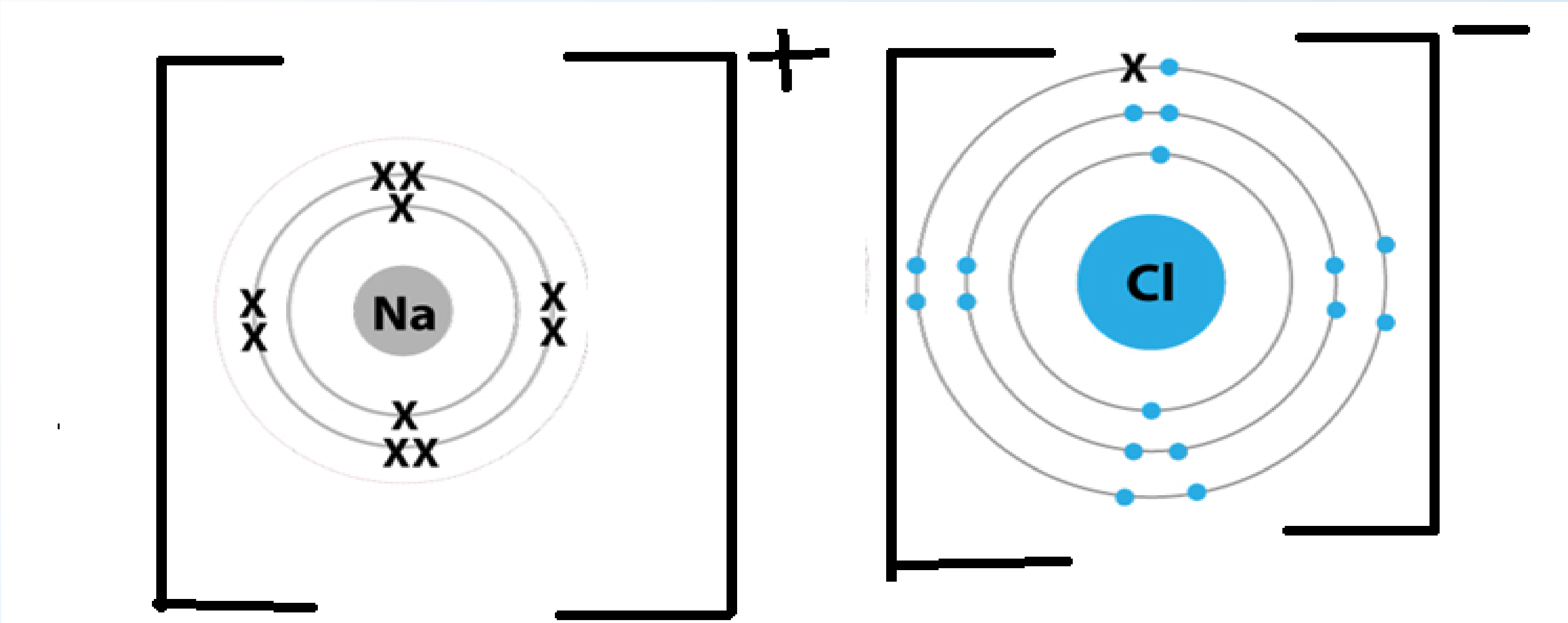
- Formed due to complete transfer of electrons from one atom to another and mainly formed between a metal and a non-metal.
- This occurs in a bid for both atoms to acquire a stable noble gas configuration.
- The other atom gains all its valence electrons forming an anion (negatively charged ion)
- The cations and the anions oppositely charged and thus develop a mutual force of attraction between them which is the ionic/ electrovalent bond

Illustration: formation of ionic bond between sodium and chlorine to form sodium chloride.

Sodium has 1 electron in its outermost shell, and chlorine has 7 electrons. It is easiest for sodium to lose its electron and form a +1 ion, and for chlorine to gain an electron, forming a -1 ion. If sodium can transfer it's "spare" electron to chlorine (as shown below, both atoms will satisfy their full outer shell requirements, and an ionic bond will be formed. If large groups of sodium and chlorine atoms bond this way, the result is a three-dimensional structure with alternating sodium and chlorine ions:



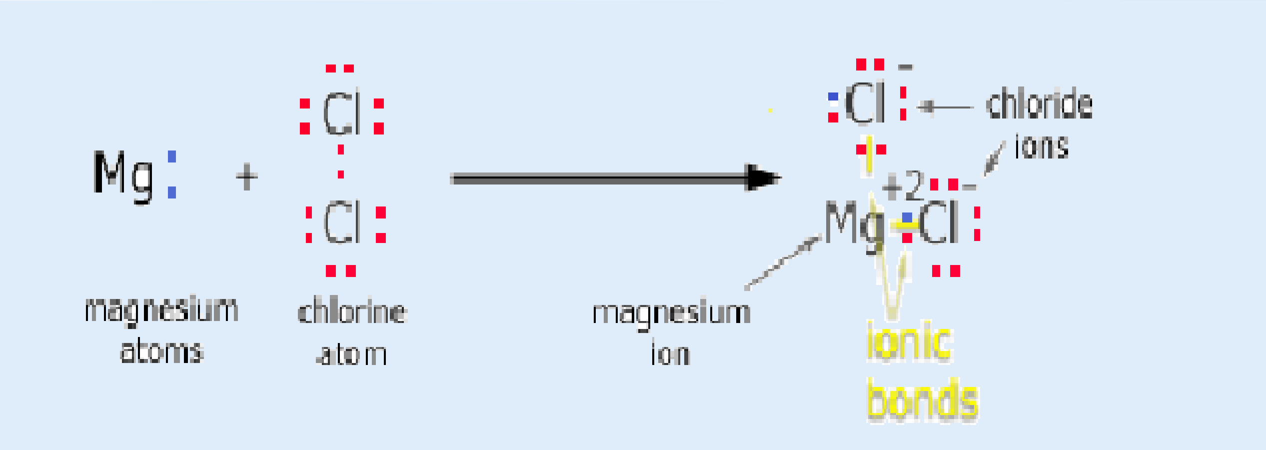
Na
+
Cl
Na
Cl


+
Na
Cl
−

More examples of ionic bond

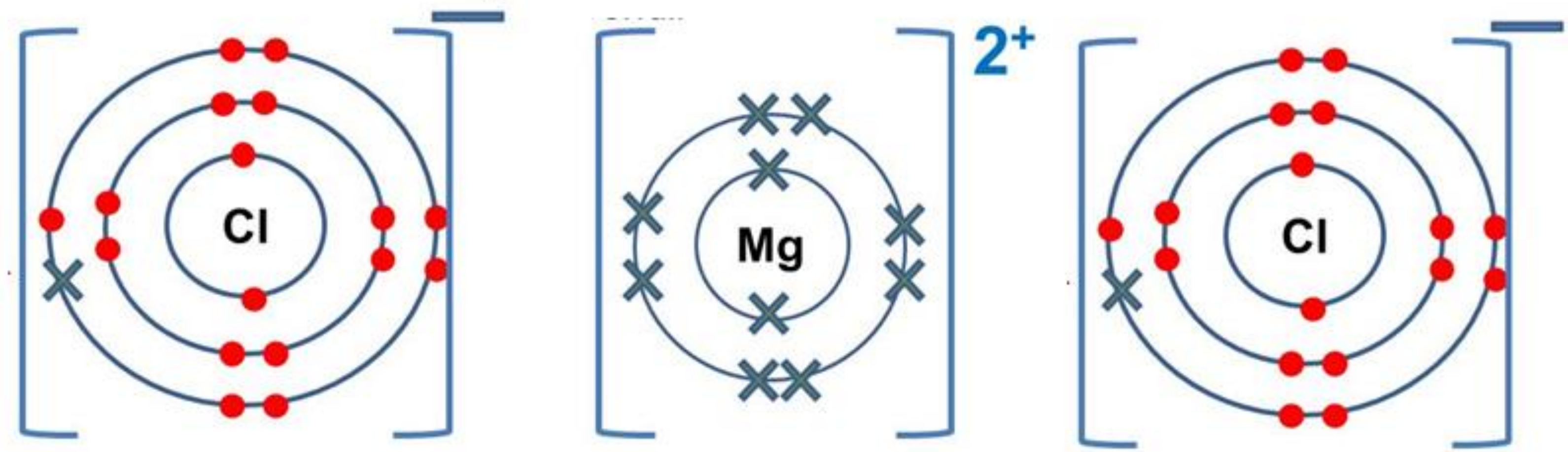
- **Magnesium chloride ($MgCl_2$)**
- MgCl2 is an ionic compound because this compound is formed by transfer of electrons between magnesium atom a nd chlorine atoms. Magnesium atom loses two electrons to form magnesium cation where as each chlorine atom accep ts one electron to form chloride ion (anion)
- **Mg forms ionic bond to Cl by donating its valence electrons to two Cl atoms.**
- The electron configuration **of Mg is 2.8.2 It can achieve a complete octet by losing its two** valence electrons **to form Mg^{2+} (2.8)**

- The electron configuration of Cl is 2.8.7. It can achieve an octet by gaining one valence electron to form Cl^- (2.8.8).
- The oppositely charges of the magnesium and chloride ions attract each other and form ionic bonds.



- Two electrons lost by a magnesium atom are gained by chlorine atoms to produce a magnesium ion and 2 chlorine ions.

After Bonding

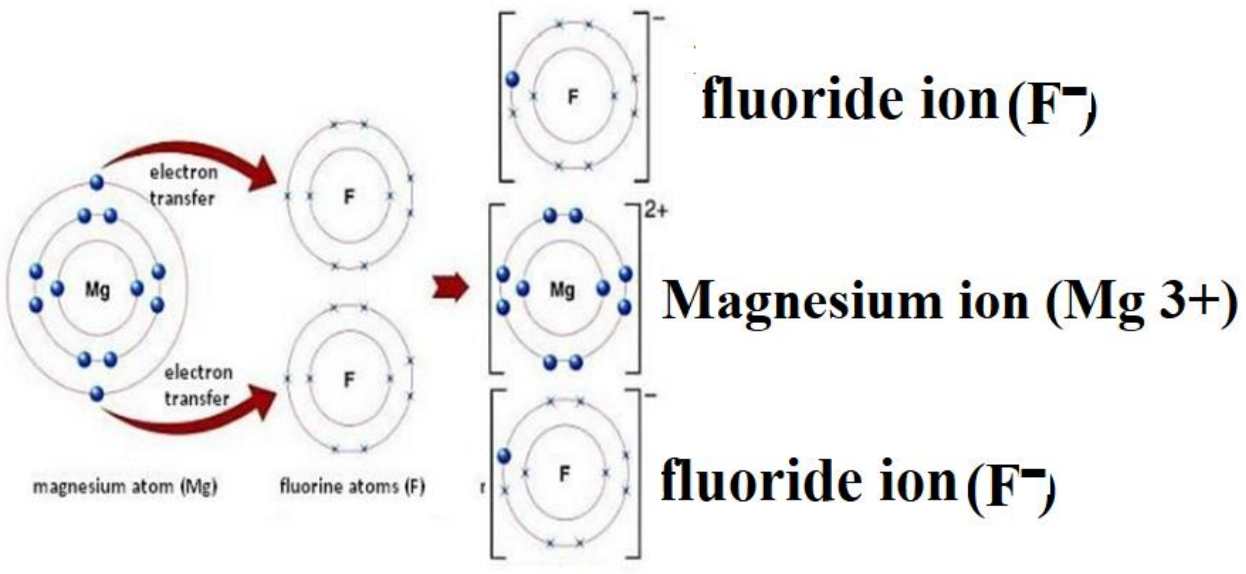


Magnesium lost 2 electrons to form magnesium ions Mg^{2+}

Each chlorine atom gained an electron to form chloride ions Cl^{-}

Magnesium chloride is $MgCl_2$

Magnesium fluoride (MgF_2)



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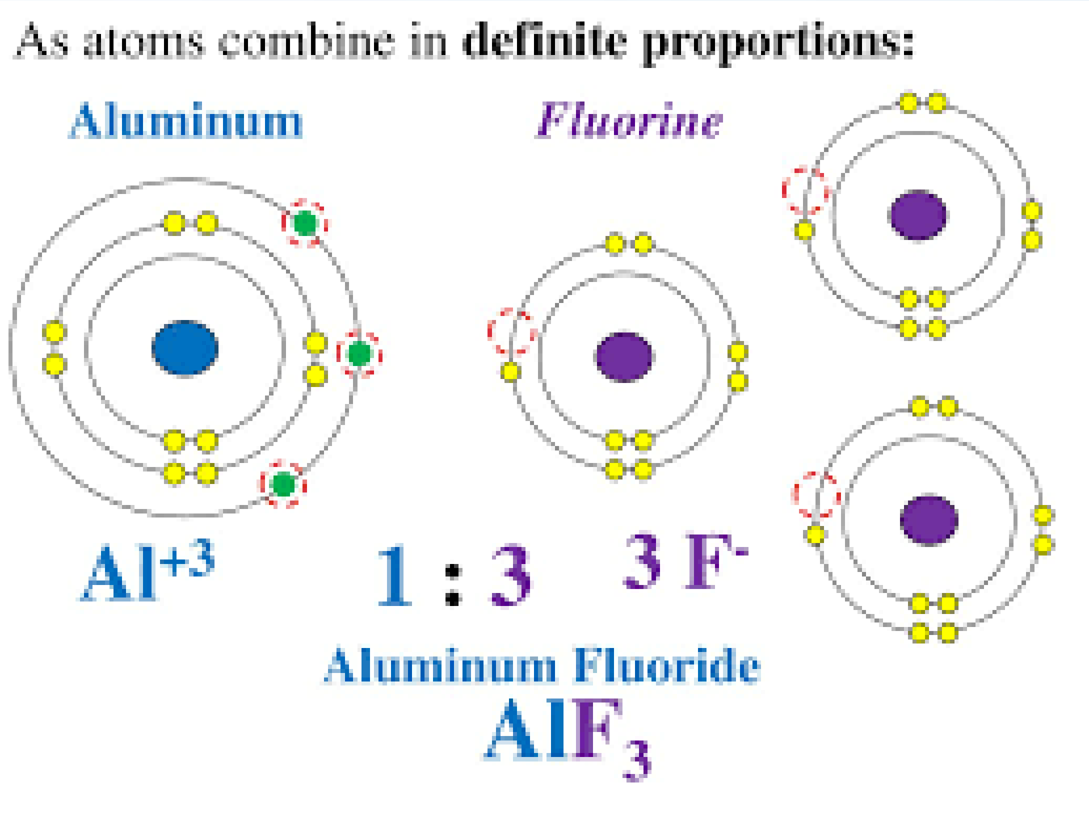
Aluminium fluoride



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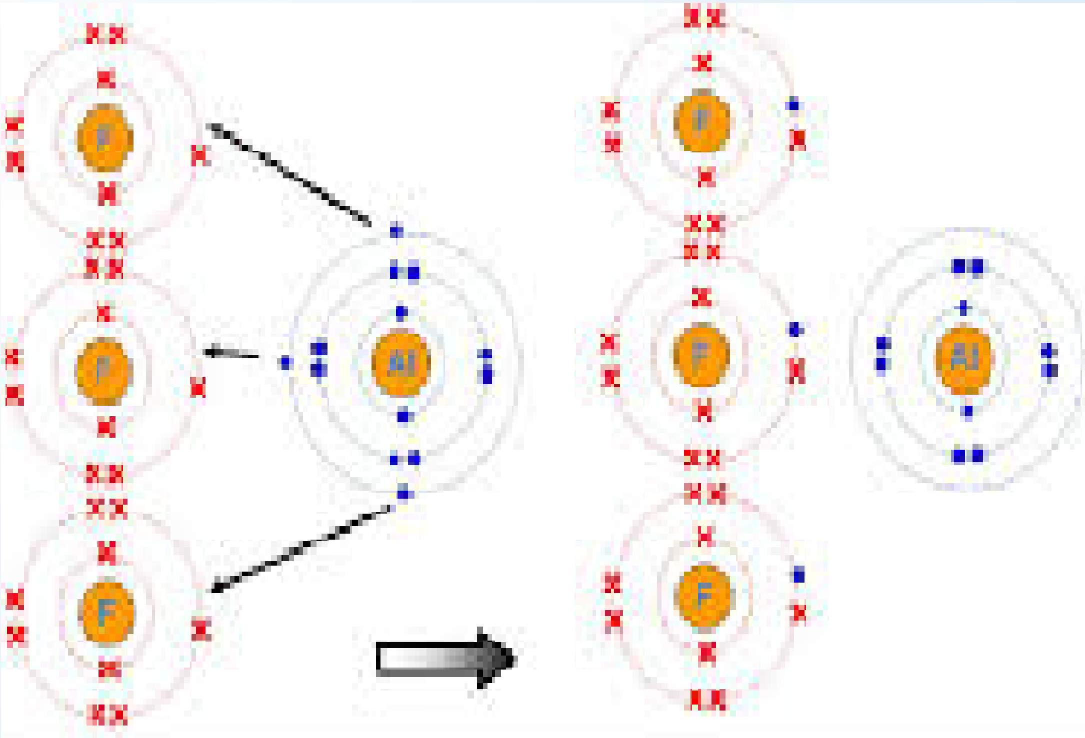
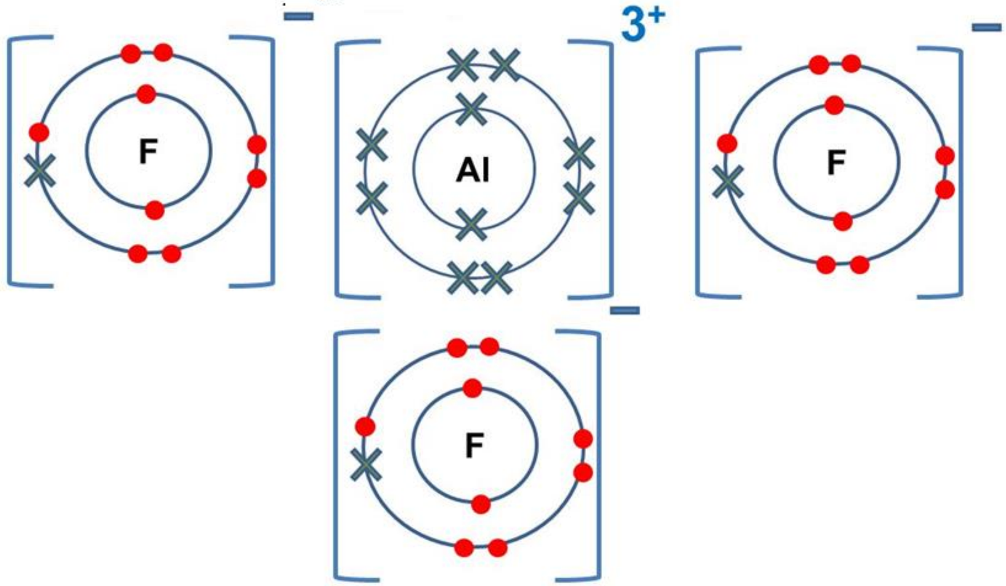

F
F
F
Al
F
F
F
Al

After bonding



Aluminium atom lost 3 electrons to form aluminium ions **Al^{3+}**

Each fluorine atom gained an electrons to form fluoride ion **F^{-}**

Aluminium Fluoride is AlF_3

► Note : Aluminium chloride does not form ionic bond. Instead it forms a dimer of both covalent and dative bonds.

Example of ionic compounds

- Sodium chloride
- Potassium fluoride
- Magnesium oxide
- Aluminium (III) oxide

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Assignment

1. By using dots (.) and crosses (x) draw the electrovalent bond betwe en the following compounds:

   a. Lithium fluoride
   b. Sodium fluoride
   c. Potassium fluoride
   d. Potassium bromide
   e. Copper (ii) oxide
   f. Lead oxide

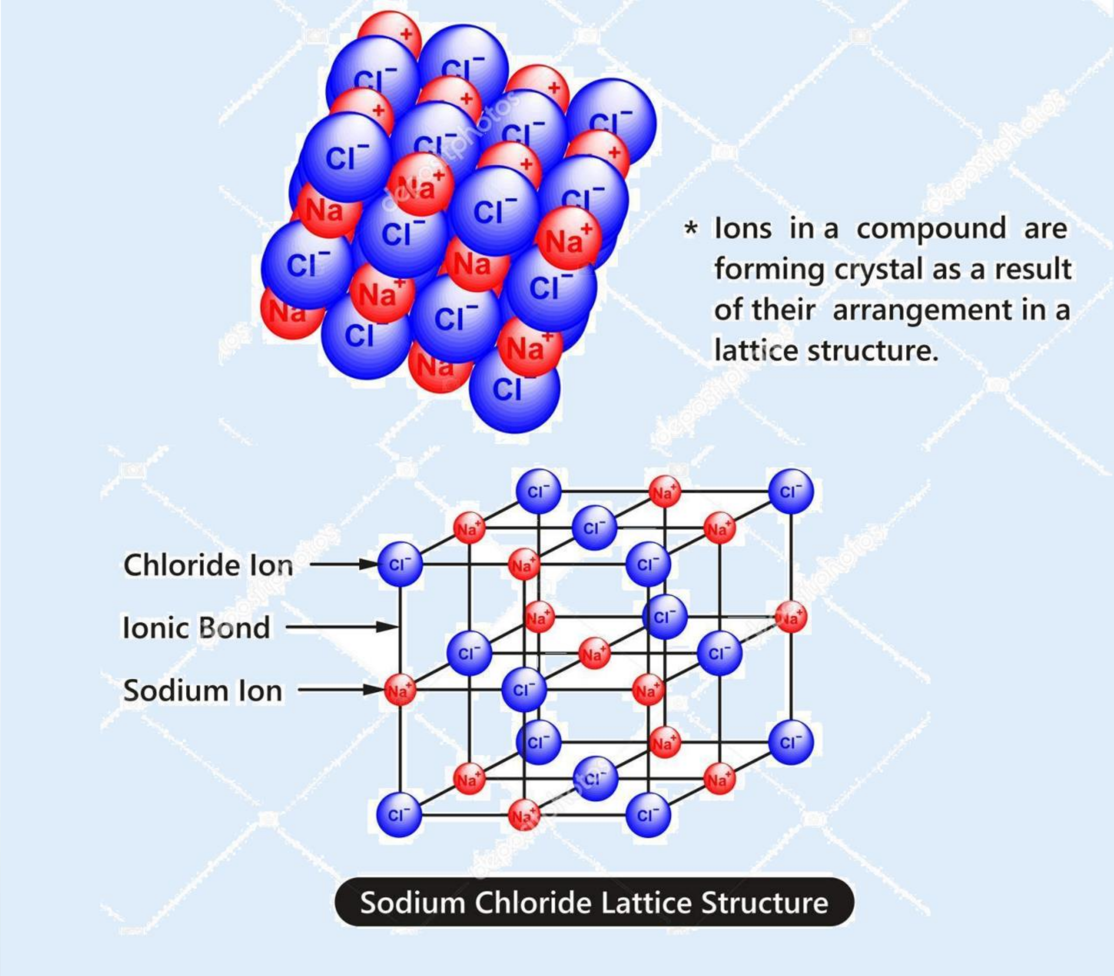
Giant Ionic structures

- Ionic bonding results into one type of structure, the giant ionic structure.
- This is a type of structure in which all ions are bonded with strong ionic bonds throughout the structure.
- Each ion in the giant ionic structure is surrounded by several others resulting into giant pattern of several ions, hence giant ionic structure.
- Most ionic substances with the giant ionic structure are crystalline in nature, made up crystals. A crystal is a solid form of a substance in which the particles are arranged in a definite pattern repeated regularly in 3 dimensions.

Illustration of the giant ionic structure: sodium chloride structure.

- The NaCl structure consists of many Na^+ and Cl^- arranged and packed in a regular pattern.
- Each Na^+ is surrounded by six Cl^- that are equidistant from it.
- Similarly each Cl^- is surrounded by six Na^+ that are equidistant from it.
- This pattern occurs repeatedly in all directions.
- The result is a giant of ions in all directions hence giant ionic structure.

Diagram of the cubic structure of sodium chloride.



Properties of giant ionic structures

- **They are hard and brittle.**
- Ionic solids are hard because each ion is held in the crystal by strong attractions from the oppositely charged ions around it.
- They are brittle and thus may be split cleanly (cleaved) using a sharp-edged razor.
- When a crystal is tapped sharply along a particular plane it is possible to displace one layer of ions relative to the next.
- Due to the displacement, ions of similar charge come together leading to repulsive forces between the portions of the crystals.
- This forces the two portions of the crystals to split apart.

- **They have high melting and boiling points.**
  - They have strong electrostatic forces / ionic bonds / electrovalent bonds between the oppositely charged ions throughout the structure which require large am ounts of energy to break.

Solubility.

- They are soluble in polar solvents like water, ethanol and acetone (propanone)
- Water contains highly polar molecules.
- The positive ends of the polar water molecules are attracted to the negative ions in the crystal, and the negative ends of the water molecules are attracted to the positive ions in the crystal. This results to the formation of ion-solvent bonds which leads to release of energy.
- This energy is sufficient to cause the detachment of ions from the crystal lattice hence dissolution. This detachment of ions is called solvation , and the energy required for this is called solvation energy.
- Where the solvent is water the ions are said to have been hydrated , and the energy involved in the process is called hydration energy.

- They are insoluble in non-polar organic solvents like tetrachloromethane , benzene and hexane
- Non-polar molecules are held together by weak intermolecular forces, the Van der Waals forces.
- The Van der Waals are much smaller in magnitude compared to the ionic bonds in the ionic solid crystal lattice.
- Thus the ion-ion interactions in the ionic solid are stronger than the solvent-solvent interactions in the solvent or the solvent-ion interactions between the solid and the solvent.
- Thus the non-polar solvent molecules cannot penetrate the ionic lattice to cause salvation.

- **Electrical conductivity.**
- Ionic substances do not conduct electric current in solid state.
- The ions are held in static positions in the solid crystal lattice and thus cannot move to conduct electric current.
- They conduct electric current in molten and solution (aqueous) states.
- In molten and aqueous states the ions are free and mobile and thus move about conducting electric current.

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Gradation in properties of some ionic compounds of sodium.

Property of compound		Compound of sodium			
		Sodium fluoride	Sodium Chloride	Sodium bromide	Sodium iodide
Solubility in water		Soluble	Soluble	Soluble	Soluble
Melting point (^{o}C)		993	801	747	661
Boiling point (^{o}C)		1695	1413	1390	1304
Electrical conductivity	Solid	Does not	Does not	Does not	Does not
	Molten / solution	Conducts	Conducts	Conducts	Conducts

- Solubility of the compounds decrease from sodium fluoride to sodium iodide.
- Melting and boiling points decrease from sodium fluoride to sodium iodide

The covalent bond.

- Refers to a bond formed when two atoms of the same or of different elements share electrons to become stable.
- Formation of covalent bond between atoms (similar or dissimilar) result to the formation of a molecule.
- Covalent bonds are usually formed by the association of non-metals.
- A molecule is a group of atoms (two or more) of the same or different elements that are held together by strong covalent bonds.

Formation of a covalent bond

- Covalent bonding is brought about by the facts that the electro-positivity and the electro-negativity of the elements involved are very close.
- For that reason, none of the atoms can completely lose its valence electrons to the next atom.
- For this reason, both atoms donate electrons which are then shared between them.
- Both atoms thus attain a stable noble gas (duplet or octet) configuration.

Illustrations:

Formation of chlorine molecule.

- Each chloride atom has electronic configuration 2.8.7 and thus need to gain a single electron in the outermost energy level to attain a stable noble gas configuration. Since both chloride atoms have same electro-negativities, none will easily lose an electron to the other
- For this reason, both donate the number of electrons required by the other atom (in this case 1), which they share between them.
- Thus chlorine molecule is formed by sharing 2 electrons between two chlorine atoms , hence a single covalent bond.

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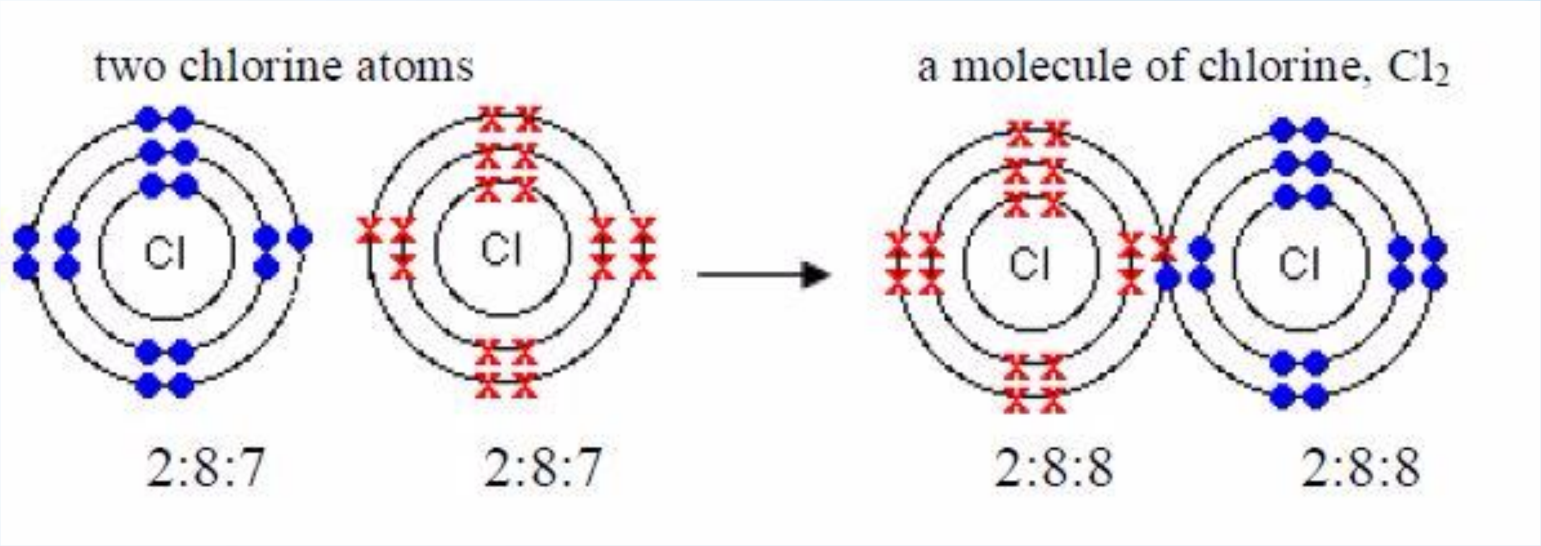
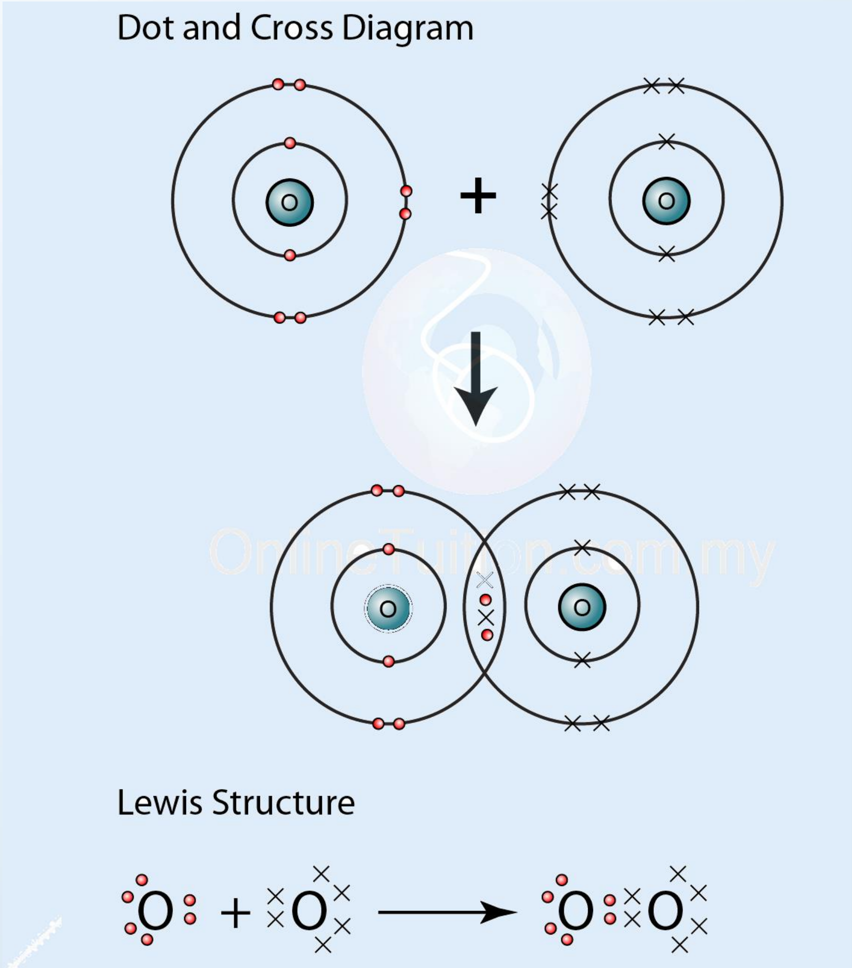
Diagram: formation of chlorine molecule



Formation of oxygen molecule

- Each oxygen atom has electronic configuration 2.8.6 and thus need to gain 2 electrons into the outermost energy level to attain a stable noble gas configuration.
- Since both oxygen atoms have same electro-negativities, none will easily lose an electron to the other.
- For this reason, both donate the number of electrons required by the other atom (in this case 2), which they share between them.
- Thus oxygen molecule is formed by sharing 4 electrons (2 from each atom) between two oxygen atoms, hence a double covalent bond .

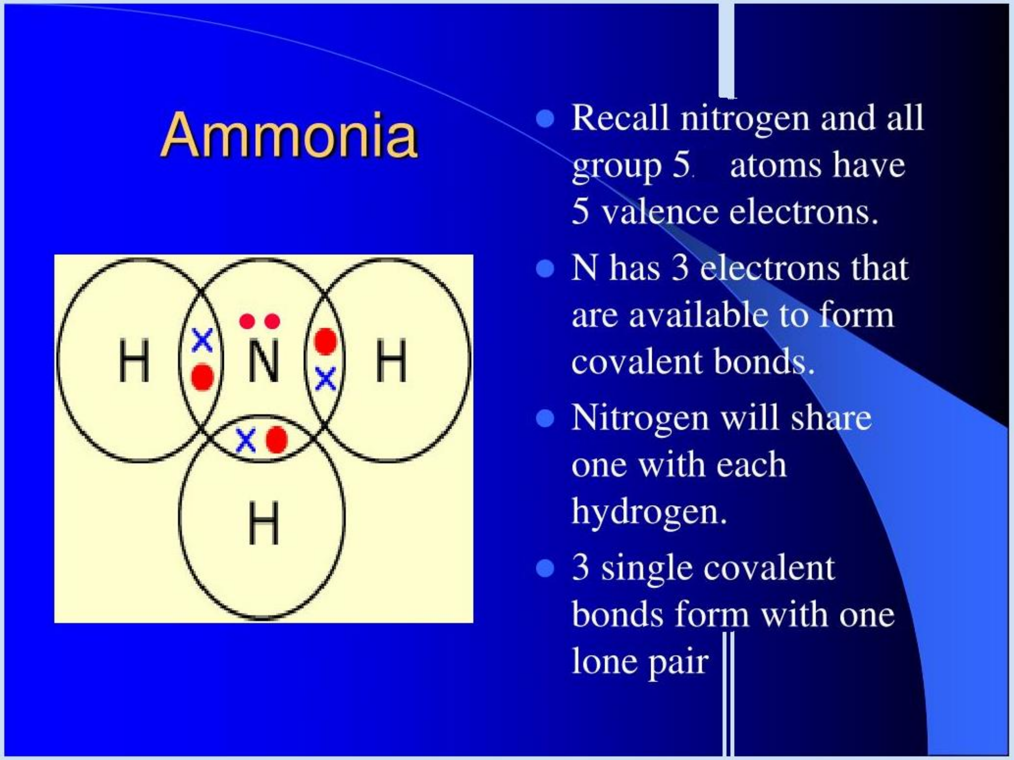
Diagram: the oxygen molecule

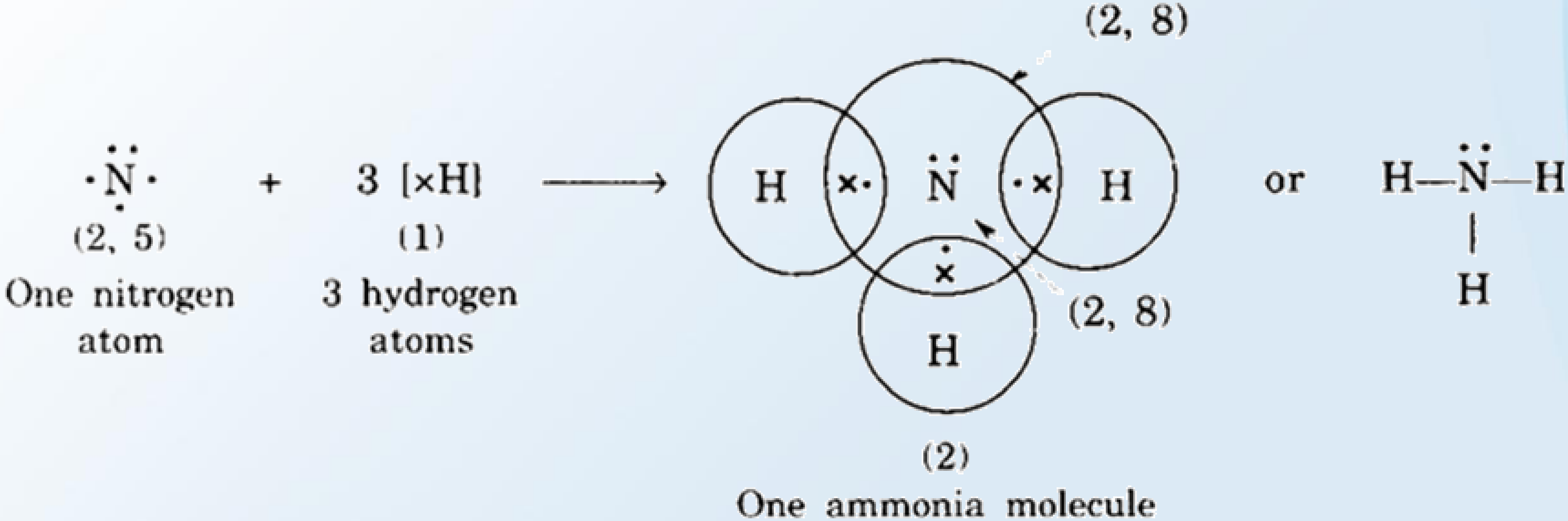


- A single covalent bond is represented in dot (.) and cross (x) diagrams using two dots, two crosses, a dot and a cross or a single line (-) between the atoms involved in the bond.
- Thus a single covalent bond like in chlorine can be represented as Cl - Cl, a double covalent bond like in oxygen can be represented as O = O while a triple covalent bond like in nitrogen can be represented as N ≡ N.

Molecular structure of ammonia

- Ammonia is a covalent molecules with 3 covalent bonds. In a simple molecular structure, the nitrogen atom has three unpaired electrons that they can share with 3 hydrogen atoms that has one valence electrons to achieve a stable noble gas configuration for both nitrogen and hydrogen atoms.





·N· (2, 5)
One nitrogen atom
+
3 [×H]
(1)
3 hydrogen atoms
(2, 8)
H
N
H
H
(2, 8)
(2)
One ammonia molecule
or
H—N—H
H

Assignment

Draw the Dot (.) and cross (x) diagrams for the following covalent compounds.

i. Hydrogen, H_2
ii. Hydrogen chloride, HCl
iii. Nitrogen, N_2
iv. Water
v. Carbon (IV) oxide, CO_2
vi. Ammonia gas, NH_3
vii. Phosphene, PH_3
viii. Methane, CH_4
ix. Ethane. CH_2CH_2
x. Ethyne, C_2H_2
xi. Ethanol, C_2H_5OH
xii. Bromoethane, C_2H_4Br.

The coordinate bond

- Refers to a type of covalent bond in which the shared pair of electrons forming the bond is contributed by only one of the atoms forming the bond.
- It is also called the dative bond

Formation of ammonium ion.

- Occurs when an ammonia gas molecule combines with a hydrogen ion (proton).
- All the atoms in the ammonia molecule have a stable noble gas configuration and thus the molecule is stable.
- However the nitrogen in the ammonia molecule has a lone pair of electrons (electrons that have not yet been used in bond formation)
- The hydrogen ion has lost its outermost single valence electron to form the hydrogen ion.
- Thus the hydrogen ion has no electron(s) in its outermost energy level.
- To be stable the hydrogen needs two electrons in its outermost energy level.
- The hydrogen ion thus accepts bonds with the lone pair (2) of electrons in the nitrogen of the ammonia molecule forming a dative bond.

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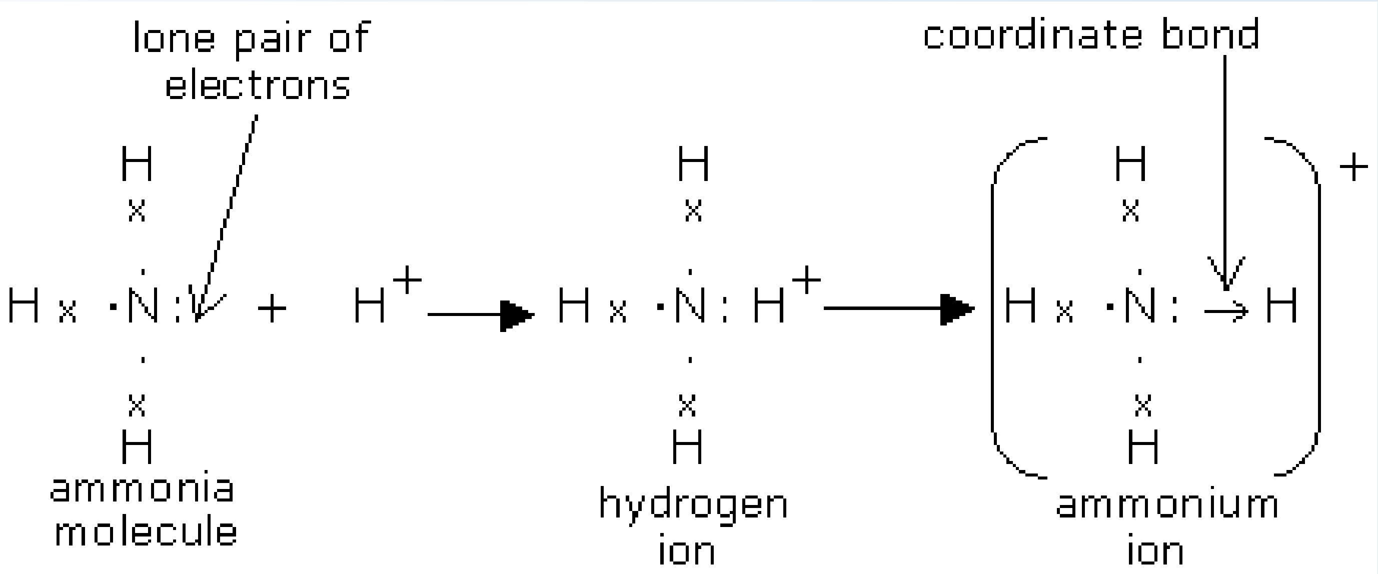
► The total number of electrons in the ammonium ion is 11 while the total number of electrons is 10 leading to a net positive charge of +1.

►In a dot (.) and cross (x) diagram where the covalent bond is represented by horizontal lines ( ), the dative / coordinate bond is represented by an arrow (→) pointing the atom that "accepts" the electrons.



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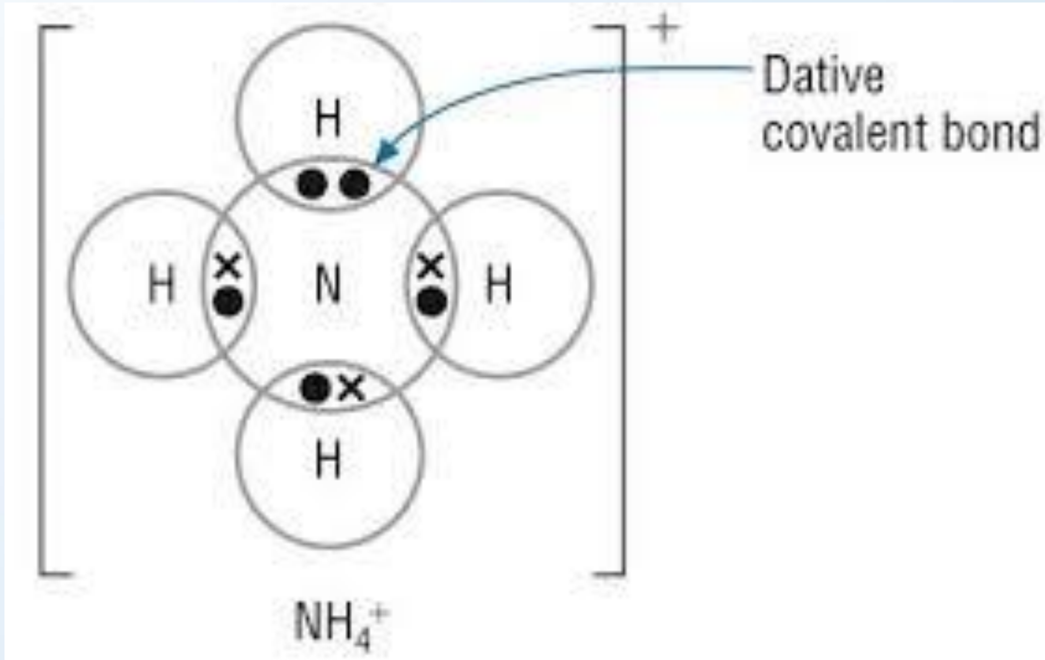

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Formation of hydronium ion (H_3O^+)

- Occurs when a water molecule combines with a hydrogen ion (proton).
- All the atoms in the water molecule have a stable noble gas configuration and thus the molecule is stable.
- However the oxygen in the ammonia molecule has 2 lone pairs of electrons // four electrons (electrons that have not yet been used in bond formation)
- The hydrogen ion has lost its outermost single valence electron to form the hydrogen ion.
- Thus the hydrogen ion has no electron(s) in its outermost energy level.
- To be stable the hydrogen needs two electrons in its outermost energy level.
- The hydrogen ion thus accepts and bonds with two of the four electrons in the oxygen of the water molecule forming a dative bond / coordinate bond.
- The total number of electrons in the hydroxonium ion is 11 while the total number of electrons is 10 leading to a net positive charge of +1

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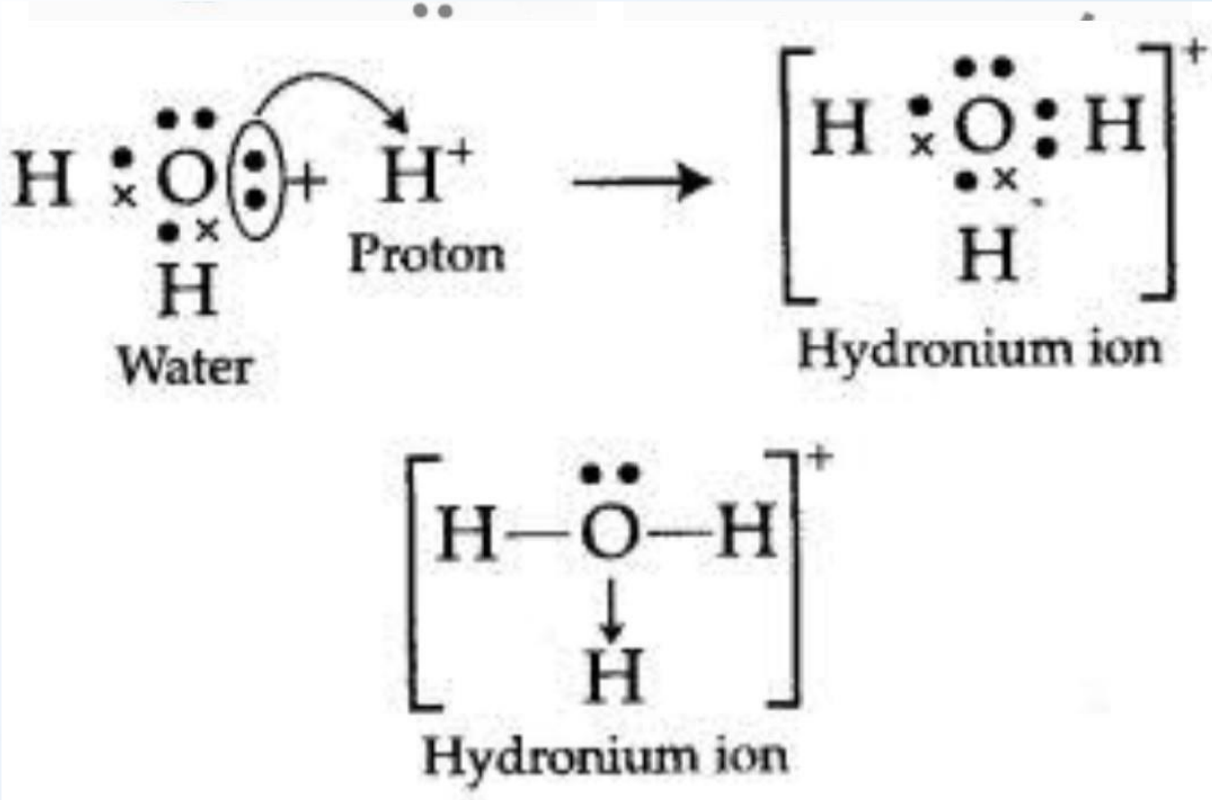

The hydronium ion (H_3O^+) can still further react with another hydrogen ion to form another ion of the formula H_4O^{2+} .

This is due to the presence of a single lone pair of electrons in the structure of the hydronium ion (H_3O^+).

The H_4O^{2+} cannot however react further since all the valence electrons in all its atoms have been used in bonding leaving no lone pairs.

Further examples of dative covalent bonds in other compounds.

I. Carbon (IV) oxide
II. PH_4^+
III. Aluminium chlorine dimer (Al_2Cl_6).

Slides prepared by Tr. Stephen O. Omondi CEO Brilliant educations publishers
Tel: 0711410583
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