Department of Mathematics and Natural Science

CHE 101: Introduction to Chemistry

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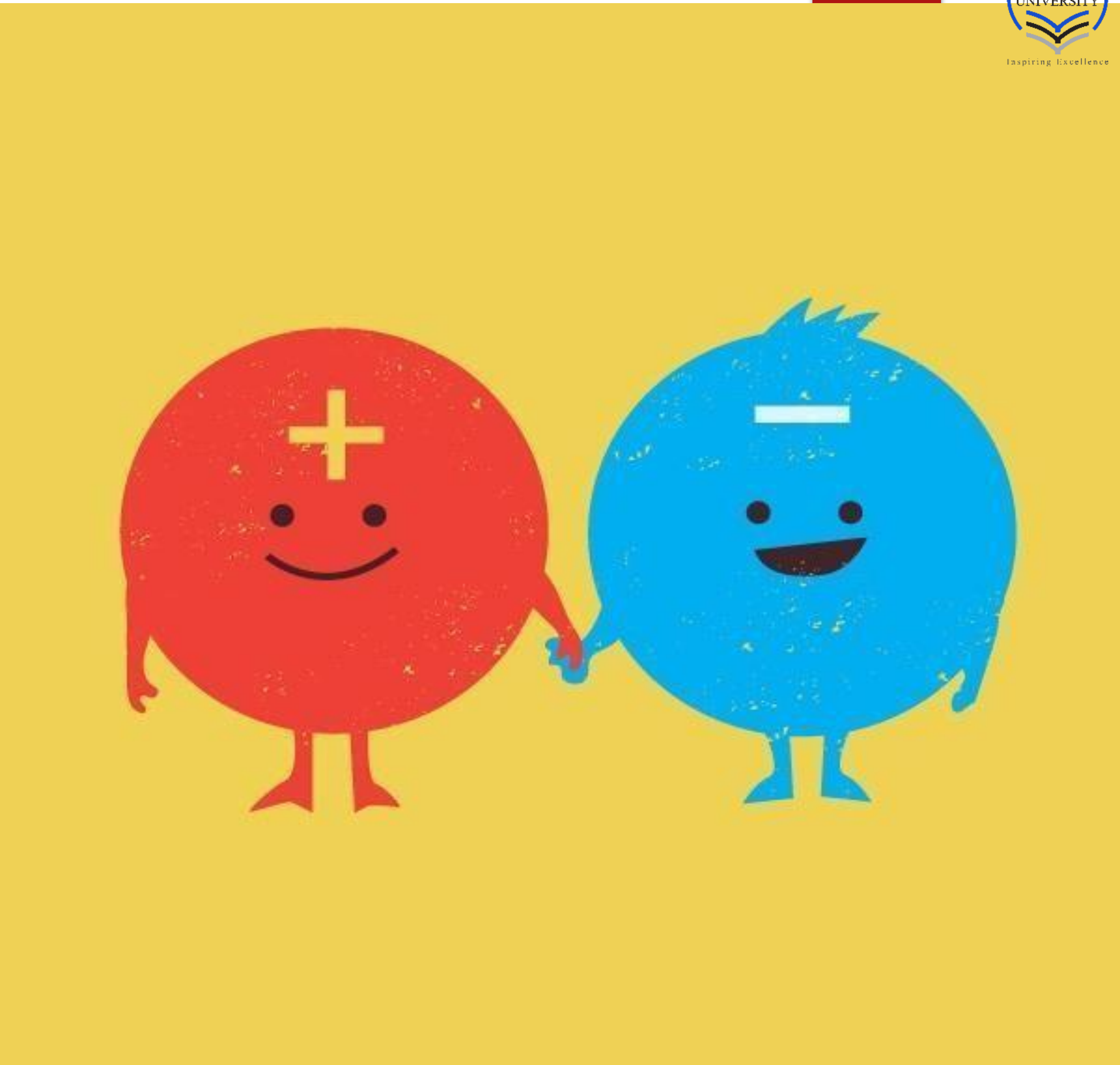
Lecture 6

Content: Chemical Bond

Chemical bond

- A chemical bond is defined as the **attractive force** that holds two or more atoms together in a molecule or an ion.
- In the formation of a chemical bond, atoms interact with each other by **losing, gaining or sharing of electron** to acquire a **stable outer shell** of eight electrons.

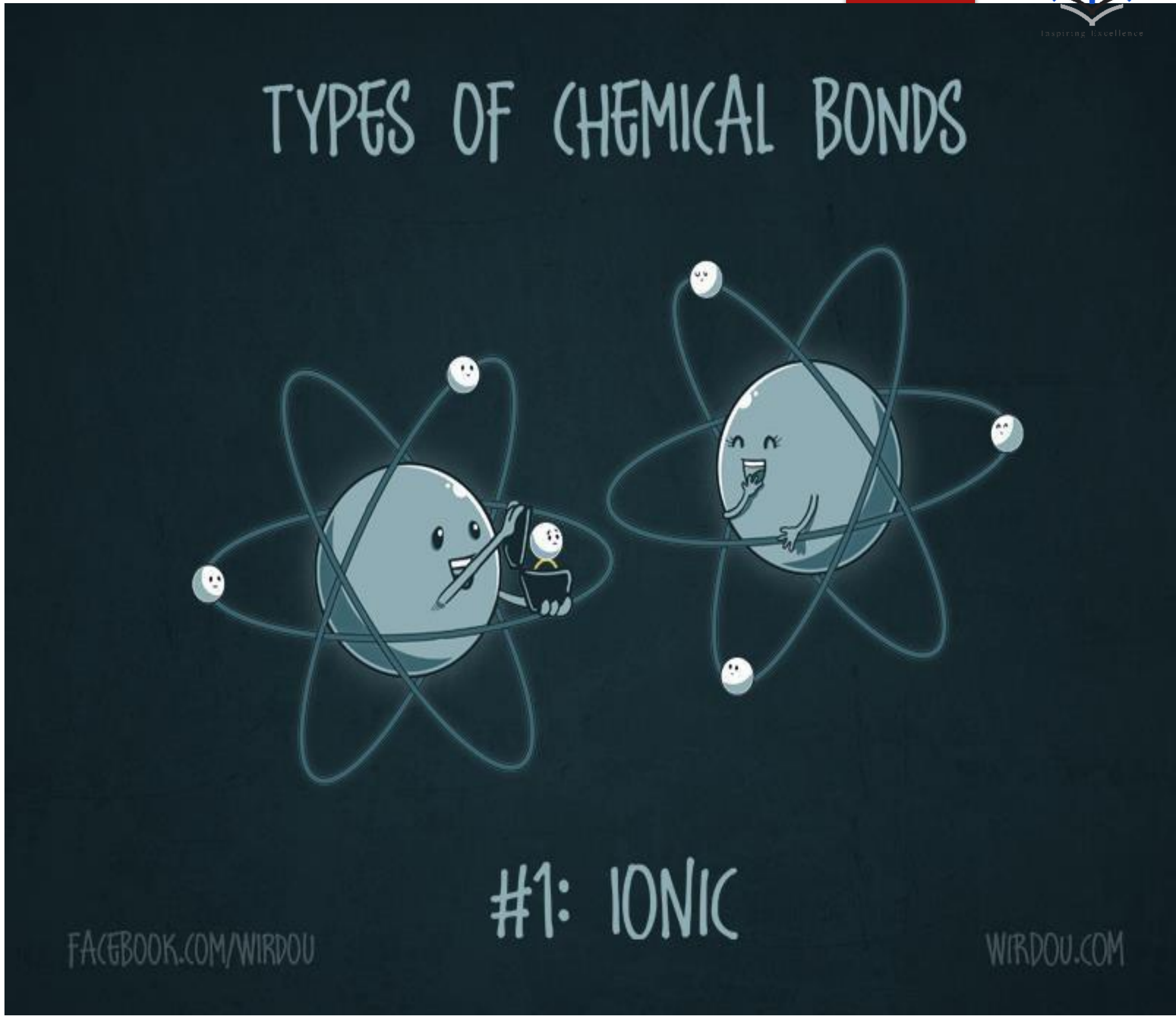


Classification of chemical bond

- Chemical bond
  - Strong Bond
    1) Ionic or Electrovalent Bond
    2) Covalent Bond
    3) Coordinate or Dative Bond
    4) Metallic Bond
  - Weaker Bond
    1) Hydrogen Bond
    2) van der Waals Interactions

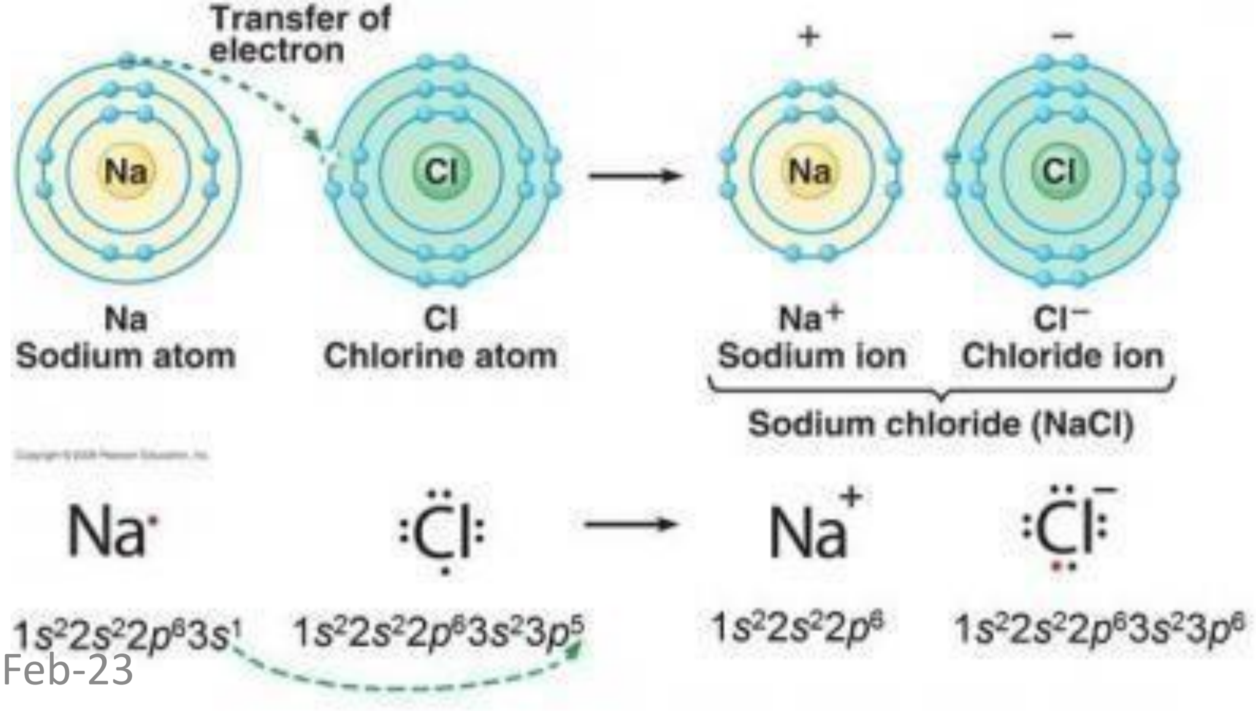
Ionic Bond

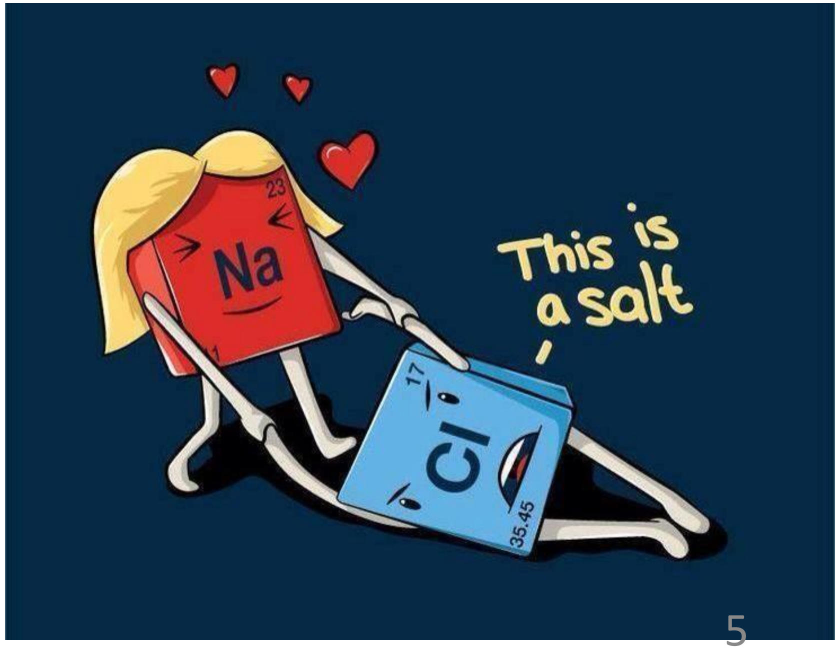
- This chemical bond formed between two atoms by **transfer of one or more valence electrons** from one atom to the other is called ionic bond.
- This bond is formed by the **electrostatic force of attraction between positive and negative ions.**
- The atom that loses electrons becomes a **cation** (positive ion), and the atom that gains electrons becomes an **anion** (negative ion). In general, metals form cations and non-metals form anions.



The formation of sodium chloride

- The sodium atom will lose its electron from outer most shell (3s) and the Cl atom will gain that electron into its 3*p* subshell and has taken on the argon configuration.
- Thus the Na atom will be converted into its cation Na+ ion and Cl atom will be converted into anion Cl-
- Both of them have electronic configuration of their nearest inert element (Ne and Ar).
- The resulting positive ion and negative ion are held together by electrostatic force of attraction which is called ionic bond or electrovalent bond.





Properties of ionic compounds

1. Physical state: Ionic compounds are crystalline solids at room temperature.

2.Electrical conductivity: Ionic compounds do not conduct electricity when they are in the solid state. The ionic solids conduct electricity when they are water solution or in the molten state.

3. They are quite hard, have low volatility and high melting and boiling points.

4.Most ionic compounds are soluble in polar and insoluble in non polar solvent. Ionic solids are freely soluble in polar solvents like H2O, liquid ammonia etc.

5. Ionic compounds are very stable.

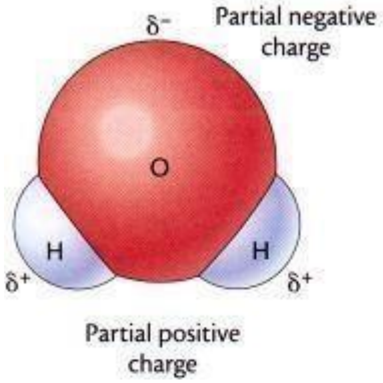
6.Crystal structure: Ionic solids do not exist as individual neutral independent molecules rather they exist as three dimensional solid aggregates which have definite geometric shape.

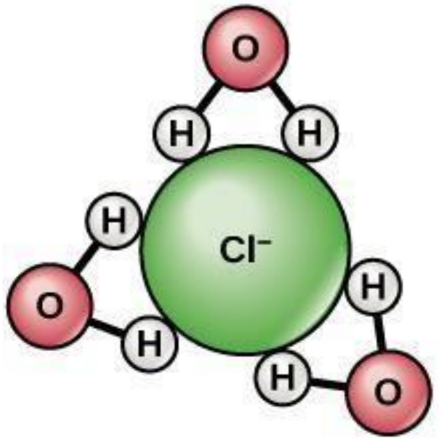
7.Highly brittle: Ionic solids are highly brittle, i.e. if a little external force is applied on ionic crystals, they are easily broken.

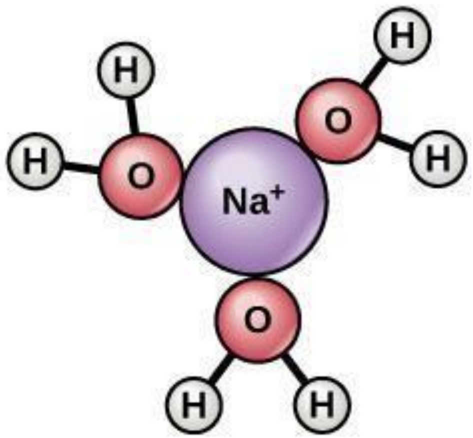
8.High density: The electrostatic force of attraction existing between the cation and anion in an ionic crystal bring these ions very close to each other. This decreases the volume of crystal and as a consequence this ionic crystal has high density.

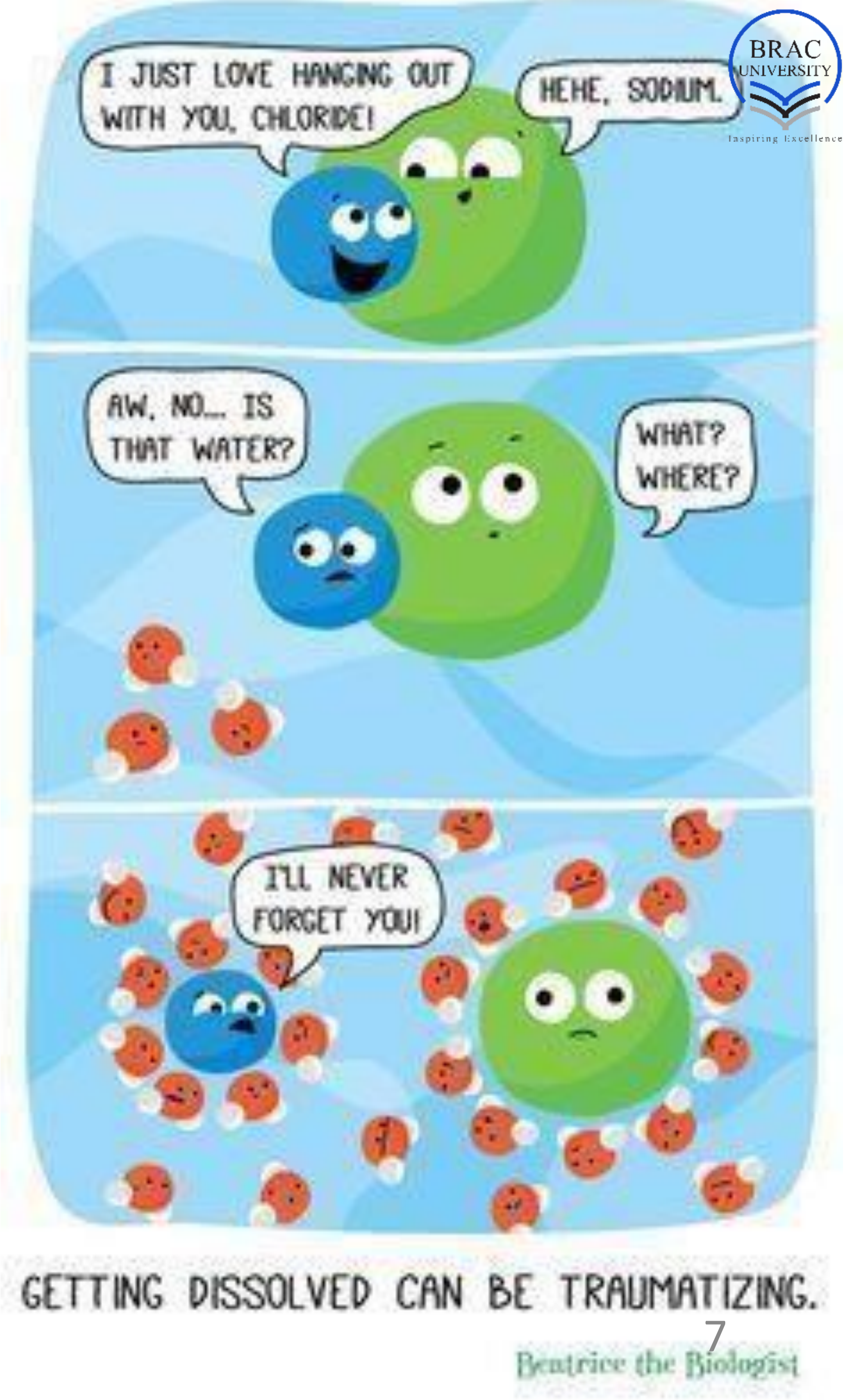
Why ionic compounds are soluble in water?

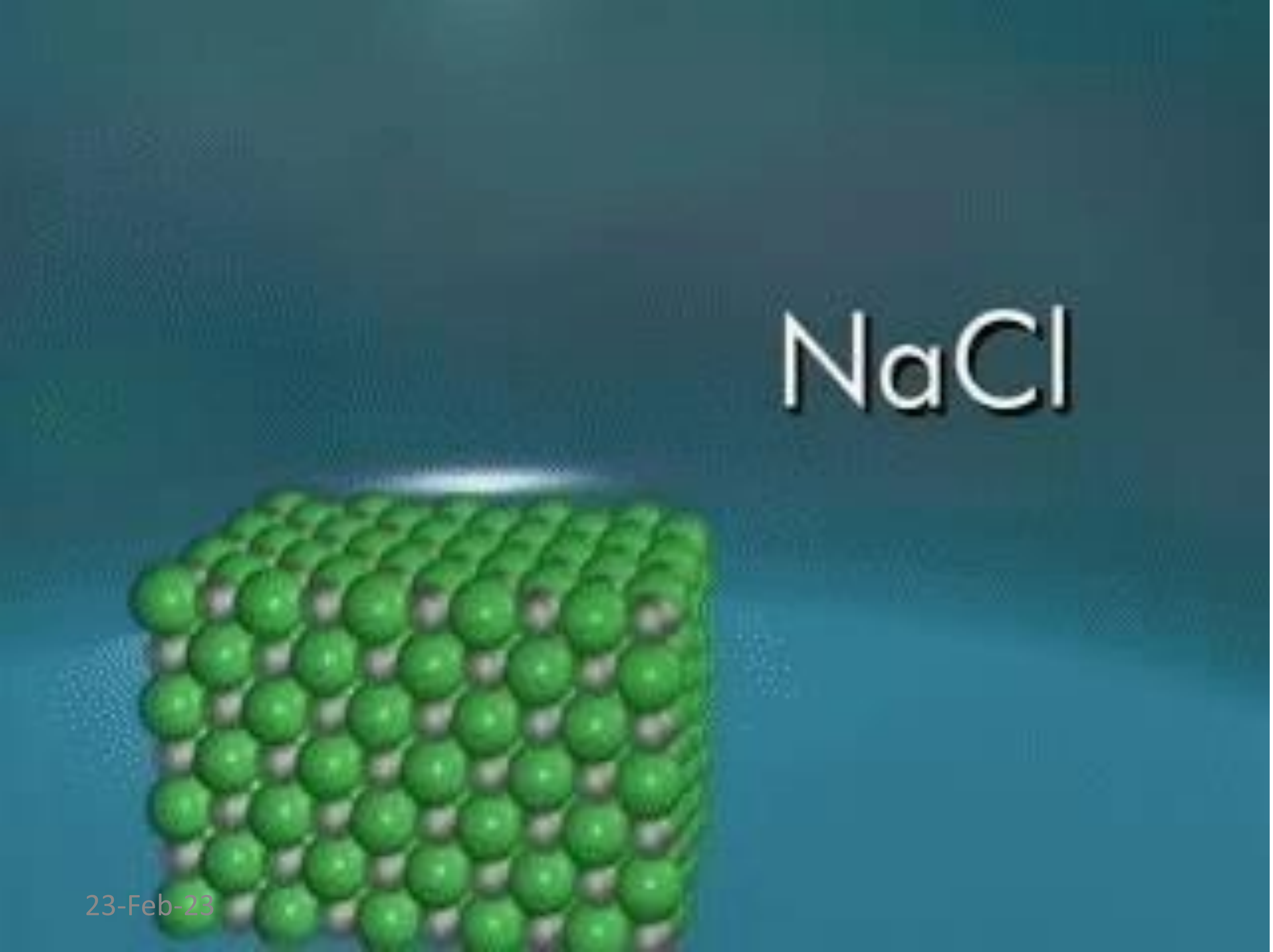
- The solubility of ionic solids in a polar solvent like water c a n be explained by saying that a **water molecule is a dipole** and hence the positive end of the dipole interacts with the negative ion of the ionic solids and the negative end of the dipole interacts with the positive ion of the same crystal.
- The interaction between the water dipole and the ions of the crystal **lowers down the energy of the system** and thus **the force of attraction between the cation and anions of the ionic solid is weakened**. Consequently the water molecules tear off the ions from the crystal lattice and make them float in the bulk of the water.





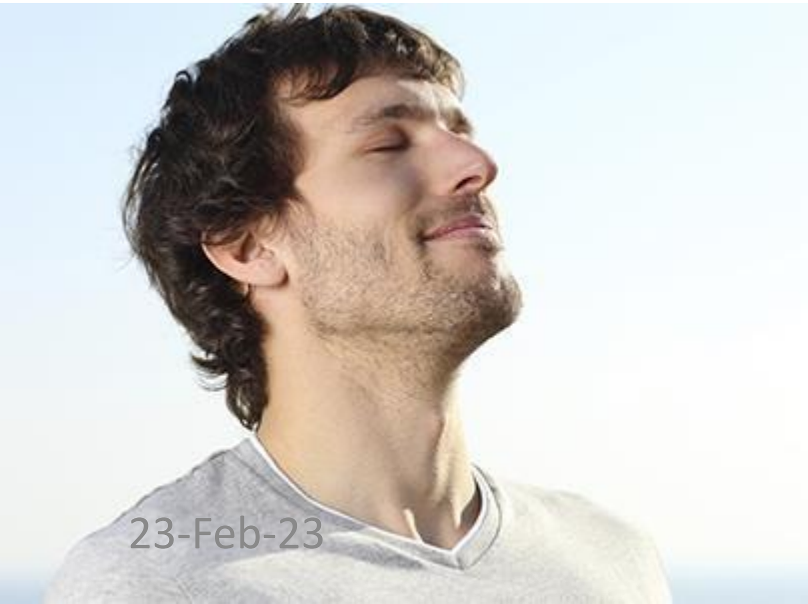


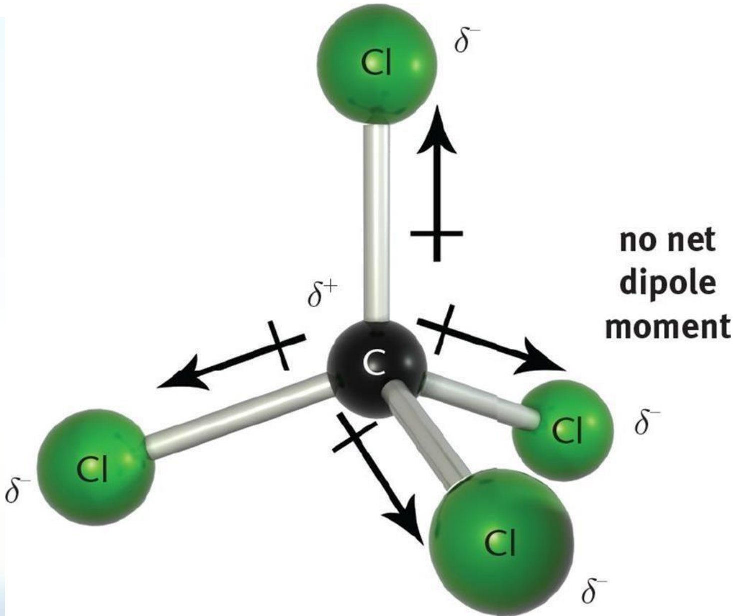




NaCl solubility

On the other hand ionic solids are insoluble or slightly soluble in nonpolar solvents (organic solvents) such as **C_6H_6, CCl_4** etc. Such solvents due to their low value of dielectric constant do not allow the ions to move freely and interact with them to form the solvated ions.





Factors favoring the formation of ionic bond

1) Number of Valence electron

The atom which is converted into **cation should posses 1, 2 or 3 valence electrons** while the atom which is co**nverted into anion should have 5, 6 or 7 valence electrons.**

The element of **group IA, IIA and IIIA satisfy** this condition for the cation and those of **group VA,VIA and VIIA satisfy this condition for anion.**

2) The ionization energy of the metal atom should be low.

3) Electron affinity of the nonmetal should be high.

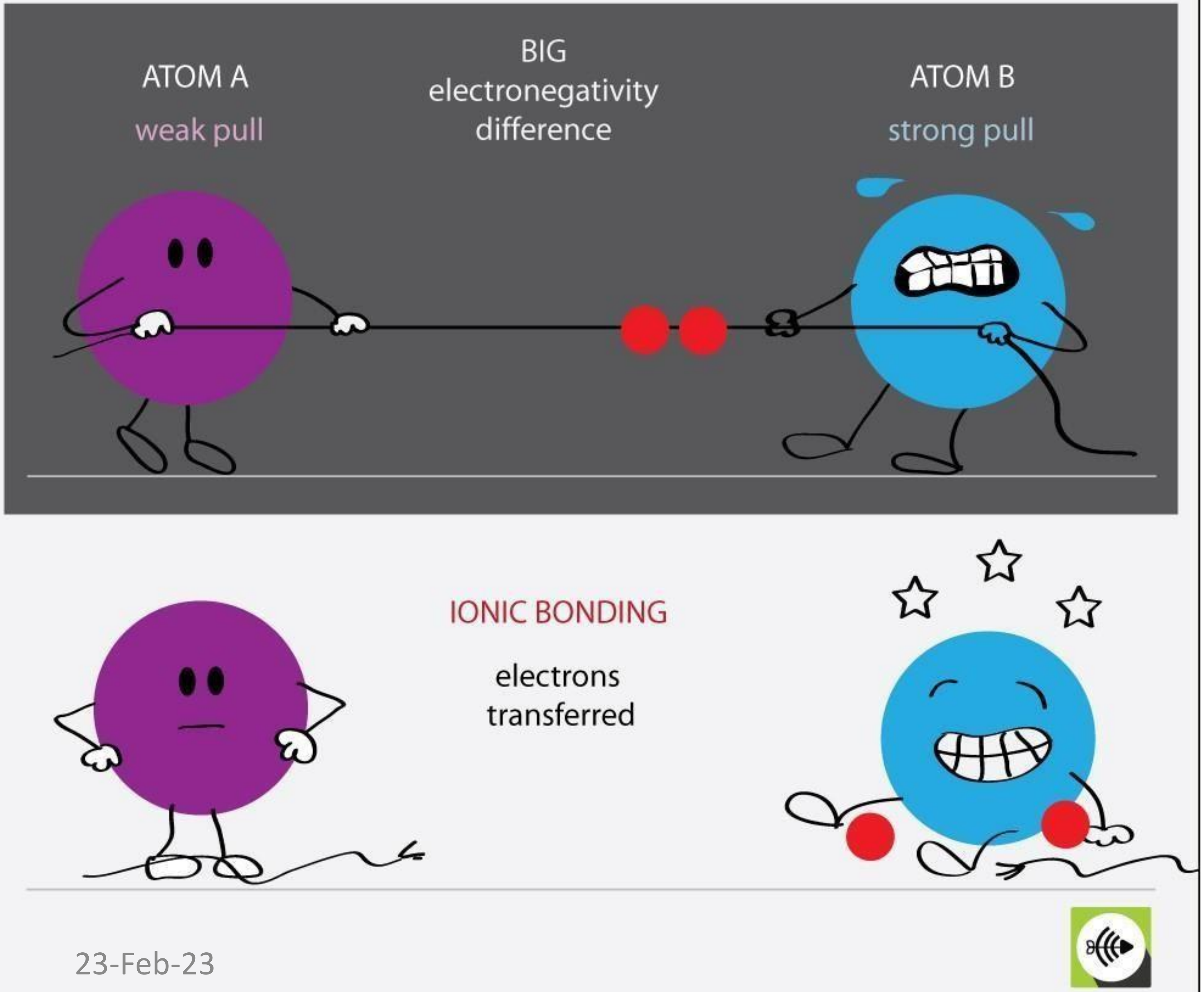
4) The lattice energy of the ionic compound formed should be high:

The energy released when one gram mole a crystal is formed from its gaseous ions is called the lattice energy of the crystal. Thus:

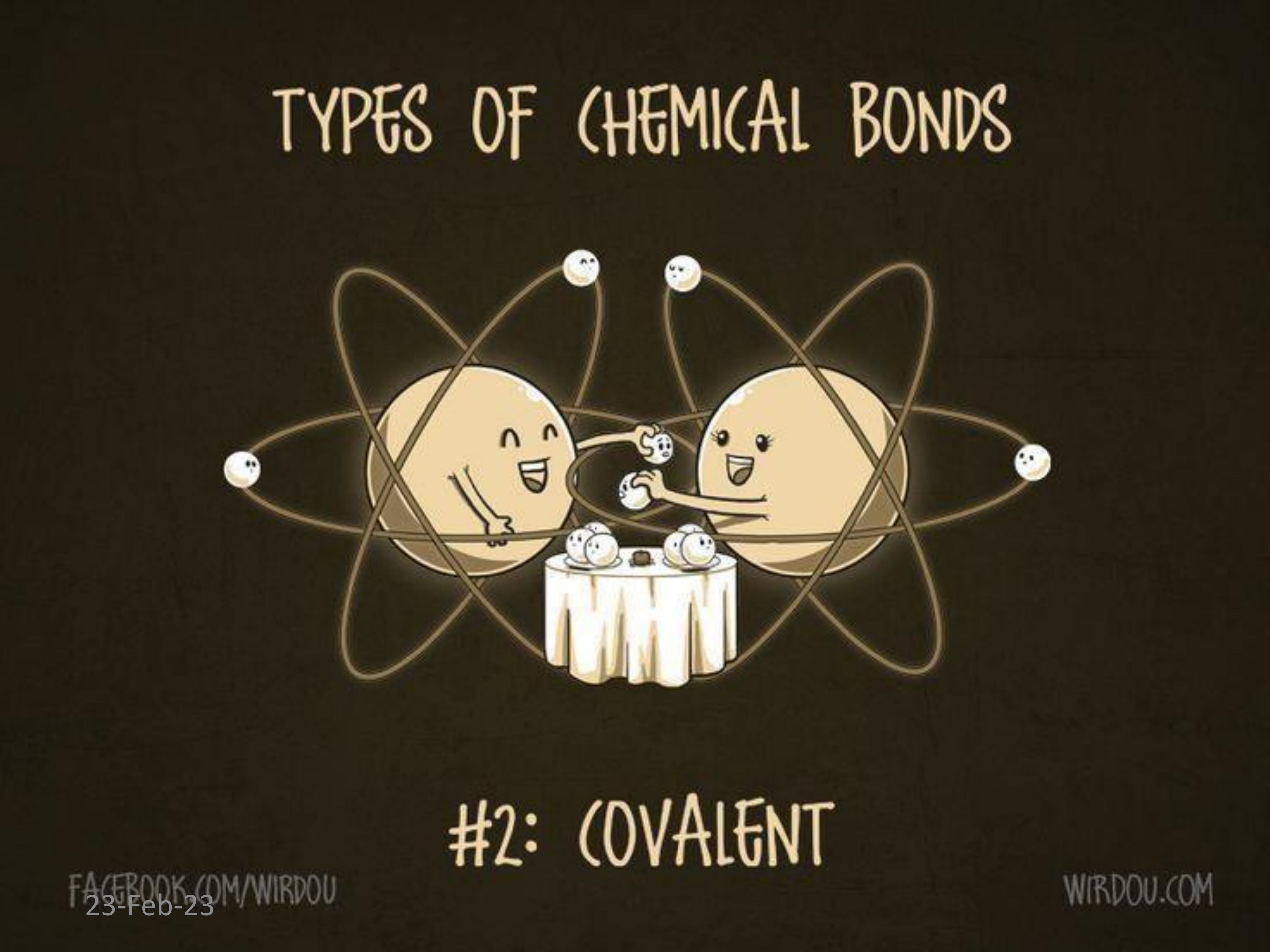
Higher the value of the lattice energy of a crystal, the greater is the ease of its formation i.e. greater will be the stability of the crystal.

5) Electronegativity difference of the two atoms forming the ionic bond should be high:

In fact a difference of 2 or more is essential for the formation of ionic bond. For example, since the electronegativity difference between Na and Cl is 2.1 (Na = 0.9, Cl= 3.0) Na and Cl will form an ionic bond in NaCl molecule.



Electronegativity is a measure of the tendency of an atom to **attract a bonding pair of electrons**. Fluorine (the most **electronegative** element) is assigned a value of 4.0, and values range down to caesium and francium which are the least **electronegative** at 0.7.



Covalent Bond

Covalent Bond

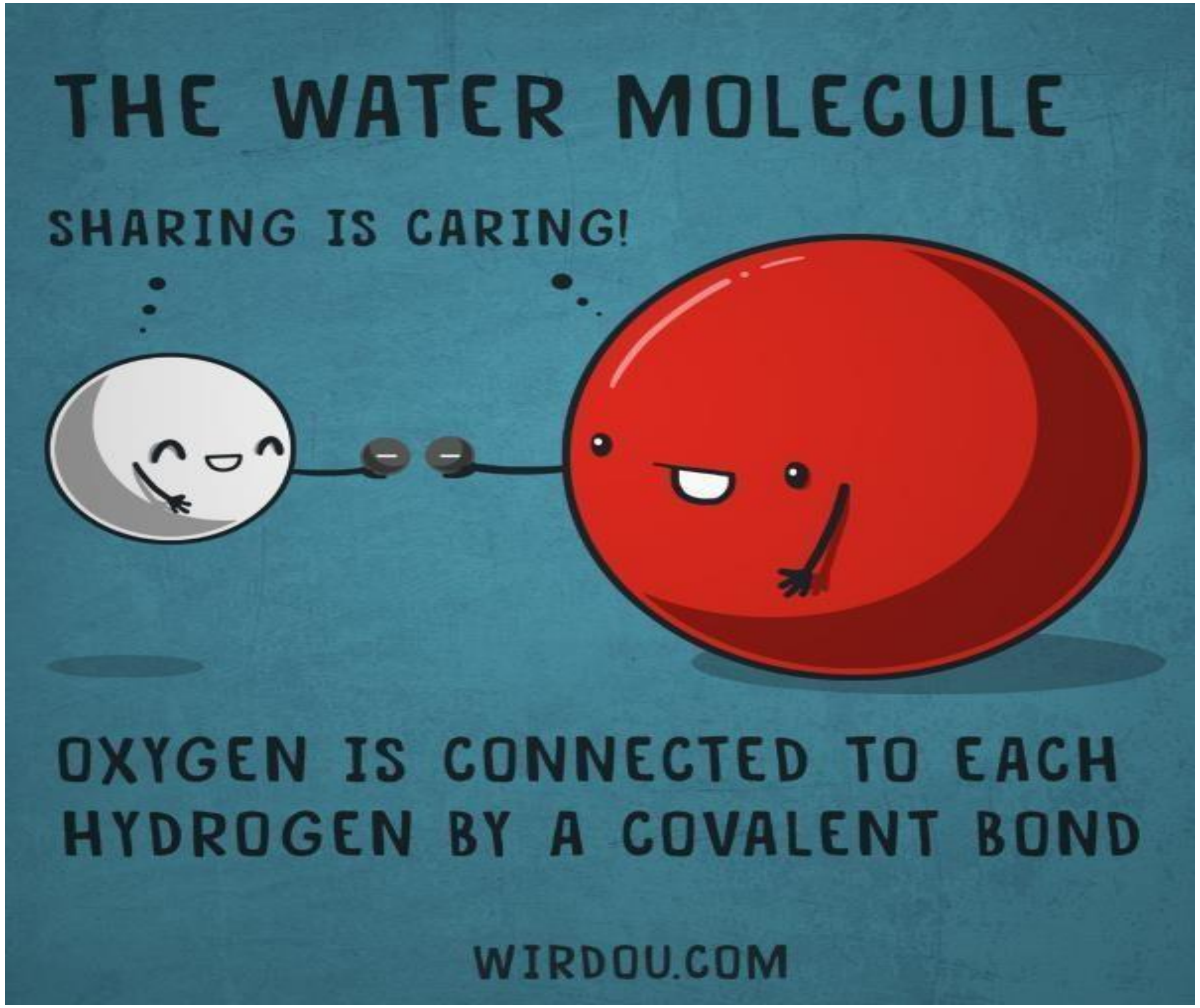
- **Definition:** Covalent bond (also called electron-pair bond) may be defined as the chemical bond or attractive force between atoms that results from **sharing of an electron-pair**. Each of the two bonding atoms **contributes one electron to the electron-pair** (and has equal claim on the shared electron-pair). The shared electron pair is indicated by **a dash (—) between the two bonded** atoms.
- **Two atoms may bind together by one, two or even three covalent bonds.**

$$H\text{-}H,\quad O{=}O,\quad N{\equiv}N.$$

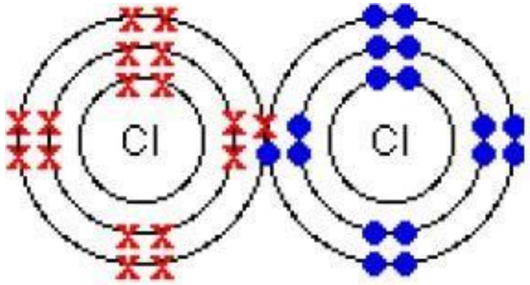
- The compounds containing a covalent bond are known as **covalent compounds.**

Conditions for Formation of Covalent Bond

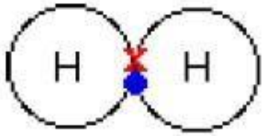
1) A covalent bond is formed between **two non-metals.**
2) The difference in electronegativity between the combining atoms of the two non-metals must be sufficiently low.
3) The shared **electrons must be unpaired and opposite spin**
5) The two combining atoms should have high ionization energy.
6) The two combining atoms should have **high electron affinity.**



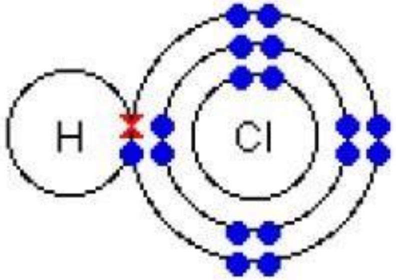
Covalent Bond



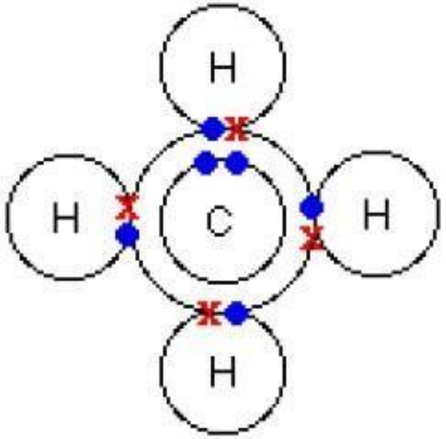
Chlorine



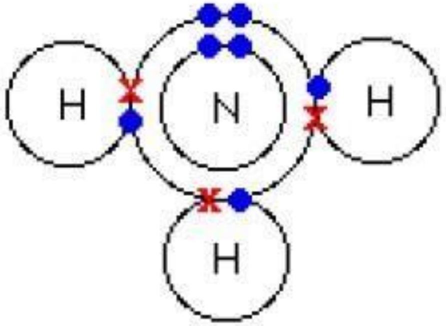
Hydrogen



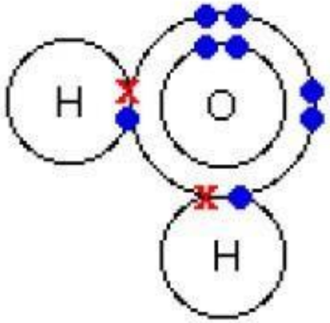
Hydrogen chloride



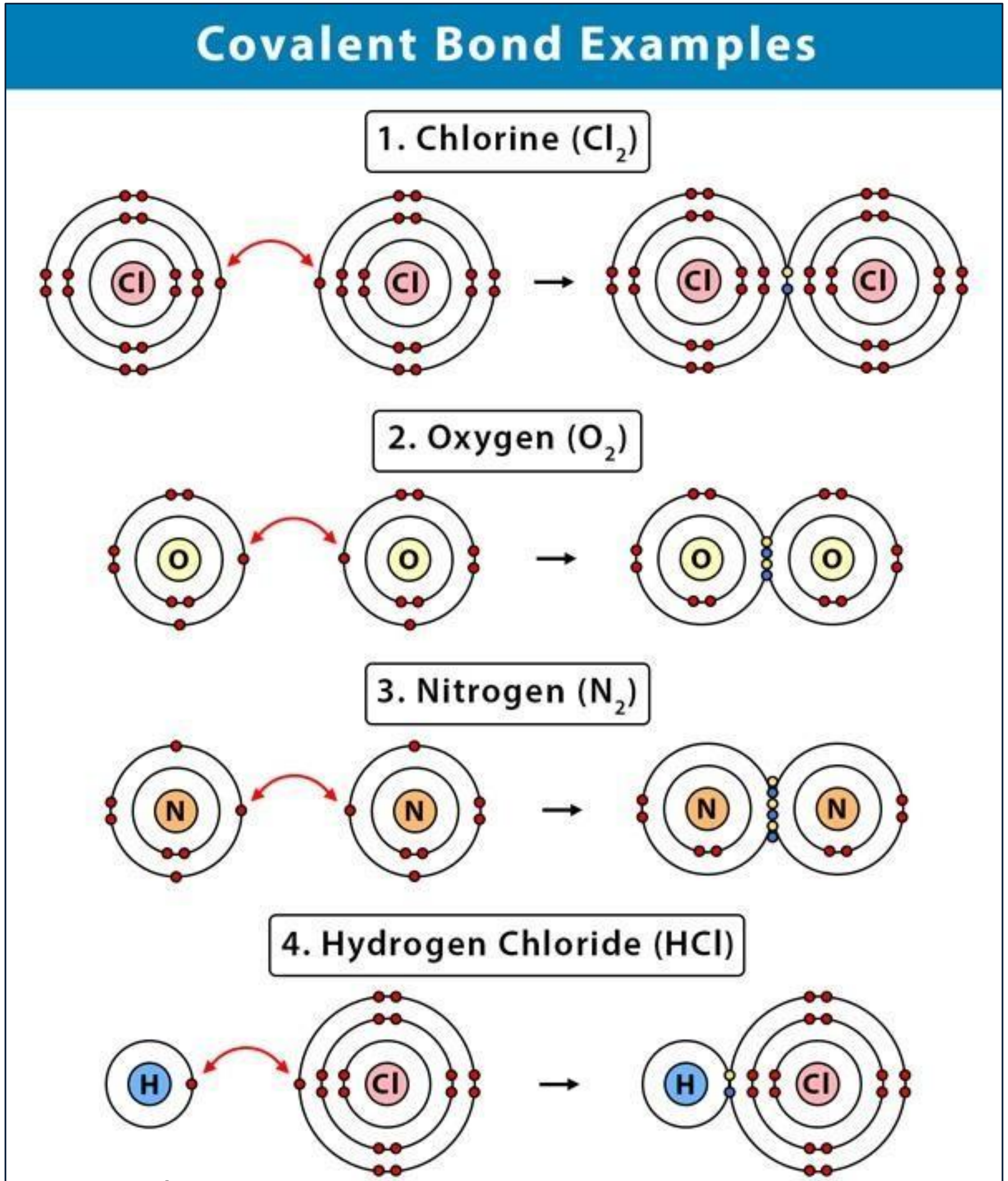
methane



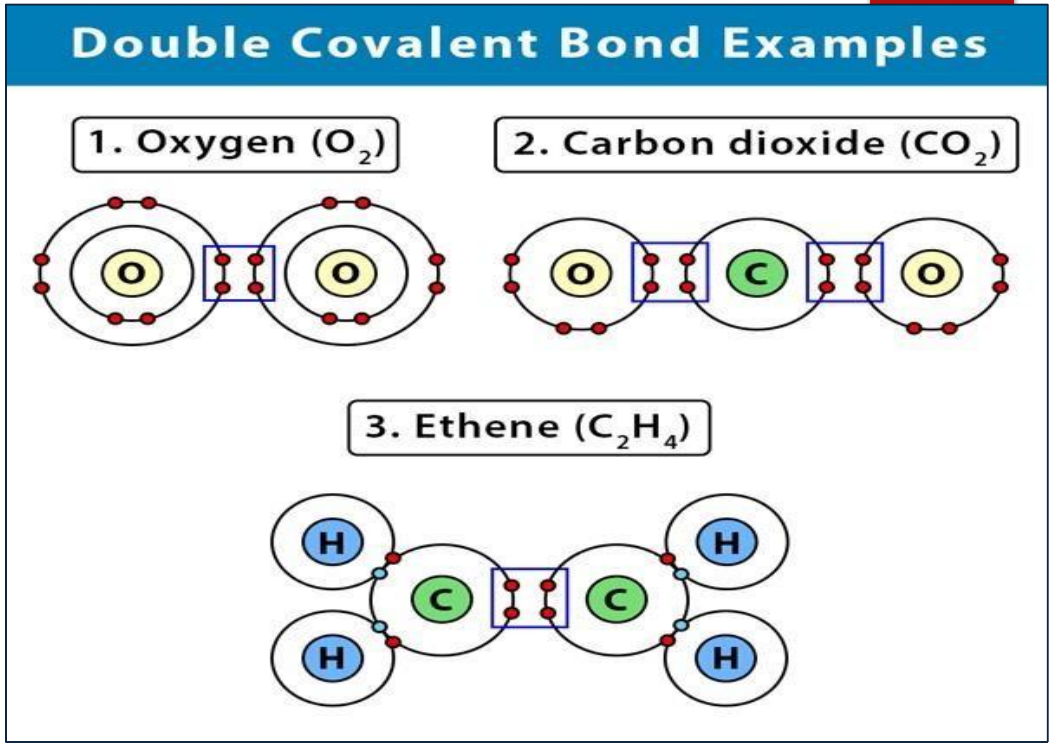
ammonia



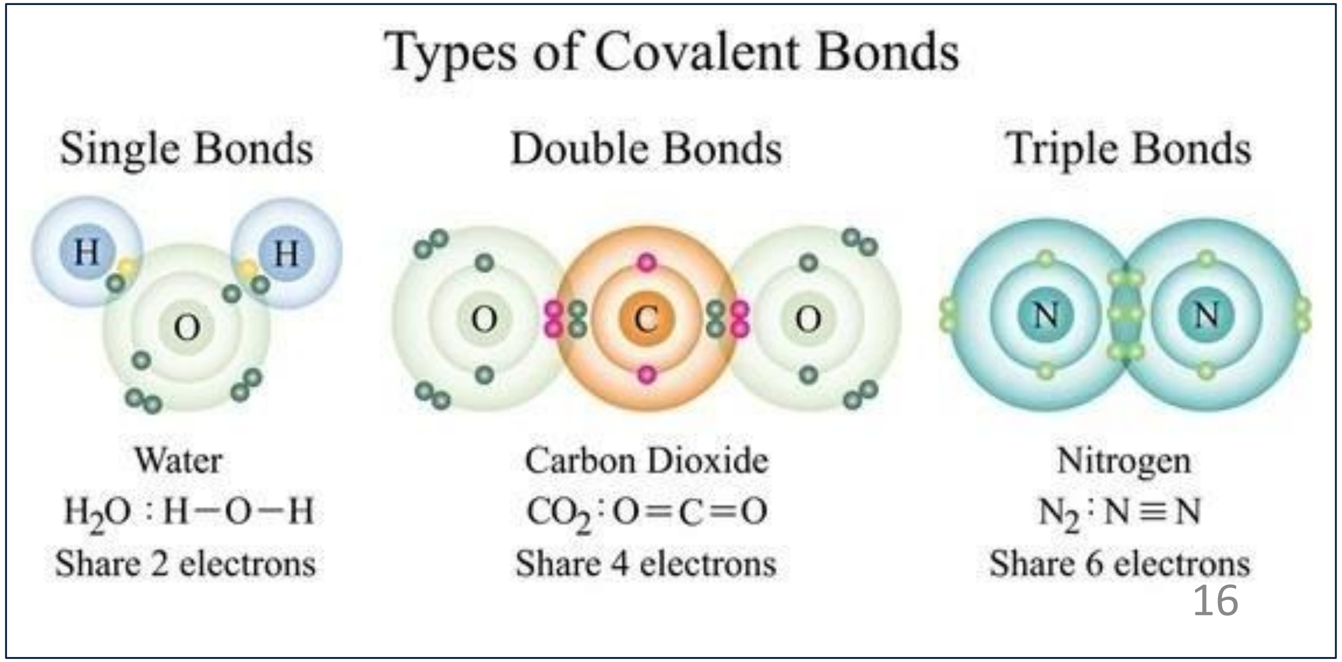
water



Covalent Bond Examples
1. Chlorine (Cl_2)
Cl
2. Oxygen (O_2)
O
3. Nitrogen (N_2)
N
4. Hydrogen Chloride (HCl)
H
Cl

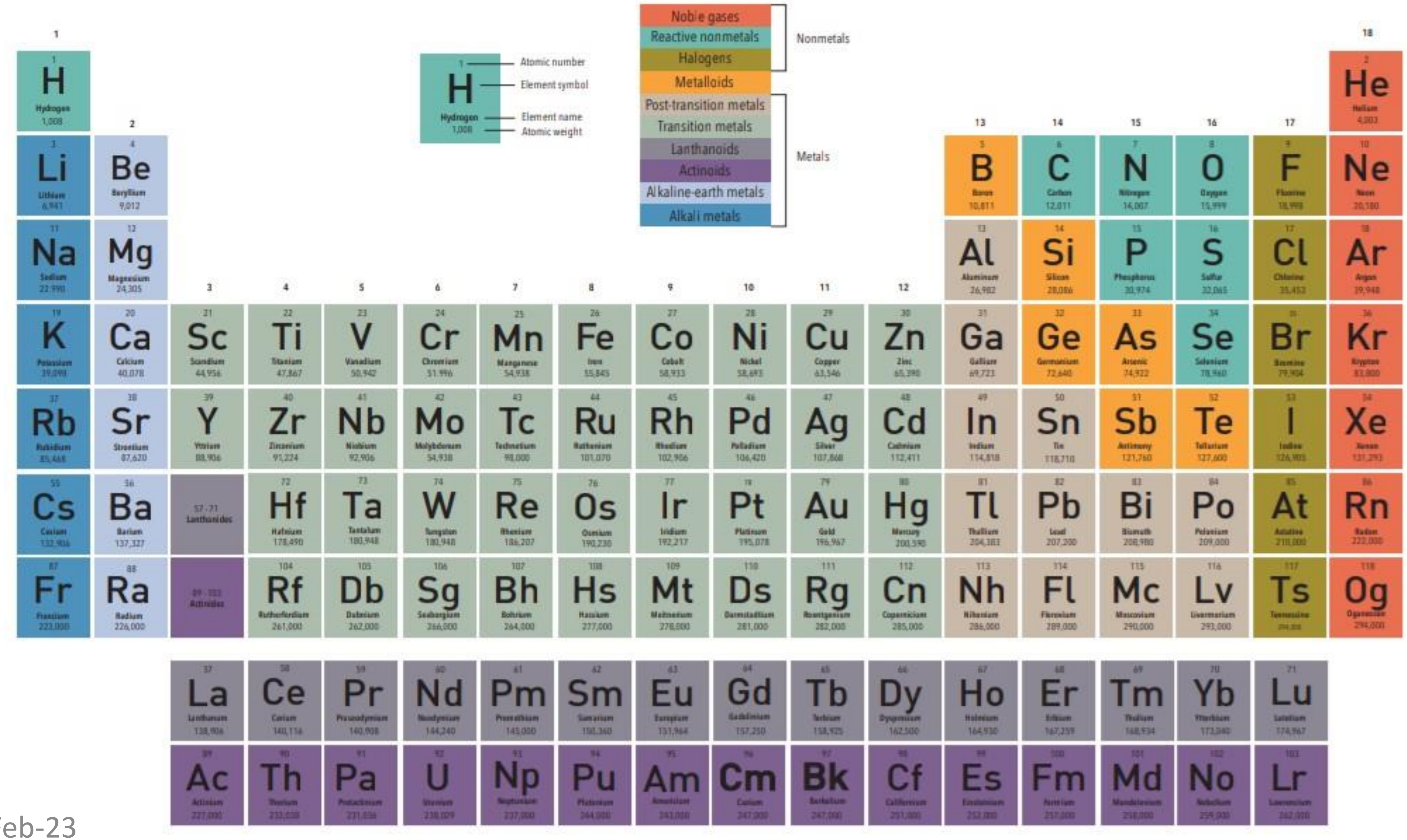


Double Covalent Bond Examples
1. Oxygen (O_2)
2. Carbon dioxide (CO_2)
O
C
3. Ethene (C_2H_4)
H
C



Types of Covalent Bonds
Single Bonds
Double Bonds
Triple Bonds
H
O
C
N
Water
H_2O : H−O−H
Share 2 electrons
Carbon Dioxide
CO_2 : O=C=O
Share 4 electrons
Nitrogen
N_2 : N≡N
Share 6 electrons

PERIODIC TABLE OF THE ELEMENTS



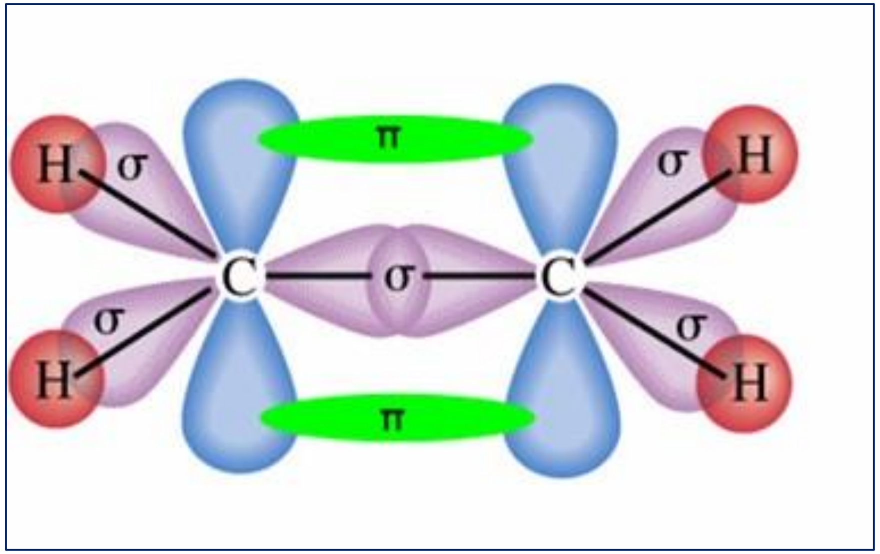
H 2.1																	He ---
Li 1.0	Be 1.5											B 2.0	C 2.5	N 3.0	O 3.5	F 4.0	Ne ---
Na 0.9	Mg 1.2											Al 1.5	Si 1.8	P 2.2	S 2.5	Cl 3.0	Ar ---
K 0.8	Ca 1.0	Sc 1.3	Ti 1.5	V 1.6	Cr 1.6	Mn 1.5	Fe 1.8	Co 1.8	Ni 1.8	Cu 1.9	Zn 1.6	Ga 1.6	Ge 1.8	As 2.0	Se 2.4	Br 2.8	Kr 3.0
Rb 0.8	Sr 1.0	Y 1.2	Zr 1.4	Nb 1.6	Mo 1.8	Tc 1.9	Ru 2.2	Rh 2.2	Pd 2.2	Ag 1.9	Cd 1.7	In 1.7	Sn 1.8	Sb 1.9	Te 2.1	I 2.5	Xe 2.6
Cs 0.7	Ba 0.9	La-Lu 1.1-1.2	Hf 1.3	Ta 1.5	W 1.7	Re 1.9	Os 2.2	Ir 2.2	Pt 2.2	Au 2.4	Hg 1.9	Tl 1.8	Pb 1.8	Bi 1.9	Po 2.0	At 2.2	Rn ---
Fr 0.7	Ra 0.9	Ac-No 1.1-1.7															

General Properties of Covalent Compounds

- **Usually gases, liquids or relatively soft solids** at room temperature.
- **Low melting points or boiling points**.
- Neither hard nor brittle.
- Usually **soluble in nonpolar organic solvents (e.g. benzene, ether) and insoluble in water.**
- **Non-conductor of electricity.**
- **Exhibit isomerism**.
- **Molecular reactions are slow**

Types of Covalent Bonds

In terms of the molecular orbitals formed, there are **two main types** of covalent bonds: Sigma (σ) bonds and pi (π) bonds.

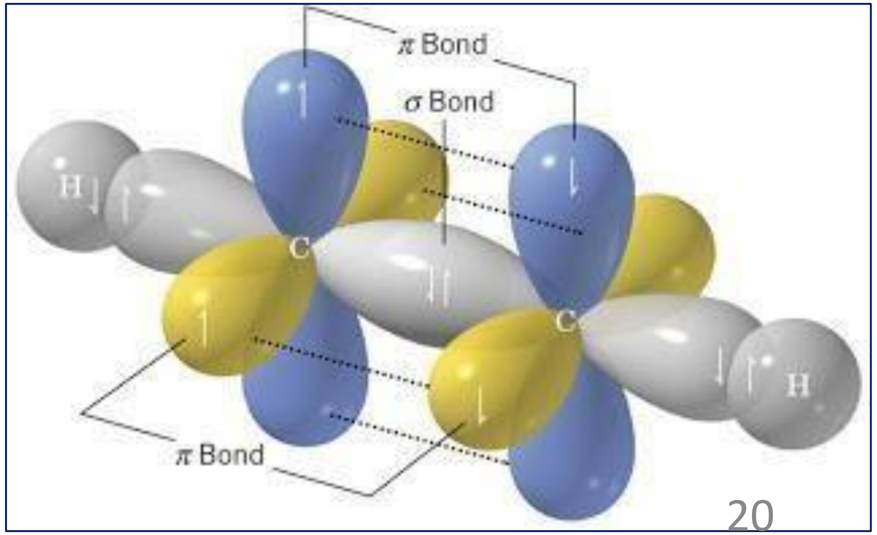


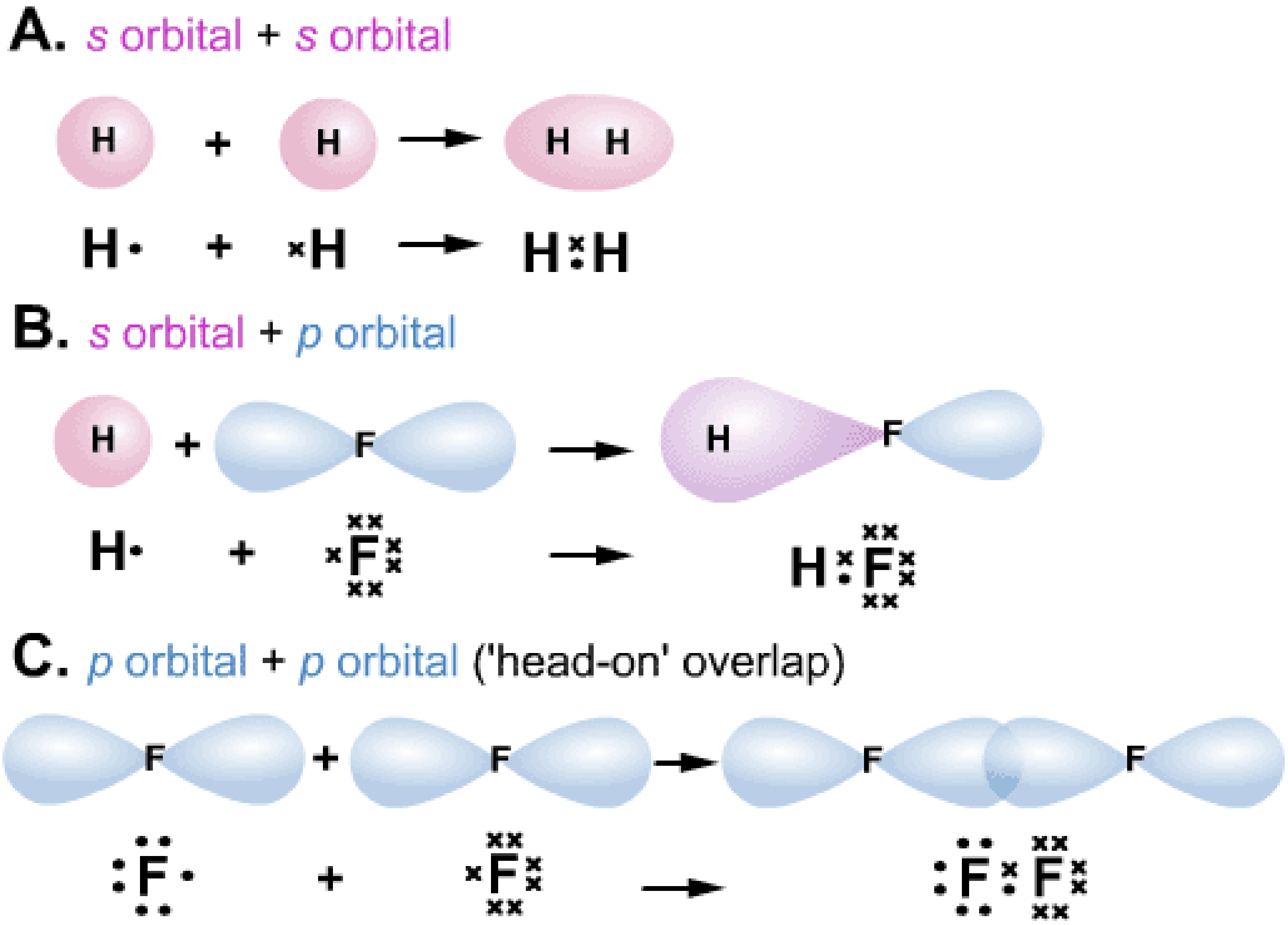
Sigma (σ) bond

- A sigma bond is formed by **linear (end-to-end) overlap of orbitals.**
- **All single covalent bonds are sigma bonds.**
- Formation of Sigma bond is possible in ***s,p,d & hybrid*** **orbitals**

Pi (π) bond

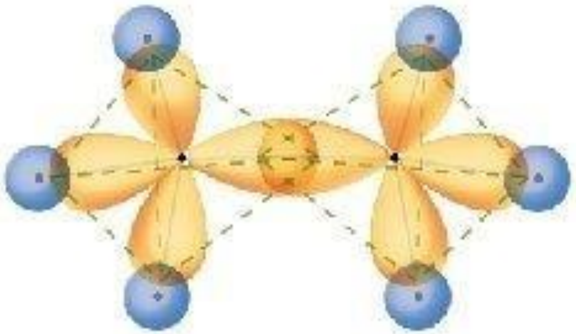
- A pi bond is formed by parallel **(side-by-side) overlap of *p* orbitals**. A pi bond has two lobes like ***p*** orbitals one half of the bond lies above the plane containing the two nuclei and the other half lies below the plane.
- **One bond in double bonds and two bonds in triple bonds are pi bonds.**
- **Mostly Possible in p & Sometimes in d orbitals**

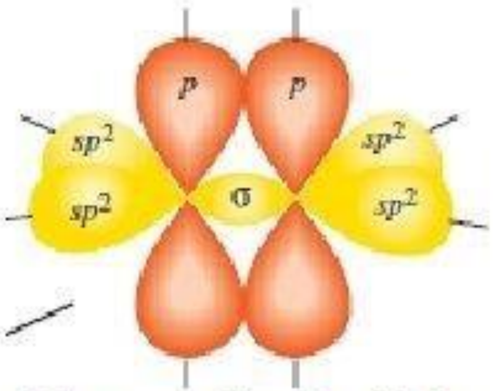



A. s orbital + s orbital
H
H
H H
B. s orbital + p orbital
H
F
H
F
C. p orbital + p orbital ('head-on' overlap)
F
F
F
F

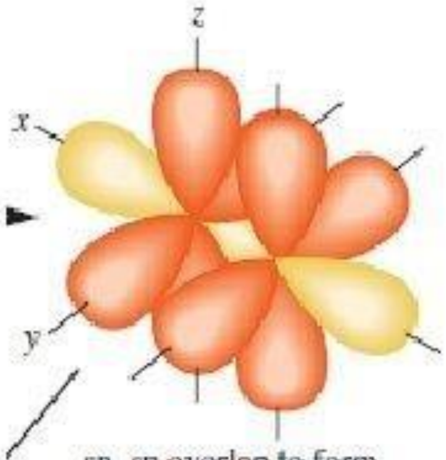
Single vs Double vs Triple Bonds

sp^3 – hybridization	sp^2 – hybridization	sp – hybridization
C—C	C=C	C≡C
147 pm	134 pm	120 pm
347 kJ/mol	614 kJ/mol	839 kJ/mol





Sideways overlap of *p* orbitals to form a pi bond



sp–*sp* overlap to form C—C sigma bond

Sigma (σ) Bond	Pi (π) Bond
(a) It is formed by the end to end overlap of orbitals.	It is formed by the lateral overlap of orbitals.
(b) The orbitals involved in the overlapping are *s–s*, *s–p*, or *p–p*.	These bonds are formed by the overlap of *p–p* orbitals only.
(c) It is a strong bond.	It is weak bond.
(d) The electron cloud is symmetrical about the line joining the two nuclei.	The electron cloud is not symmetrical.
(e) It consists of one electron cloud, which is symmetrical about the internuclear axis.	There are two electron clouds lying above and below the plane of the atomic nuclei.
(f) Free rotation about σ bonds is possible.	Rotation is restricted in case of pi-bonds.

Co-ordination bond

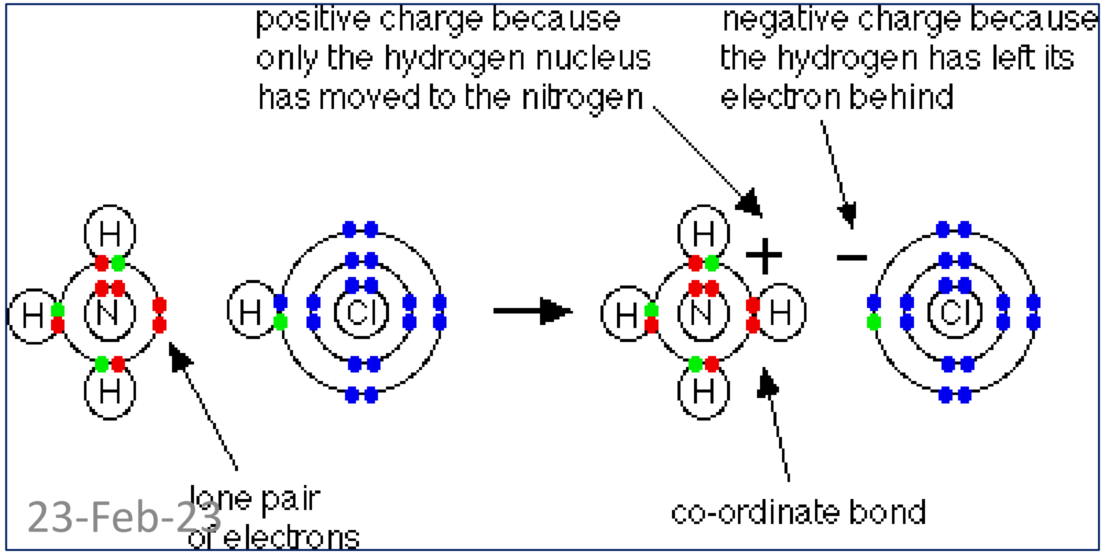
If the **ion-pair forming the bond is donated by one of the two combining atoms-** it is known as Co-ordinate covalent bond or simply the co-ordination bond.

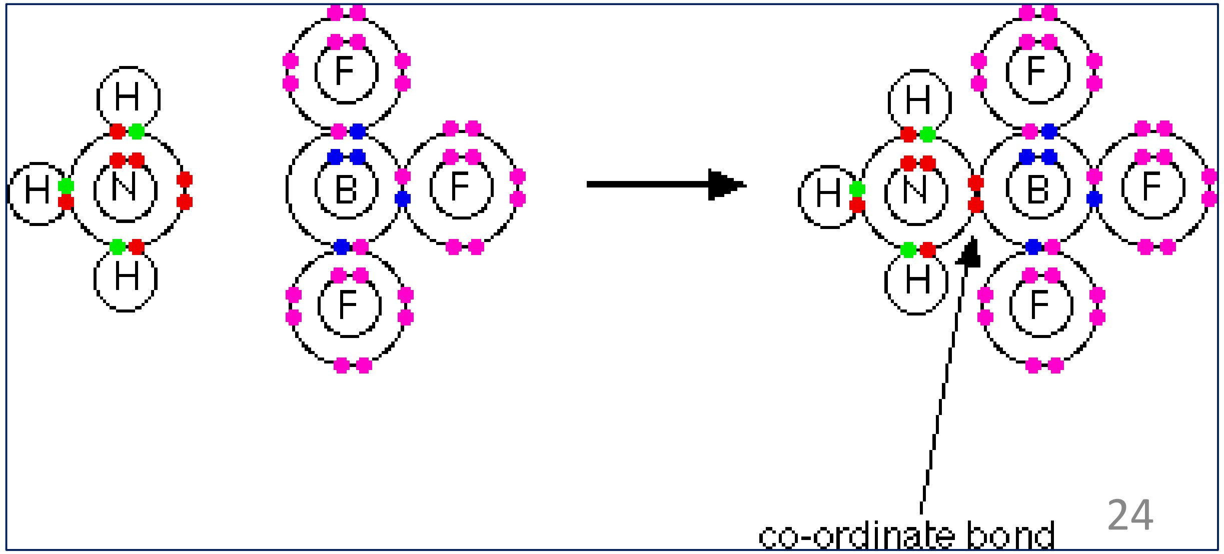
In the formation of a simple covalent bond, each **atom supplies one electron to the bond - but that doesn't have to be the case.** A co-ordinate bond is a covalent bond in which both electrons come from the same atom.

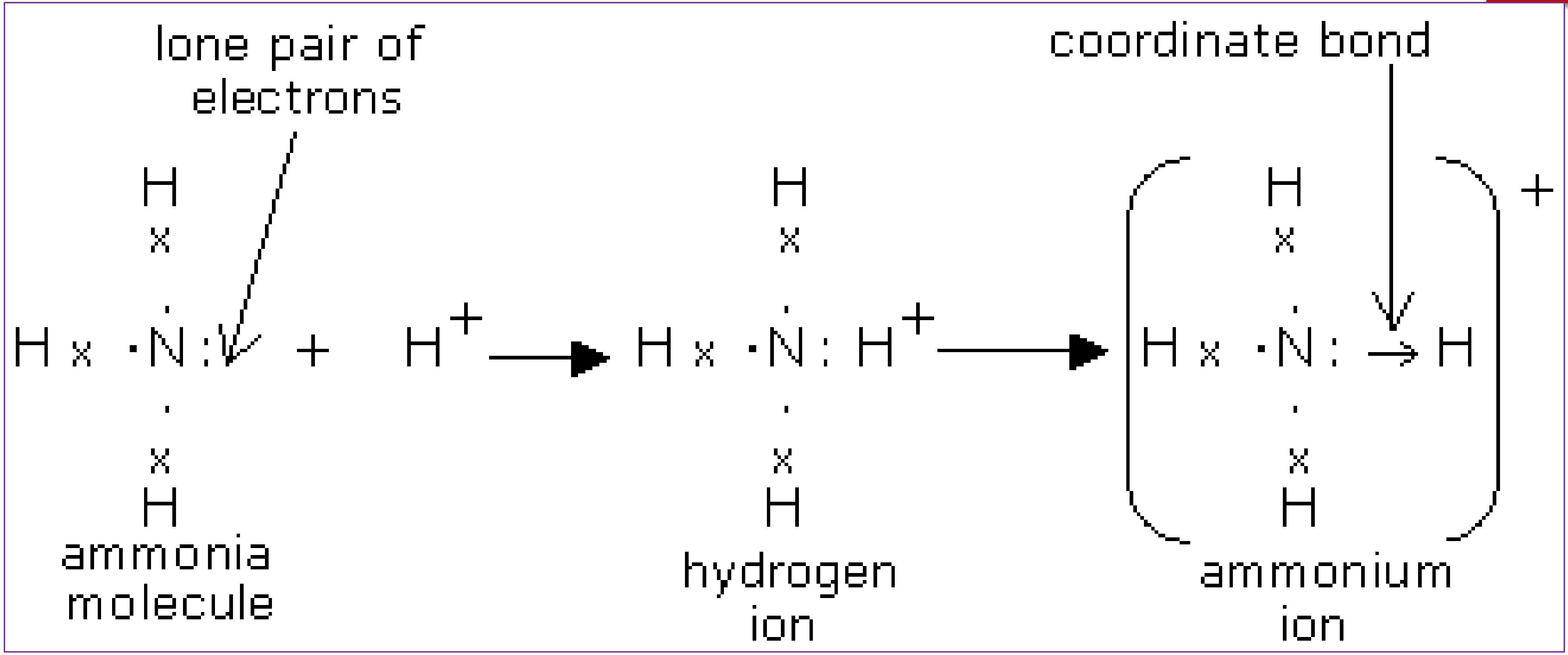
Examples: H_2O (donor) + H^+ (acceptor) → H_3O^+

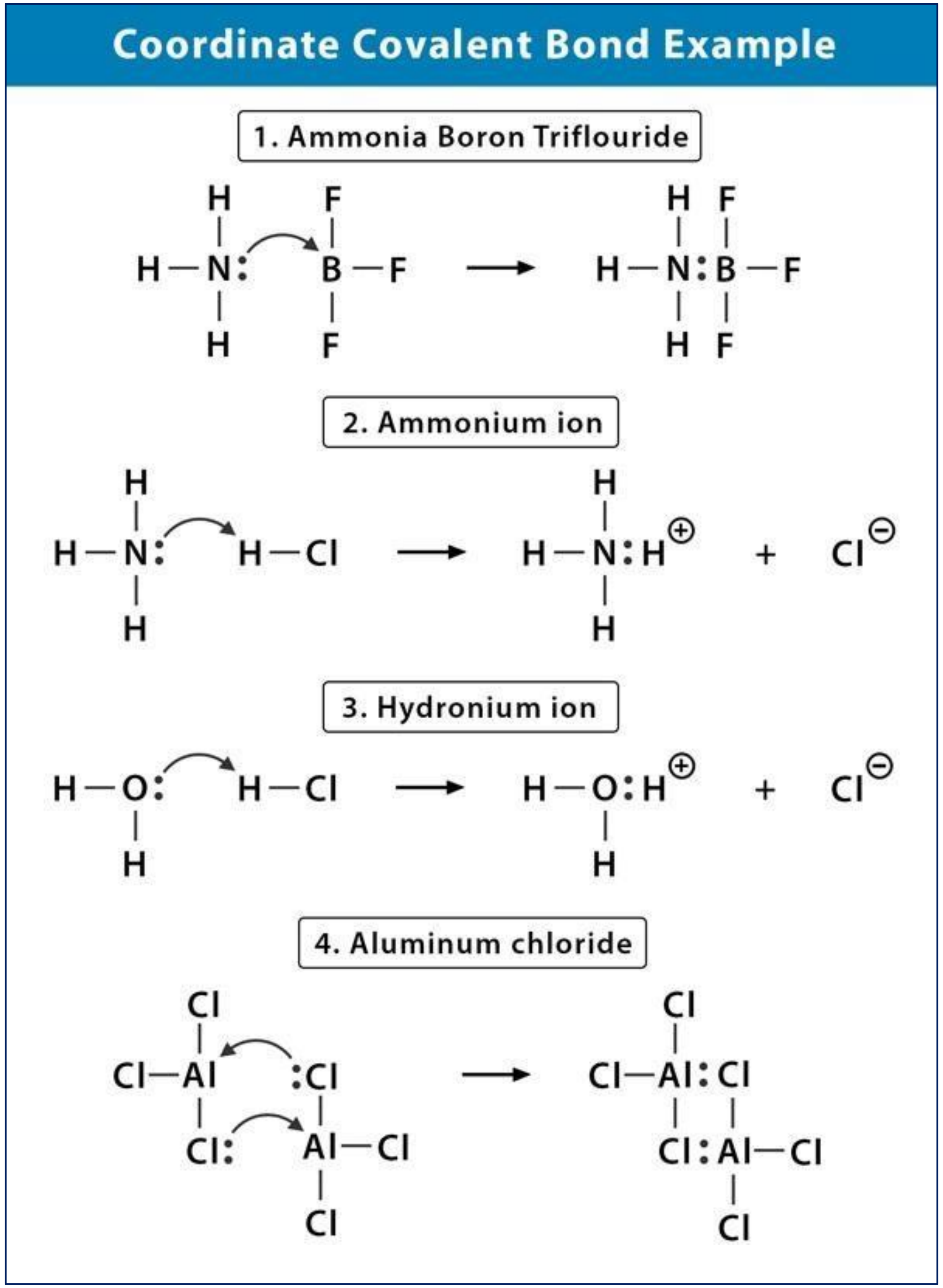
NH_3 (donor) + H^+ (acceptor) → NH_4^+

The compounds containing a coordinate bond are called **coordinate compounds** and **the molecule or ion that contains the donor atom is called the ligand.**






lone pair of electrons
coordinate bond
H
H x ·N: + H+
H
ammonia molecule
hydrogen ion
ammonium ion


Coordinate Covalent Bond Example
1. Ammonia Boron Triflouride
2. Ammonium ion
3. Hydronium ion
4. Aluminum chloride

Properties of co-ordination bonds

- They are gases or liquids due to weak inter molecular forces.
- The melting & boiling points of co-ordinate compounds are higher than covalent compounds, but lower than ionic compounds.
- Co-ordinate compounds are soluble in non polar solvents like benzene and carbon tetrachloride.

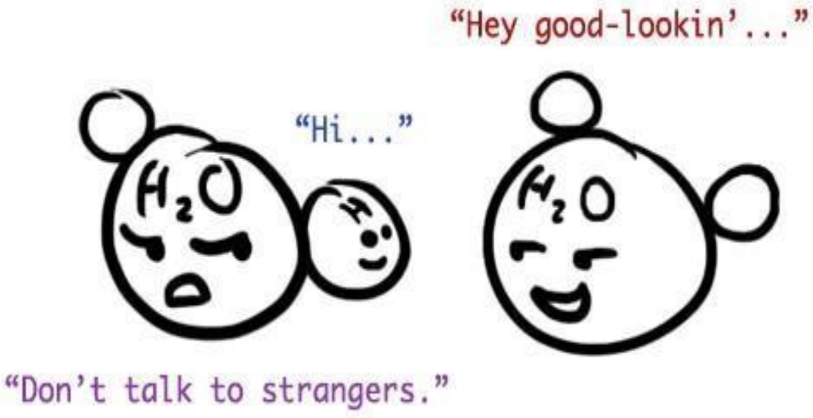
Difference between Covalent Bond and Coordinate Covalent Bond?

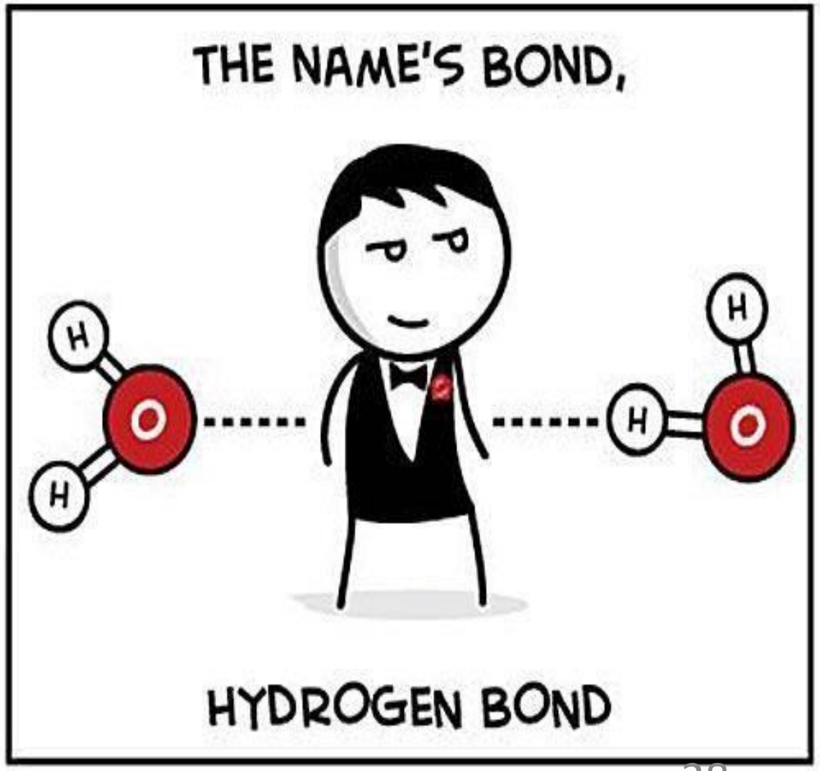
- In a **covalent bond, both atoms are contributing same number of electrons to the bond**, but **in a coordinate covalent bond, two electrons are donated by a single atom**.
- In a **covalent bond, the electronegativity difference between the two atoms can be zero or a very low value**, but in **coordinate covalent bond, type of a polar covalent bond is forming, which means the value of electronegativity will be high**.

H-Bond

A proton or a hydrogen nucleus has a high concentration of positive charge. **When a hydrogen atom is bonded to a highly electronegative atom, its positive charge will have an attraction for the neighboring electron pairs.** This kind of dipole-dipole attraction is called a hydrogen bond. Hydrogen bond is defined as follows:

In compounds where a hydrogen atom is covalently bonded to a **highly electronegative atom such as nitrogen, oxygen or fluorine the strong attractive** force between hydrogen atoms of one molecule for the electronegative atom of another molecule is called the hydrogen bond.

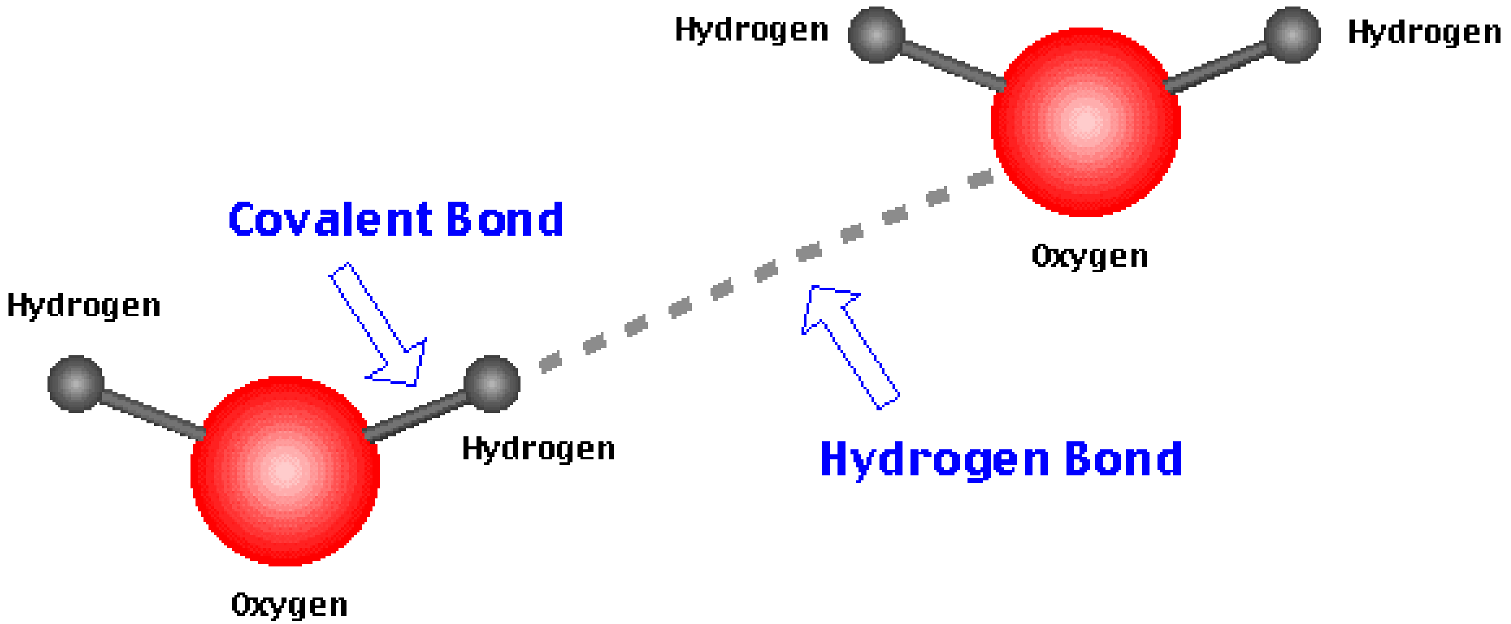




H-Bond

H-bond is of two types::
1. Intermolecular H-bond (e.g H_2O)
2. Intramolecular (e.g nitro phenol)

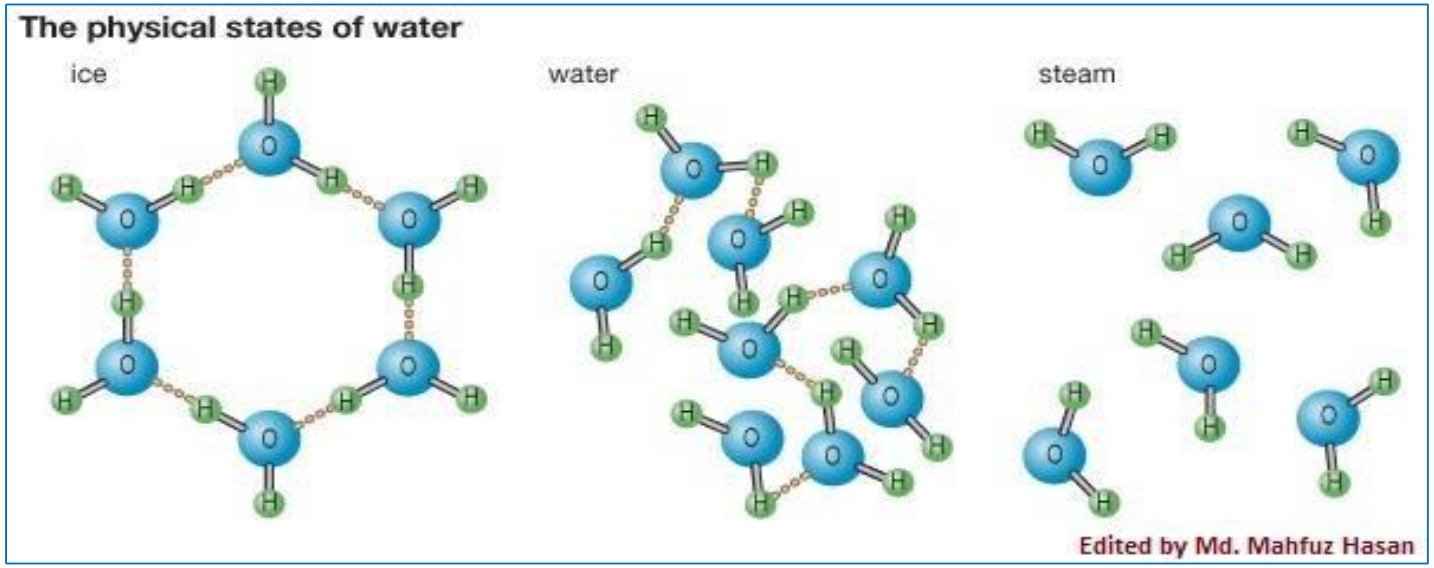
- A **common example of *H-bonding* is found in water.**
- It should be understood that in **hydrogen bond No transfer or sharing of electrons occur**



Why the density of ice is less than that of liquid water?

In the liquid state large number of **water molecules joined together by hydrogen bond**. When **water starts freezing the hydrogen bonds between the molecules get fixed and in the solid state**, as the molecules cannot move, the **hydrogen bonds between molecules get fixed in position**. In the solid state (ice) **each oxygen atom is surrounded tetrahedrally by four hydrogen atoms: two forming covalent bonds with the *O* atom and are close to it to form *H2O* molecule and two from other *H2O* molecules farther away from it forming two hydrogen bonds.** The result is a **three-dimensional structure with empty space.**

This is why ice is less dense than water: When **ice melts and liquid is formed again hydrogen bonds are constantly breaking and forming so that molecules can get close to each other giving rise to the liquid.** This is a unique property of water and is very important to life on earth. Normally the volume increases by 9% for ice than water, hence the ice becomes less denser.From liquid to solid water molecules arrange in a crystalline lattice that is orderly and entails more empty space than in the liquid form.

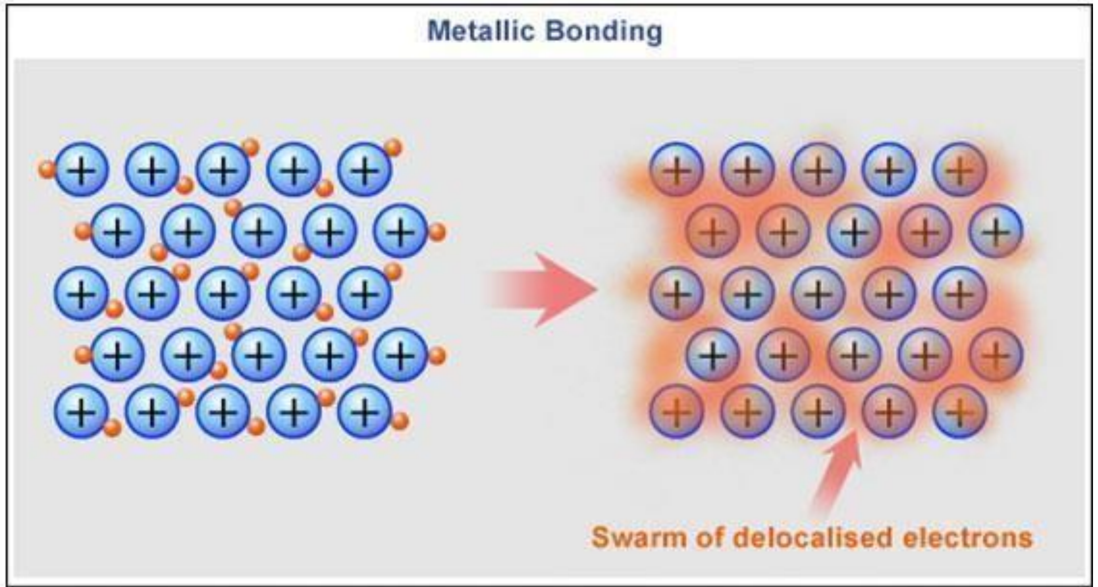


Metallic Bond

Bond found in metals; holds metal atoms together very strongly as a result of the attraction between the positive metal cations and surrounding freely mobile negatively electrons.
Examples: Na, Al, Fe, Cu etc.

Physical properties of metal

1. Metals are good conductors of electricity.
2. Metals are good conductors of heat.
3. Metals are opaque and have lusture or colour.
4. Metals are malleable or plastic and ductile.
5. Metals do not combine with metals. They form Alloys which is a solution of a metal in a metal. Examples are steel, brass, bronze and pewter.
6. Metals have elasticity.
7. They possess high tensile strength.
8. They are solid and have high density.
9. Melting and boiling points are higher than covalent compounds.
10. Metals emit electrons.



The outer electrons are so weakly bound to metal atoms that they are free to roam across the entire metal. Having 'lost' their outer electrons, individual metal atoms are more like positive ions in a swarm of communal electrons.

Three Types of Chemical Bonds are Important in Biology

Type of Bond	Characteristics	Biological Importance
Covalent	Bonding electrons shared between 2 atoms.	This type of bond holds together the long chains of macromolecules.
Ionic	Complete transfer of electron from one atom to another. Oppositely charged atoms attract one another.	Compounds with ionic bonds split into ions in water. Ions conduct electricity. Gives specialized cells (nerve, muscle) excitable properties.
Hydrogen	Weaker than covalent or ionic bonds. Formed between a hydrogen covalently bonded to O or N and a second O or N. The second O or N may be on the same molecule or on another nearby molecule.	**Water:** makes water molecules stick together. Responsible for many of the strange properties of water. **Proteins:** cause protein chains to spiral and bend, giving unique shapes. **DNA:** hold together the 2 chains to form the double helix. Allow chains to "unzip" for replication and transcription.

Thank you All