2 The particulate nature of matter

Content

2.1 Kinetic particle theory
2.2 Atomic structure
2.3 Structure and properties of materials
2.4 Ionic bonding
2.5 Covalent bonding
2.6 Metallic bonding

Learning outcomes

Candidates should be able to:

2.1 Kinetic particle theory

- *(a)* describe the solid, liquid and gaseous states of matter and explain their interconversion in terms of the kinetic particle theory and of the energy changes involved
- *(b)* describe and explain evidence for the movement of particles in liquids and gases (the treatment of Brownian motion is not required)
- *(c)* explain everyday effects of diffusion in terms of particles, e.g. the spread of perfumes and cooking aromas; tea and coffee grains in water
- *(d)* state qualitatively the effect of molecular mass on the rate of diffusion and explain the dependence of rate of diffusion on temperature
- *(e)* state qualitatively and explain the effects of temperature and pressure on the volumes of gases

2.2 Atomic structure

- *(a)* state the relative charges and approximate relative masses of a proton, a neutron and an electron
- *(b)* describe, with the aid of diagrams, the structure of an atom as containing protons and neutrons (nucleons) in the nucleus and electrons arranged in shells (energy levels) (no knowledge of s, p, d and f classification will be expected; a copy of the Periodic Table will be available in Papers 1 and 2)
- *(c)* define proton number and nucleon number
- *(d)* interpret and use symbols such as $^{12}_{6}C$
- *(e)* define the term *isotopes*
- *(f)* deduce the numbers of protons, neutrons and electrons in atoms and ions from proton and nucleon numbers

2.3 Structure and properties of materials

- *(a)* describe the differences between elements, compounds and mixtures
- *(b)* compare the structure of simple molecular substances, e.g. methane, iodine, with those of giant covalent substances, e.g. sand, diamond, graphite in order to deduce their properties
- *(c)* compare the bonding and structures of diamond and graphite in order to deduce properties such as electrical conductivity, lubricating or cutting action (candidates will not be required to draw the structures)
- *(d)* deduce the physical and chemical properties of substances from their structures and bonding and vice versa

2.4 Ionic bonding

(a) describe the formation of ions by electron loss/gain in order to obtain the electronic configuration of an inert gas

(b) describe the formation of ionic bonds between metals and non-metals, e.g. $NaCl$; $MgCl_2$

(c) state that ionic materials contain a giant lattice in which the ions are held by electrostatic attraction, e.g. $NaCl$ (candidates will not be required to draw diagrams of ionic lattices)

(d) relate the physical properties (including electrical property) of ionic compounds to their lattice structure

2.5 Covalent bonding

(a) describe the formation of a covalent bond by the sharing of a pair of electrons in order to gain the electronic configuration of an inert gas

(b) describe, using 'dot-and-cross' diagrams, the formation of covalent bonds between non-metallic elements, e.g. H_2; Cl_2; O_2; HCl; N_2; H_2O; CH_4; C_2H_4; CO_2

(c) deduce the arrangement of electrons in other covalent molecules

(d) relate the physical properties (including electrical properties) of covalent compounds to their structure and bonding

2.6 Metallic bonding

(a) describe metallic bonding as the electrostatic attraction between positive ions in a lattice and a 'sea of electrons'

(b) relate the malleability of metals to their structure and the electrical conductivity of metals to the mobility of the electrons in the structure

(1)

Particle nature of Matter

Kinetic particle theory

According to this theory all matter is made up of particles which are in a constant motion.

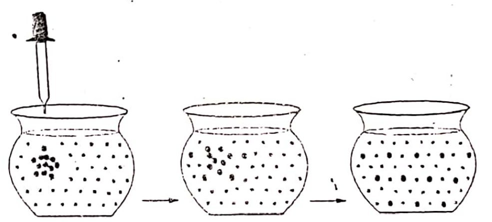
verification or evidence of particle nature of matter

Diffusion is the evidence of Kinetic particle theory, it can be defined as "mixing up of particles due to their motion".

Comparison of diffusion in Solid, liquid and gases

EXAMPLES:

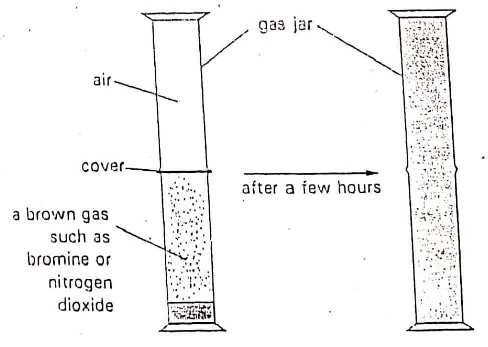
① When a crystal of potassium manganate(VII) is dropped into water, the purple colour will spread slowly throughout the liquid until a uniform purple colour is observed.



Diffusion of solid (potassium manganate(VII) crystals) in water

② When perfume is sprayed in one corner of a room, the particles spread until the scent is detected in all parts of the room. This is evidence of diffusion of a liquid.

③ When a few drops of bromine is put into a gas jar as in Figure 2.4, the bromine will vapourise to fill up the gas jar. A gas jar full of air is then placed on top of the gas jar full of bromine vapour and the jar lids are removed. The reddish brown vapour spreads throughout the two gas jars over a period of time, even though the bromine vapour is denser than air.



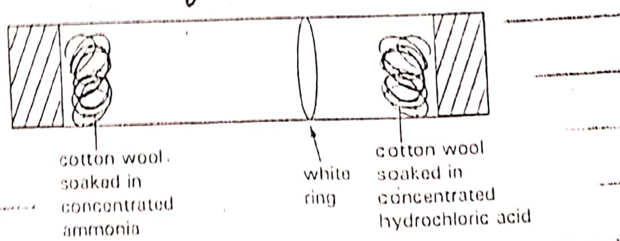
Diffusion of gas (bromine)

Factors affecting rate of diffusion

Rate of diffusion is affected by the temperature and Molecular mass of density of the substance.

Temperature:- Higher the temperature, greater will be the rate of diffusion due to the faster motion of particles.

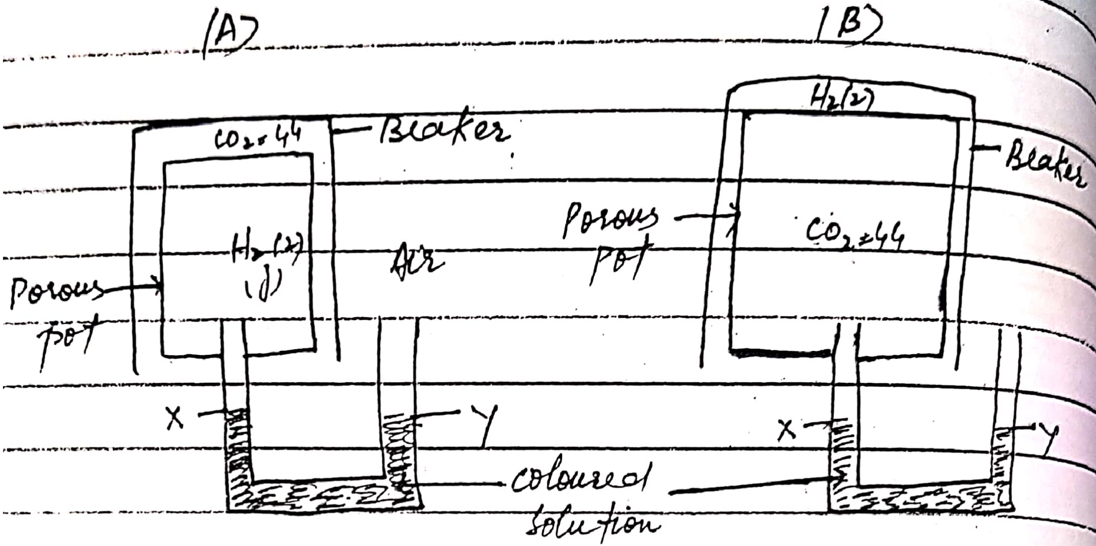
Molecular mass or Density:- Substances with lower Mr or lower density diffuse faster. This can be proved by the reaction HCl gas and ammonia gas



Reaction between hydrogen chloride gas and ammonia gas

After a few minutes a white ring of solid ammonium chloride appears inside the glass tube. This white ring is closer to the hydrogen chloride end rather than the ammonia end.
This is because HCl molecules have larger relative molecular mass as compared to ammonia molecules (17) so HCl molecules move slower than ammonia molecules and cover lesser distance.

Relative diffusion of gases



What will happen with the level of coloured solution at x in diagram A and in B?

A: Level of solution at x will rise and then after sometime it will fall and come back to its original position.

Reason

H_2 has lower mass so so its rate of diffusion from the porous pot will be faster, as a result vaccum will be created in the porous which will allow the level of solution to rise at x but after some both the gases will diffuse in air and level of solution fall back to its original position.

B: Level of solution at x will fall and then it will come back to its original position after sometime.

Reason

H_2 being lighter and will diffuse faster inside the porous pot, this will cause an increase in pressure inside the porous pot and will cause the level of solution at x to fall but when both gases diffuse in air, level of solution rises and come back to its original position.

States of Matter
or
Elements, compounds and Mixtures

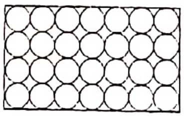
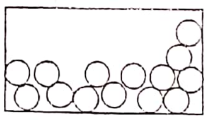
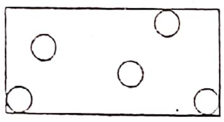
Anything which has mass and occupies space is called matter.

States of Matter

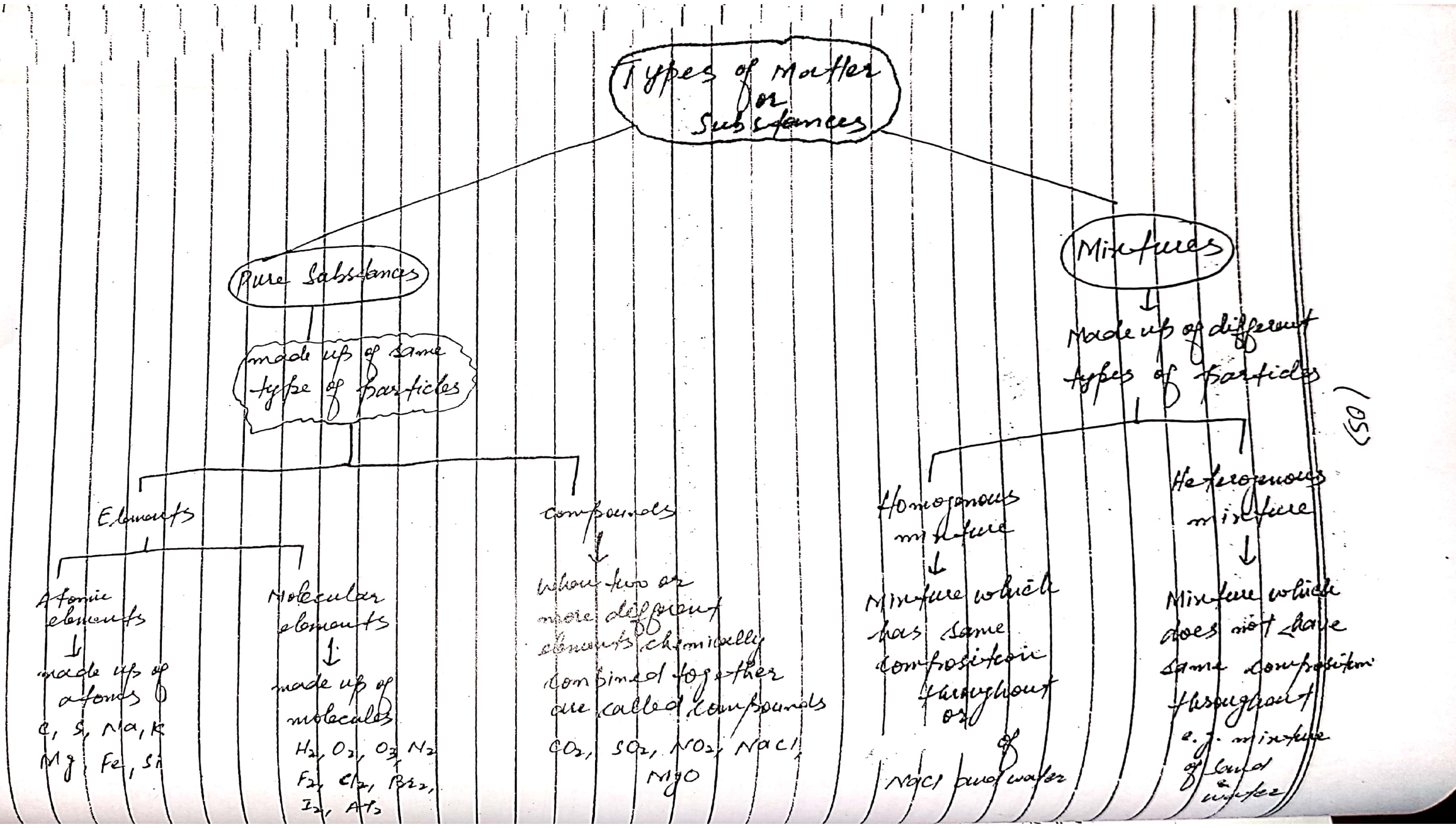
Solid	Liquid	Gas
Fixed volume	Fixed volume	No fixed volume
Fixed shape	No fixed shape. Takes the shape of the container it is in	No fixed shape. Takes the shape of the container it is in

Three states of matter

Difference between Solid, liquid and gas

Property	Solid	Liquid	Gas
Packing between particles	Very closely packed	Closely packed	Very far apart
Forces of attraction between particles	Very strong forces of attraction between particles	Strong forces of attraction between particles	Very weak forces of attraction between particles
Motion of particles	Vibrate about a fixed position	Particles can slide over each other	Particles are in random motion
Diagrammatic representation of the particles in each of the physical states			

Differences between solid, liquid and gas

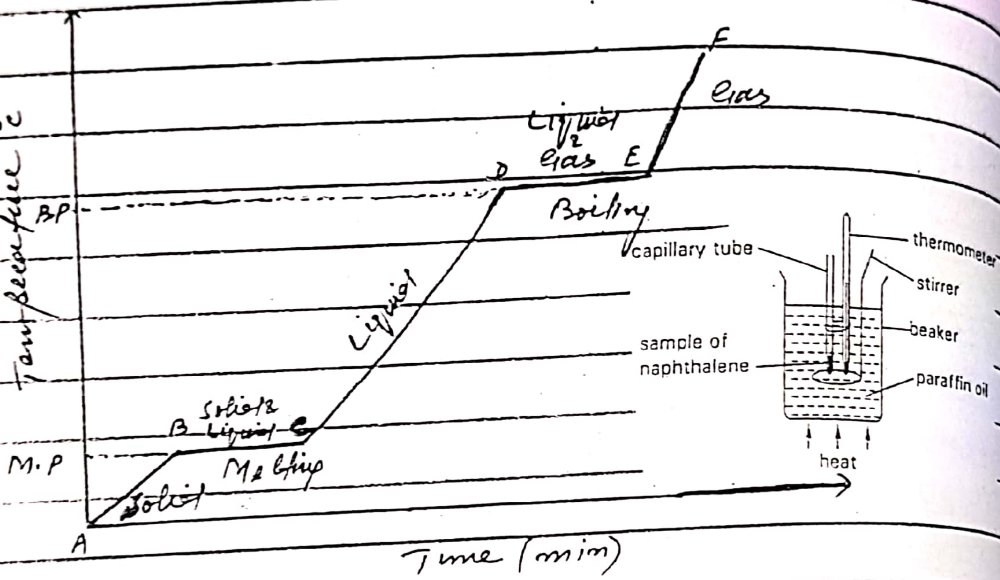

Types of Matter or Substances
Pure Substances
made up of same type of particles
Elements
Atomic elements
made up of atoms
C, S, Na, K, Mg, Fe, Si
Molecular elements
made up of molecules
H2, O2, O3, N2, F2, Cl2, Br2, I2, At2
Compounds
When two or more different elements chemically combined together are called compounds
CO2, SO2, NO2, NaCl, MgO
Mixtures
Made up of different types of particles
Homogenous mixture
Mixture which has same composition throughout
eg NaCl and water
Heterogenous mixture
Mixture which does not have same composition throughout
e.g. mixture of sand and water
(50)

Difference between mixture and compound

Compound	Mixture
It is formed when two or more substances chemically combined together.	⇒ It is formed when two or more substances physically combined
It can be represented by a chemical formula.	⇒ It cannot be represented by a chemical formula
components of a compound loose their individual properties.	⇒ Components of mixture maintain their individual properties.
components of a compound are always in a fixed proportion by mass.	⇒ components of a mixture are not in a fixed proportion
Components of a compound cannot be separated by a physical method, rather a chemical method is required e.g; thermal decomposition or electrolysis	⇒ Components of a mixture can be easily separated by using simple physical methods e.g. filteration, sublimation, distillation etc

Change in the state of Matter

Heating curve



Melting point :- It is the temperature at which the two state (solid & liquid) of a substance coexist.

Boiling point :- It is the temperature at which the two states (liquid & gas) of a substance coexist.

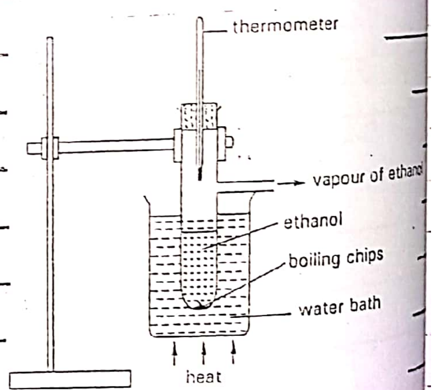
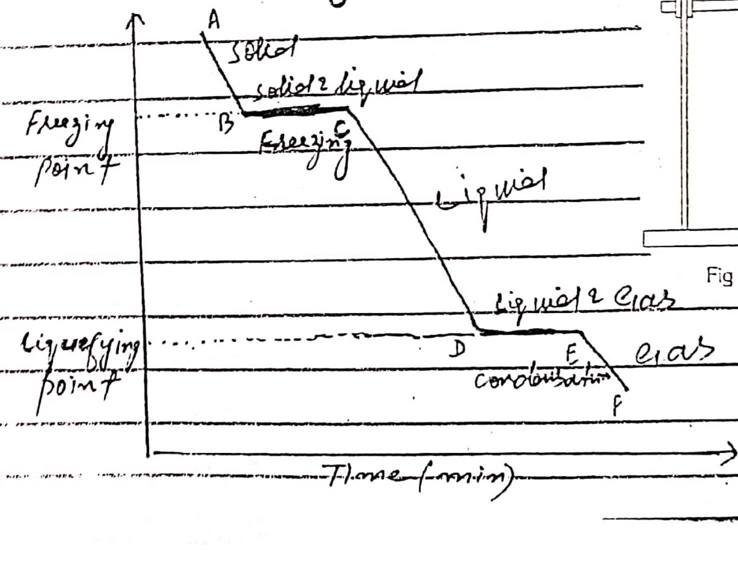
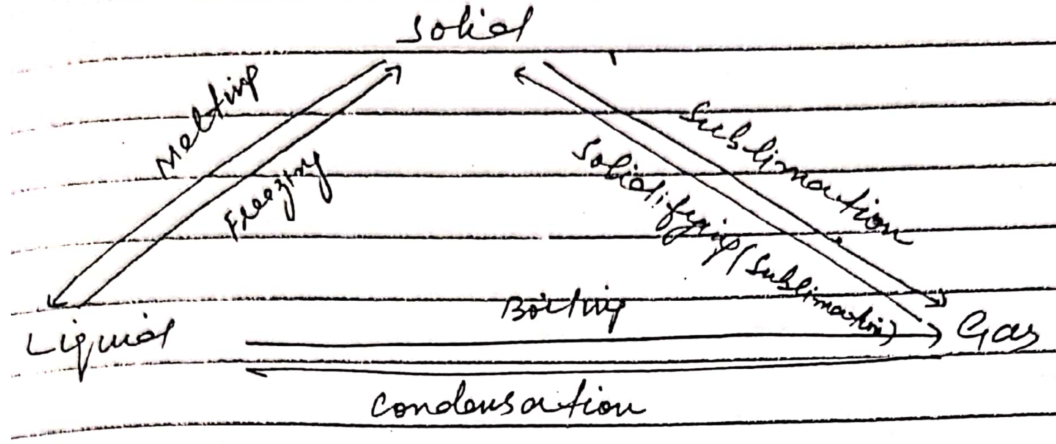


Fig 1.9 Boiling point determination

Cooling curve





Effect of impurities on the melting point and boiling point

Impurities always decrease the melting point of solids while Increase the boiling point of liquids.

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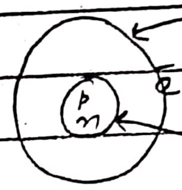
Atomic Structure & Chemical Bonding

Atoms:- Atoms are the building blocks of matter. An atom is represented by a sphere.



Structure of atom

⇒ An atom is electrically neutral due to equal number of positively charged particles (protons) and negatively charged particles (electrons).

⇒ Protons and electrons have same but opposite charges

Properties of electrons, protons and neutrons

Particle	Relative charge	Relative mass
Proton	+1	1
neutron	0	1
electron	−1	$\frac{1}{1840}$ of the mass of proton

Atomic number or Proton number

The number of protons present in an atom is called its atomic number or proton number.

Atomic mass or mass number or nucleon number

The sum of protons and neutrons present in the nucleus of an atom is called its mass number or nucleon number.

Mass number → $^{23}_{11}Na$ ← atomic number

Relative atomic mass (Ar)

The mass of an atom of an element as compared to the $\frac{1}{12}$ th of the mass of an atom of carbon which is taken as 12.

⇒ $\frac{1}{12}$ of 12 is equal to 1.

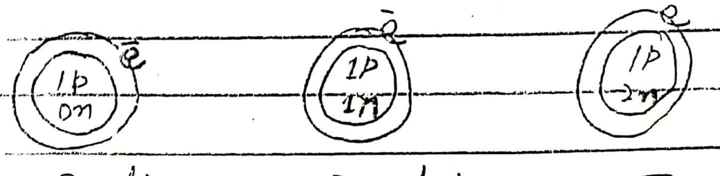
⇒ Ar of ^{24}Mg, so one atom of magnesium is 24 times heavier than $\frac{1}{12}$ th of the mass of an atom of carbon 12.

Isotopes

Atoms of the same element which have same proton number but different mass number due to the different number of neutrons are called isotopes.

e.g; Hydrogen has 3 isotopes

$^{1}_{1}H$ $^{2}_{1}H$ $^{3}_{1}H$



Protium Deuterium Tritium

Mass number of chlorine is in fraction i.e. 35.5

A_r of Chlorine is 35.5, it has 17 protons and 18 neutrons.
Sum of 17 and 18 is 35.
Atomic mass of chlorine is the average of the atomic masses of its isotopes with respect to their abundance.

	^{35}Cl	^{37}Cl
Abundance	75%	25%

$$A_r = \frac{\text{Mass of isotope} \times \text{Abundance} + \text{Mass of isotope} \times \text{Abundance}}{\text{Total abundance}}$$

$$\frac{35 \times 75 + 37 \times 25}{100} = 35.5$$

Radioactive isotopes
Some isotopes emit radioactive rays (alpha, beta and gamma rays) and are used in the treatment of cancer.

Relative molecular mass (M_r)

The mass of a molecule of a compound or element as compared to $\frac{1}{12}$th of the mass of an atom of carbon 12.

M_r of H_2 = 2

M_r of O_2 = 32

One molecule of O_2 is 32 times heavier than $\frac{1}{12}$th of the mass of an atom of carbon taken as 12.

Electronic configuration

Arrangement of electrons in different shells or orbits is called electronic configuration.

Shells	Electrons
1	2
2	8
3	8
4	8

Electronic configuration of 1st twenty elements

$_1H$ = 1

$_2He$ = 2

$_3Li$ = 2,1

$_4Be$ = 2,2

$_5B$ = 2,3

$_6C$ = 2,4

$_7N$ = 2,5

$_8O$ = 2,6

$_9F$ = 2,7

$_{10}Ne$ = 2,8

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

$_{12}Mg$ = 2,8,2

$_{13}Al$ = 2,8,3

$_{14}Si$ = 2,8,4

$_{15}P$ = 2,8,5

$_{16}S$ = 2,8,6

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

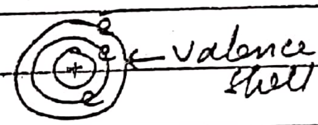
$_{18}Ar$ = 2,8,8

$_{19}K$ = 2,8,8,1

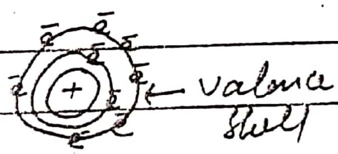
$_{20}Ca$ = 2,8,8,2

Atomic structures

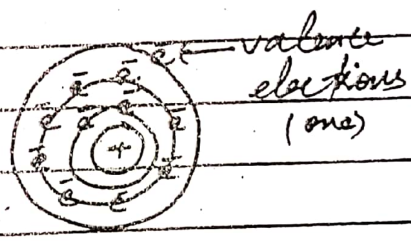
$_3Li$



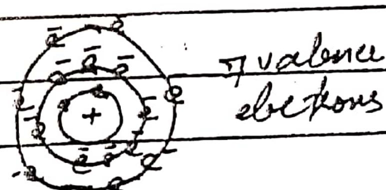
$_9F$



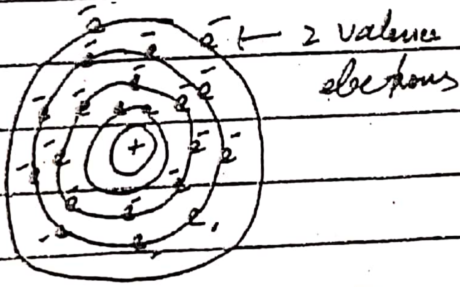
$_{11}Na$



$_{17}Cl$



$_{20}Ca$



Chemical Bonding

Chemical Bond:- Chemical bond is a force of attraction which holds atoms together in the form of molecule or compound.

H — H
↑
Bond

NaCl
↑
Bond

Why atoms form chemical bond?
Atoms form chemical bond to complete their valence shell by 2 electrons or by 8 electrons.
Presence of two electrons in the valence shell is called duplet.
Presence of 8 electrons in the valence shell is called octet.

Types of Chemical bond

There are three types of Chemical bond
(i) Ionic bond
(ii) Covalent bond
(iii) Metallic bond

Ionic bond

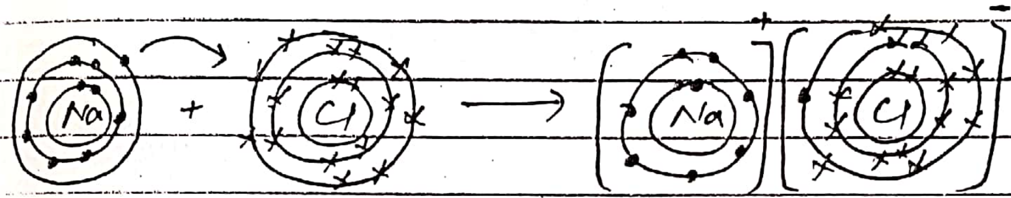
Charge containing substances are called ions.
Ionic bond is formed by the transfer of electron from metal atoms to non metal atoms.
Metals after losing electron get positive charge while non metals after gaining

electrons get negative chage.

Formation of NaCl

$_{11}Na + _{17}Cl \longrightarrow \overset{+}{Na}\overset{-}{Cl}$

2,8,1   2,8,7   2,8   2,8,8



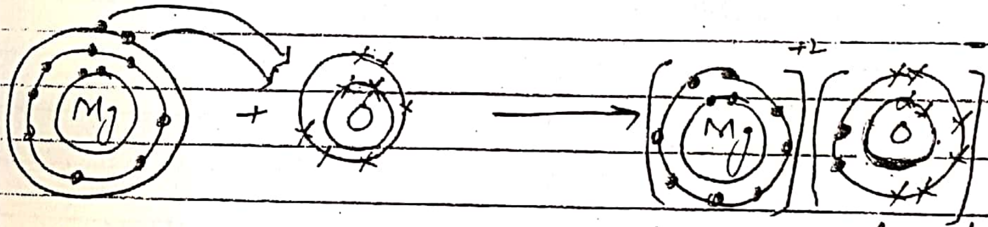
Electrostatic force of attraction

(Dot & cross structure)

Formation of MgO

$_{12}Mg + _{8}O \longrightarrow Mg^{+2}O^{-2}$

2,8,2   2,6   2,8   2,8

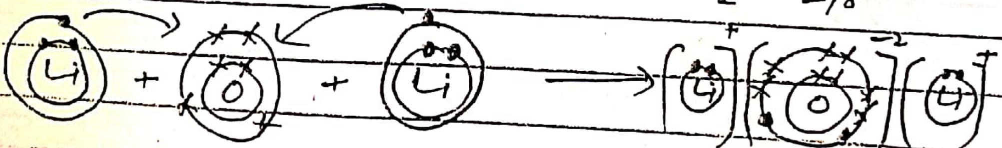


Dot & cross stucture

Formation of Li_2O

$_{3}Li + _{8}O + _{3}Li \longrightarrow Li_2O$

2,1   2,6   2,1   2   2,8



Definition of Ionic bond

It is an electrostatic force of attraction which holds oppositely charged ions together.

Covalent bond

A type of Bond which is formed by sharing one or more pairs of electrons between two non metals.

Types of Covelant bond

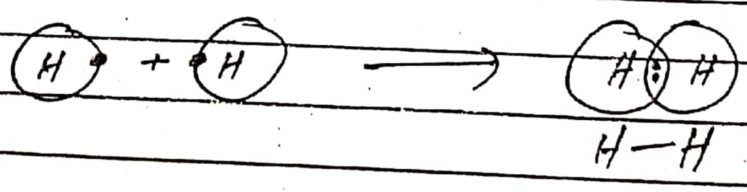
(i) Single covalent bond
(ii) Double covalent bond
(iii) Triple covalent bond

Single covalent bond

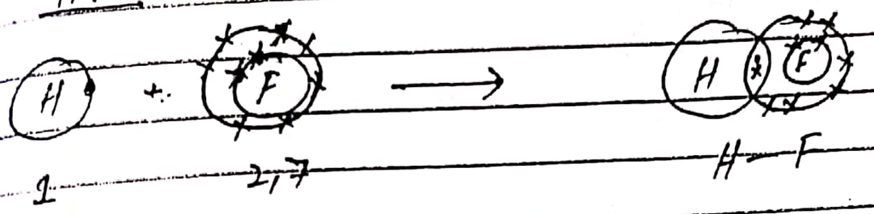
A covalent bond which is formed by sharing one pair of electrons.

Following are the examples of molecule have single covalent bond.

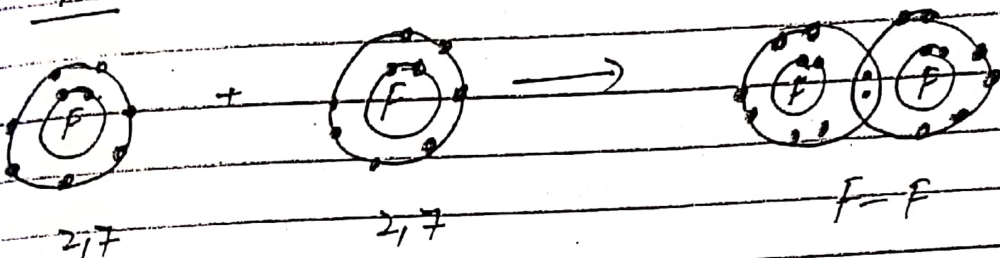
H_2



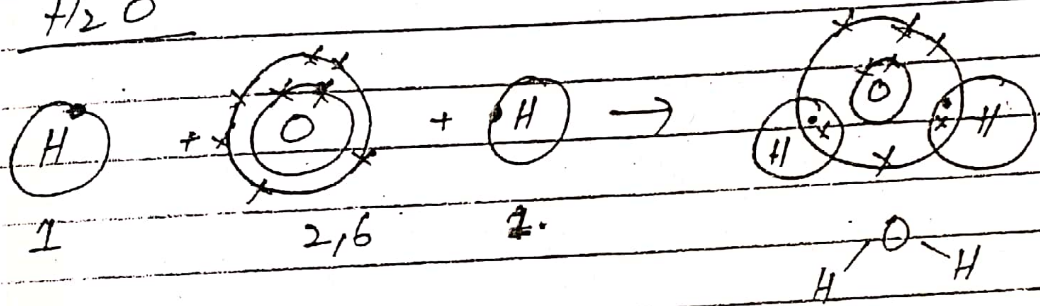
HF



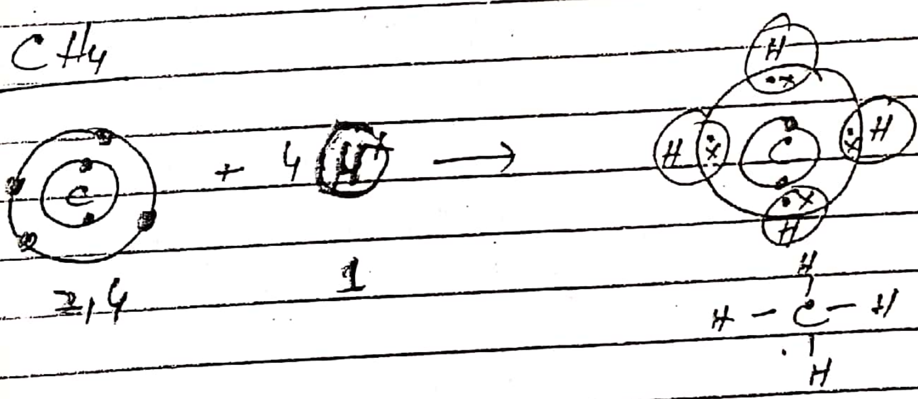
F_2



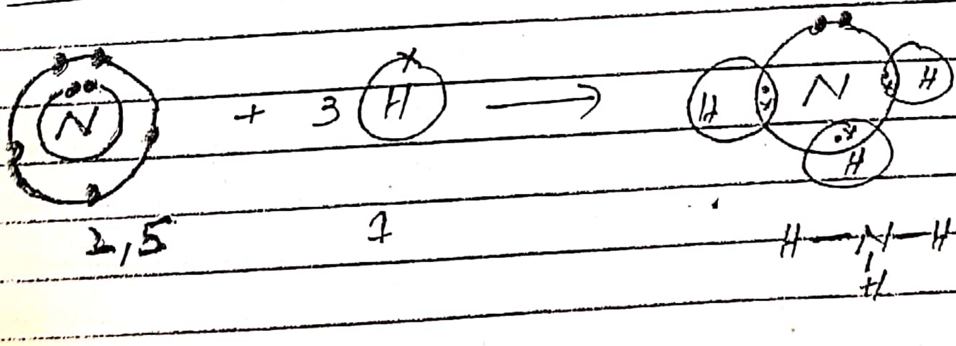
H_2O



CH_4



NH_3



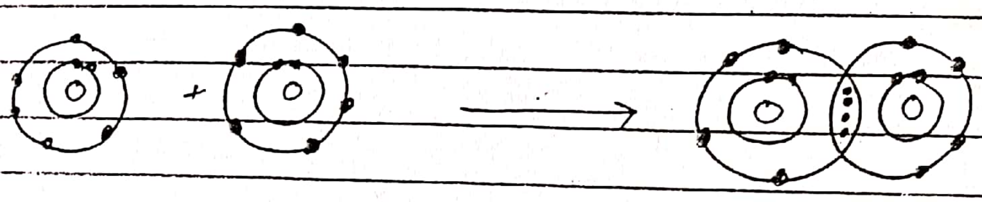
Double covalent bond

A covalent bond which is formed by sharing two pairs of electrons between two atoms.

O_2

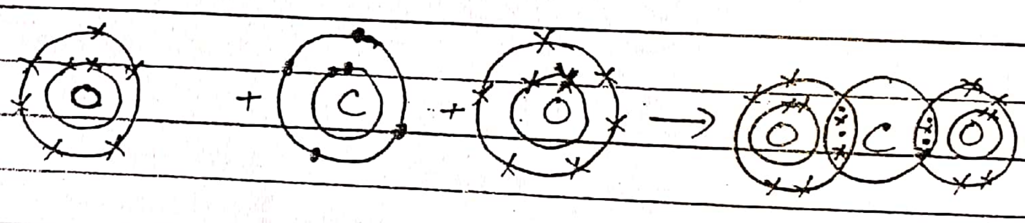
$_8O + _8O \longrightarrow O_2$

2,6   2,6



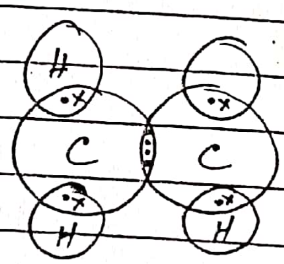
O = O

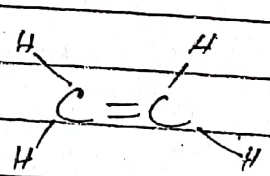
CO_2



O = C = O

C_2H_4



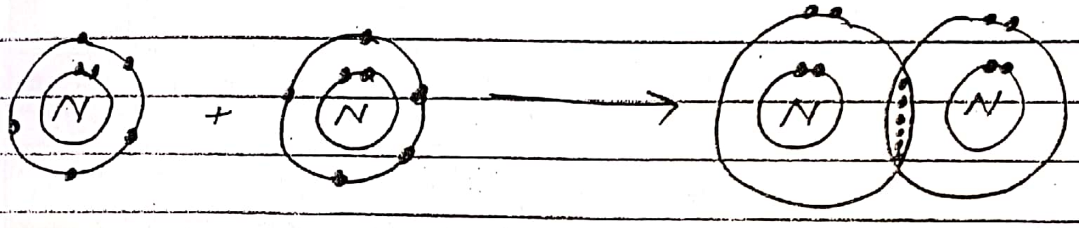


Triple covalent bond

A covalent bond which is formed by sharing three pairs of electrons between two atoms.

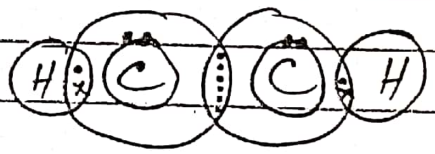
N_2

$$\underset{2,5}{{}_7N} + \underset{2,5}{{}_7N} \longrightarrow N_2$$



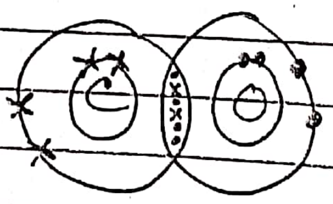
$N \equiv N$

C_2H_2



$H-C\equiv C-H$

CO



$C \equiv O$

Properties of Ionic & Covalent compounds

Ionic Compounds	Covalent compounds
(i) Most are solids with high M.P, B.P and high density	(i) Most are gases and liquids with low M.P, B.P and low density
Reason Due to many strong electrostatic forces between opposite ions, which need high energy to separate ions	Due to weak van der waal's forces between molecules which need lesser energy to break these forces.
(ii) Can conduct electricity in their molten and aqueous state but not in their solid state.	(ii) Cannot conduct electricity in any of their state.
Reason When solid, their ions are fixed but in molten and aqueous state, ions can move freely	Reason Do not have freely moving ions in any of their state, only molecules
(iii) Most are soluble in water but are insoluble in organic solvents e.g; in petrol, ethanol etc	(iii) Most are insoluble in water but are soluble in organic solvents.

Ionic compounds	Covalent compounds
Ionic compounds exist as giant ionic crystal lattice	Covalent compounds exist as simple and giant molecular lattice.

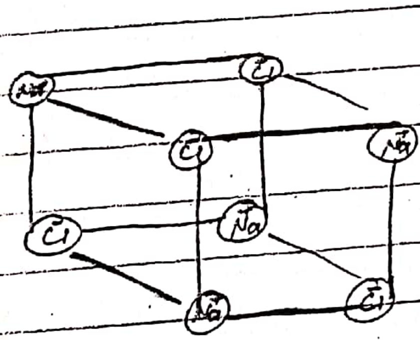
Ionic crystal lattice

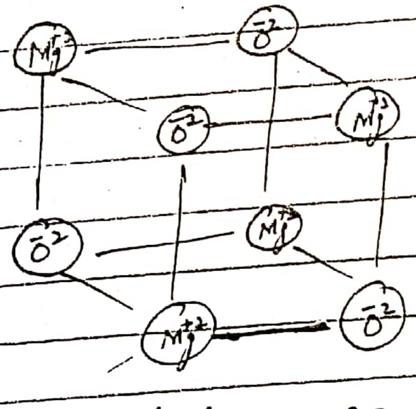
All Ionic compounds exist as giant ionic lattice.

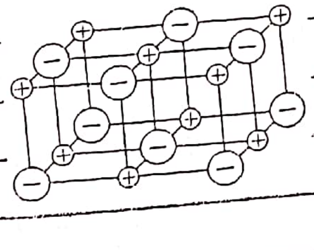
Lattice:- Regular, repeating and three dimensional arrangement of particles is called lattice.

Crystal lattice of NaCl and MgO

NaCl and MgO both have cubic crystal lattice.

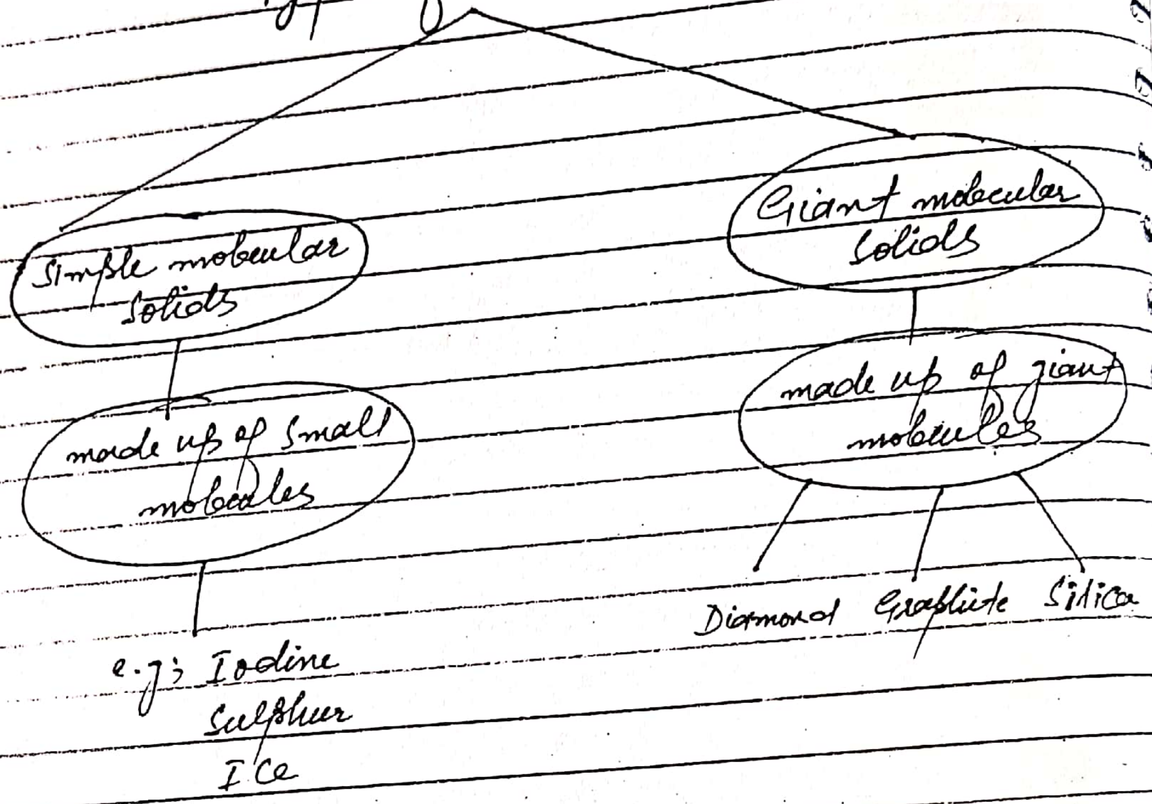






MgO has higher M.P & B.P than NaCl due to greater charges over opposite ion and have stronger electrostatic forces which need greater energy to separate ions.

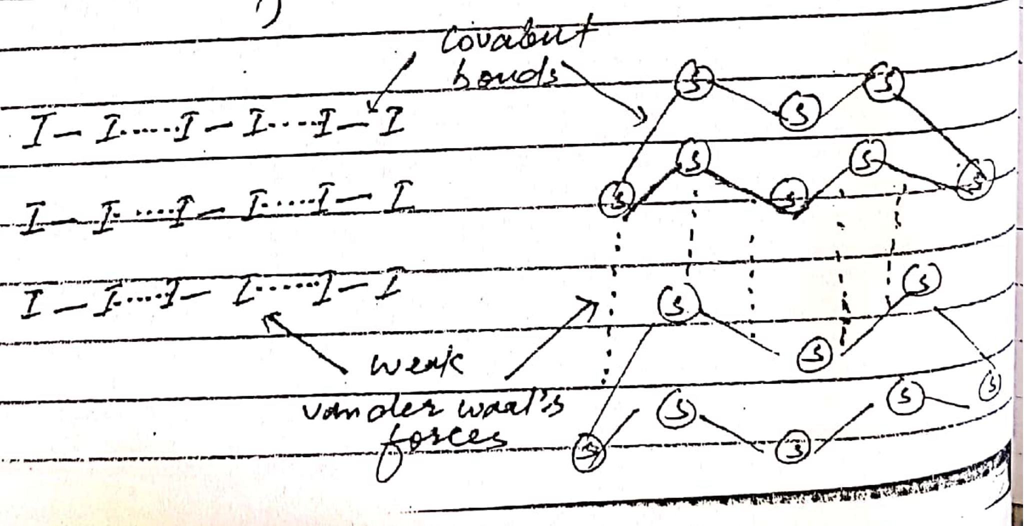
Types of covalent Solids



Simple molecular Solids

Simple molecular Solids are made up of Small molecules, which have weak van der waal's forces between their molecules, therefore they have low M.P & B.P and lower density.

Structure of iodine **Structure of sulphur**



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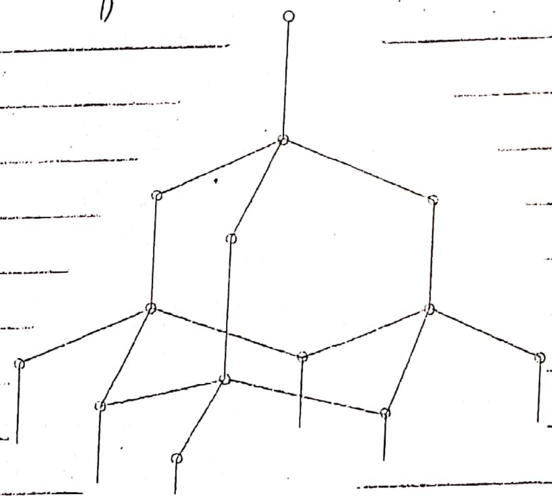
Giant molecular Solids

Giant molecular solids are made ups of large number of atoms with many strong covalent bonds between atoms.

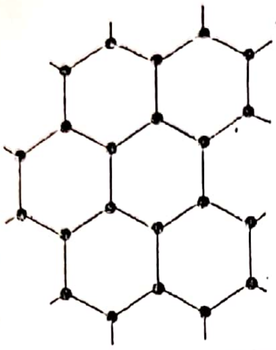
Structure of Diamond

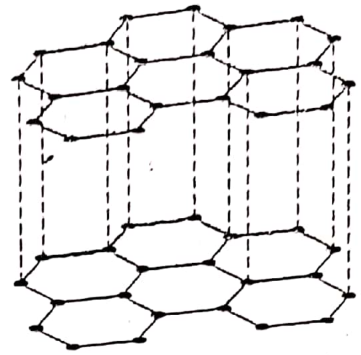
Diamond is an allotrope of carbon. In diamond large number of carbon atoms are bonded to form a giant tetrahedral structure.
In Diamond each carbon atom is covalently bonded with four other carbon atoms.



Structure of Graphite

Graphite is another allotrope of Carbon.
Graphite has a layered structure.
In Graphite each carbon atom is covalently bonded with 3 other carbon atoms to form hexagonal rings.
Layers in Graphite are held together by weak van der waal's forces.





Allotropes: Different forms of the same element which are same chemically but have different structures.

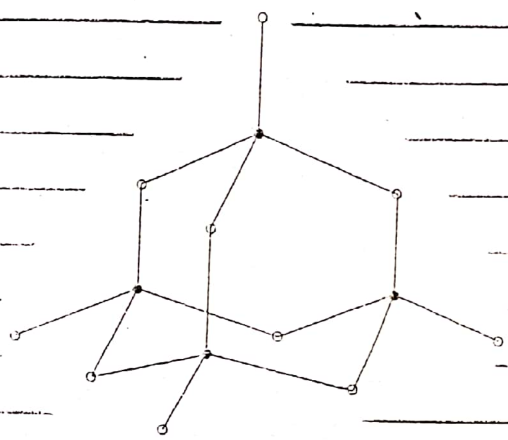
Properties of Diamond and Graphite

Diamond	Graphite
(i) High M.P, B.P and density. Due to many strong covalent bonds which need high energy to break	High M.P, B.P and density. Due to many strong covalent bonds which need higher energy to break. Graphite has lesser number of covalent bonds therefore its M.P is slightly lower than that of Diamond.
(ii) Cannot conduct electricity due to the absence of freely moving electrons.	Can conduct electricity due to the presence of freely moving electrons. Therefore used as electrodes in batteries.
(iii) Hard and strong due to high M.P and Giant structure and is used as drills to cut rocks and cut glass.	Soft and slippery due to weak van der waal's forces between layer which allow layers to slide. Therefore Graphite

Diamond	Graphite
	is used as Lubricant in machines and as lead in pencils.

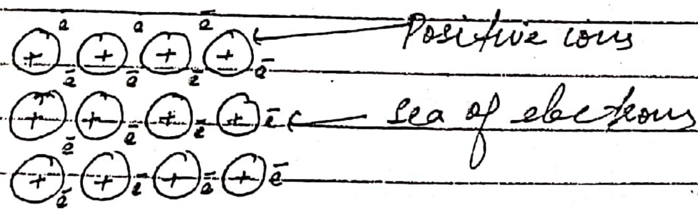
Structure of Silica (SiO_2)

In Silica each silicon atom is covalently bonded with four oxygen and each oxygen is bonded with two Silicon atoms to form a giant tetrahedral structure.



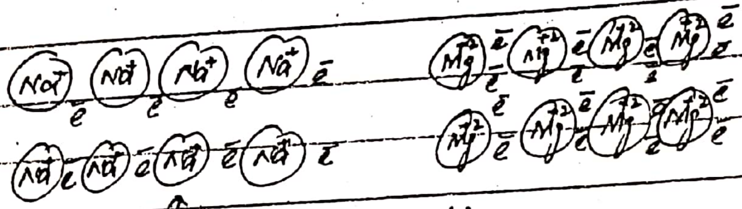
Metallic bonding

Metallic bonding is an electrostatic force of attraction between positive ions and sea of electrons.

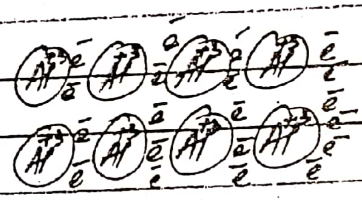


Strength of Metallic bonding

Strength of metallic bonding depends upon number of valence electrons. Greater the number of valence electrons stronger will be the metallic bonding.



Weakest metallic bonding
Lower M.P & B.P

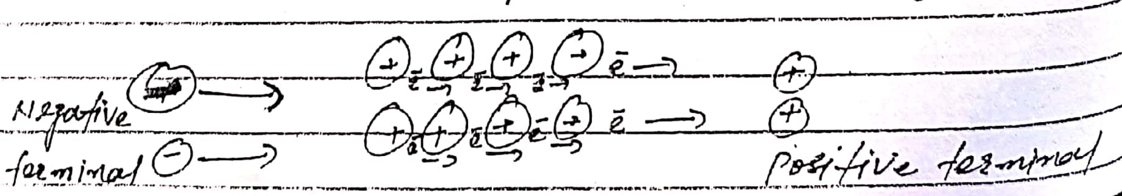


Strongest metallic bonding
Higher M.P & B.P

Properties of metals

⇒ Metals have high M.P & B.P & density due to many strong electrostatic forces between positive ions and sea of electrons.

⇒ Metals are good conductors of heat and electricity due to the sea of electrons.



Metals are malleable and ductile i.e. can be converted into sheets and wires. This is due to the presence of metal atoms in the form of rows or layers which slide over each other when force is applied over metal.