Bonding and Structure

Learning Objectives

At the end of the topic, students should be able to:

a) describe formation of ionic bonds between metals and non-metals e.g. $NaCl$, $MgCl_2$
b) describe, using "dot-and-cross" diagrams, the formation of an ionic compound, e.g. MgO and $NaCl$
c) state that ionic materials contain a giant lattice in which the ions are held by electrostatic attraction, e.g. $NaCl$
d) deduce the formulae of other ionic compounds from diagrams of their lattice structures, limited to binary compounds
e) relate the physical properties (including electrical property) of ionic compounds to their lattice structure
f) describe the formation of covalent bond by the sharing of a pair of electrons in order to gain the electronic configuration of a noble gas
g) describe, using 'dot-and-cross' diagrams, the formation of covalent bonds between non-metallic elements, e.g. H_2; O_2; H_2O; CH_4; CO_2
h) describe electronegativity and the formation of polar covalent bond
i) relate the physical properties (including electrical property) of covalent substances to their structure and bonding
j) relate the electrical conductivity of metals to the mobility of the electrons in the structure
k) compare the structure of simple molecular substances, e.g. methane, iodine, with those of giant molecular substances, e.g. poly(ethene), sand (silicon dioxide), diamond, graphite in order to deduce their properties
l) compare the bonding and structures of diamond and graphite in order to deduce their properties such as electrical conductivity, lubricating or cutting action
m) deduce the physical and chemical properties of substances from their structures and bonding and vice versa

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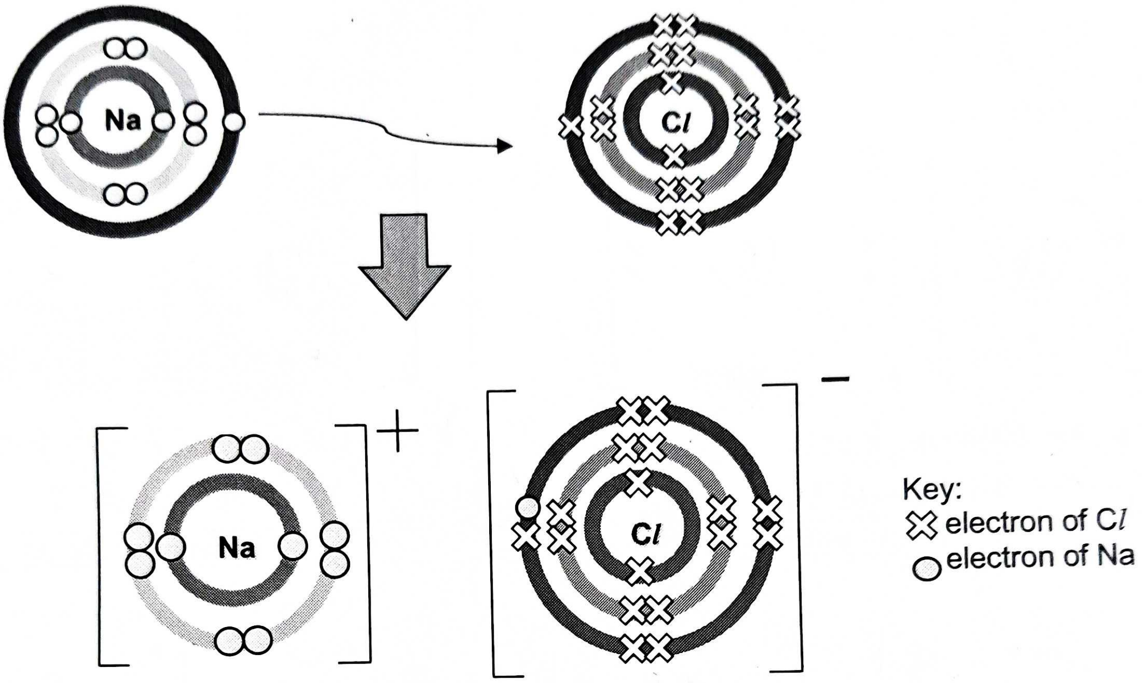
A. Ionic Bonding

- In order to attain a noble gas configuration, metal atoms tend to lose electrons to non-metal atoms.
- After the transfer of electrons, the positive ions and negative ions formed as a result are attracted together by strong electrostatic forces of attraction known as ionic bonds.
- Definition of ionic bonds:
  Ionic bonds are strong electrostatic forces of attraction between oppositely-charged ions.

Example: *sodium chloride*

Sodium (metal) reacts with chlorine (non-metal) to produce a white solid called sodium chloride.



Two common misconceptions regarding ionic bonds:

Misconception # 1:
"Ionic bond is the transfer of electrons between atoms."

This is a misconception because the transfer of electrons is the process of forming ions from atoms.
Ionic bonding occurs after the ions are formed.

Misconception #2:
"Metals and non-metals form only ionic bond."

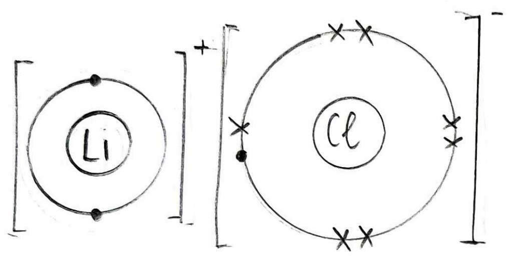
This is only a general trend and does not apply to all compounds made up of a metal and a non-metal.
For example, aluminium chloride ($AlCl_3$) a simple molecular substance and not an ionic compound.

HW

Quick check:

Use 'dot-and-cross' diagrams to represent the following ionic compounds. You only need to show the valence shell electrons.

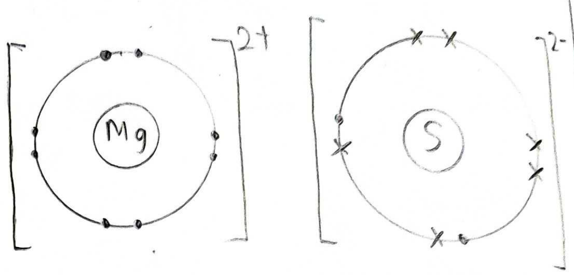
Lithium chloride $_{3}Li$ $_{17}Cl$



key : • – electron of Li
x – electron of Cl

✓

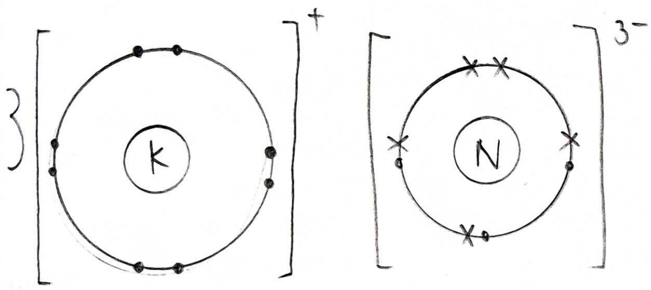
Magnesium sulfide $_{12}Mg$ $_{16}S$



key: • - electron of Mg
x - electron of S

✓

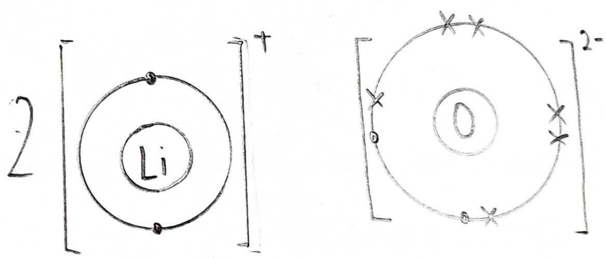
Potassium nitride $_{19}K$ $_{7}N$



key: •– electron of k
x – electron of N

✓

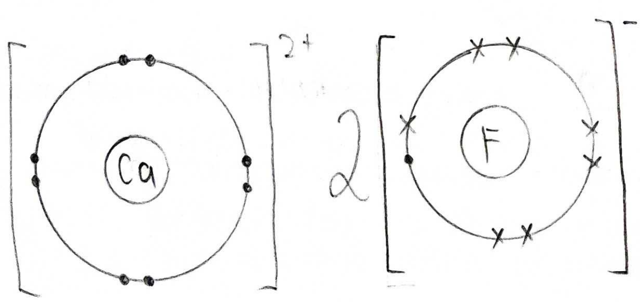
Lithium oxide $_{3}Li$ $_{8}O$



key: • – electron of Li
x – electron of O

✓

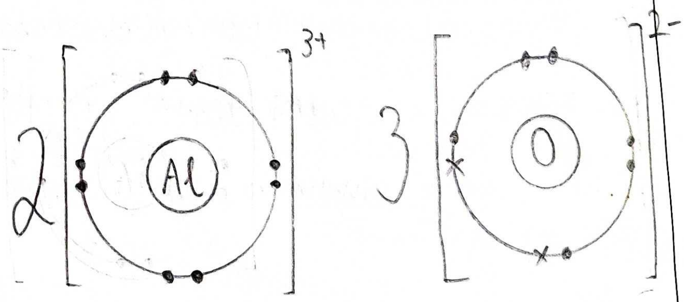
Calcium fluoride $_{20}Ca$ $_{7}F$



key: • - electron of Ca
x - electron of N

✓

Aluminium oxide $_{13}Al$ $_{8}O$



key : • - electron of Al
x - electron of O

✓

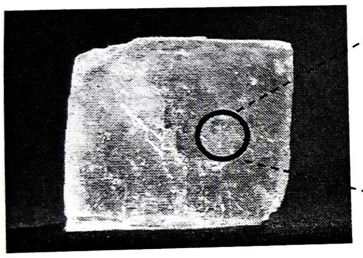
B. Structure of Ionic Compound

- The 'dot-and-cross' diagram only shows one formula unit of the ionic compound. For example, in $NaCl$, only one Na^{+} and one Cl^{-} are shown; in MgF_2, only one Mg^{2+} and two F^{-} are shown.
- However, the actual structure consists of a continuously repeating 3-dimensional lattice of positive and negative ions.
- Ions are closely packed, arranged in an orderly manner and held in fixed positions by strong electrostatic forces of attraction between oppositely charged ions
- The structure formed by ionic compounds is known as giant ionic structure.
- The electrostatic attraction of each ion affects **all** the other ions around it. It acts equally in all directions.

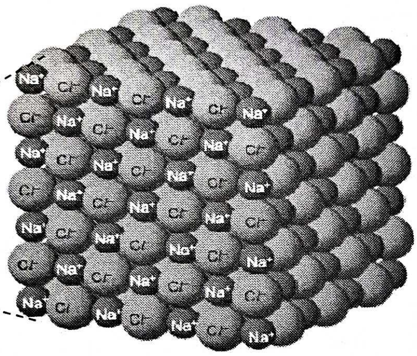
<u>Note</u>: lattice refers *to a* regular three-dimensional arrangement of atoms, molecules or ions.

B1. Structure of Sodium Chloride

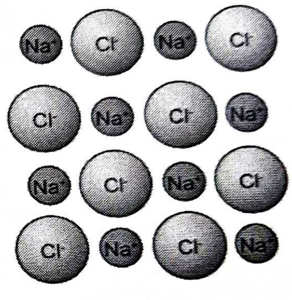
- Sodium chloride has a giant ionic structure.



sodium chloride crystal

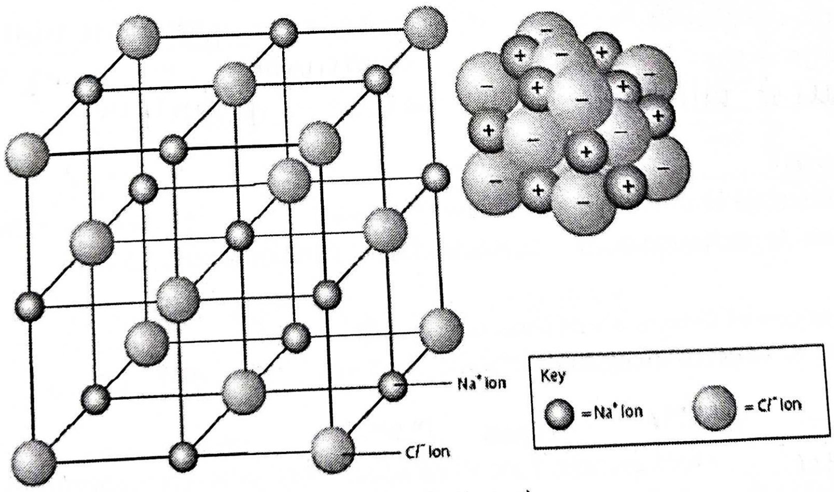


three-dimensional arrangement of sodium ions and chloride ions



sodium ions and chloride ions alternate with each other

- In the structure of sodium chloride, the ratio of sodium ions to chloride ions is 1 : 1.
  - Each sodium ion is surrounded by 6 chloride ions.
  - Each chloride ions is surrounded by 6 sodium ions.



Arrangement of ions in a sodium chloride crystal

Quick check:
Compound X is made up of two elements, metal Y and non-metal Z.
X consists of a lattice of positive ions and negative ions. Each positive ion is surrounded by eight negative ions and each negative ion is surrounded by four positive ions.

Which ions are present in, and what is the formula of, compound X?

	ions present	formula
A	Y^+ Z^{2-}	Y_2Z
B	Y^{2+} Z^-	YZ_2
C	Z^+ Y^{2-}	Z_2Y
D	Z^{2+} Y^-	ZY_2

(B)

B2. Physical Properties of Ionic Compounds

- Table below shows physical properties of some ionic compounds.

Substance	Melting point (°C)	Boiling point (°C)	Solubility in water	Electrical conductivity (when molten)	Electrical conductivity (in solid state)
Sodium chloride	801	1413	soluble	good	does not conduct
Magnesium oxide	2852	3600	soluble	good	does not conduct
Potassium bromide	728	1376	soluble	good	does not conduct
Copper(II) chloride	620	990	soluble	good	does not conduct

Property #1: High melting point

- Ionic compounds generally have high melting points. For example, Na*Cl* melts at 801°C.
- They generally exist as solids at room temperature and pressure.

Explanation:

- Ionic compounds, such as sodium chloride, have giant ionic structure.
- Large amount of energy is required to overcome the strong electrostatic forces of attraction of attraction between oppositely charged ions..

Quick check:
Based on the data in the table, suggest why magnesium oxide has a much higher melting point than sodium chloride, although both substances have giant ionic structures?

- The **charges** of **magnesium ions** and **oxide ions** are 2^+ and 2^- respectively while the **charges** of **sodium ions** and **chloride ions** are 1^+ and 1^-.
- Due to the greater **charges**, more **energy** is required to **overcome** the stronger **electrostatic forces of attraction** between magnesium ions and oxide ions compared to those between sodium ions and chloride ions.

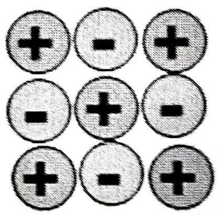
Property #2: Conductor of electricity in molten and aqueous state

Note: For a substance to be a conductor of electricity, there must be presence of free-moving charged particles
Examples of charged particles: electrons, ions.

- In the solid state, ionic compounds cannot conduct electricity.
- Ionic compounds conduct electricity only when in molten state or ~~aqe~~ aqueous state
  - Molten state is a state when a solid substance has melted (at high temperature)
  - Aqueous state is a state when a substance has dissolved in water.

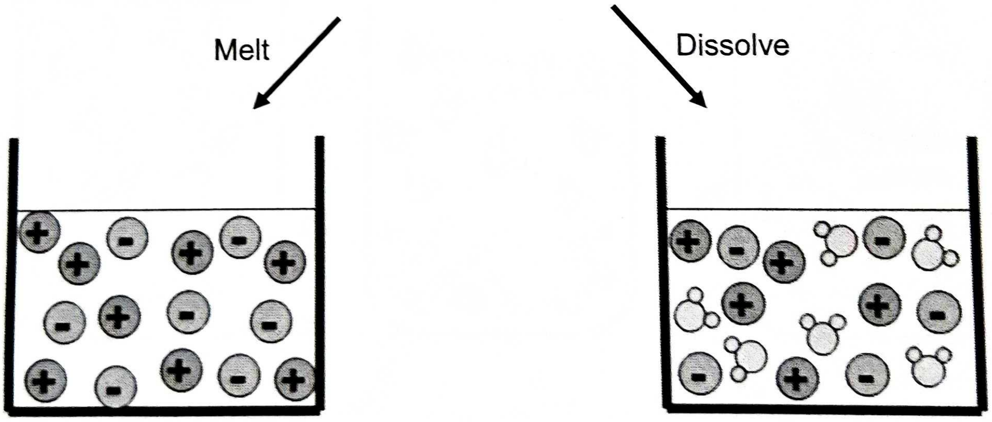
Explanation:

- Ionic compounds, such as sodium chloride, have giant ionic structure.
- In the **solid** state, the oppositely-charged ions are held in fixed positions by strong electrostatic forces of attraction. Thus, ions are not free-moving and hence cannot conduct electricity.
- In the **molten** or **aqueous** state, the strong electrostatic forces of attractions between oppositely-charged ions have been overcome. The ions are free-moving and hence can conduct electricity.



Solid state:

Ions are in fixed position and not free-moving



In molten state or aqueous solution:

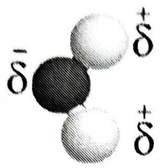
Ions are now free-moving and can conduct electricity

Property #3: Soluble in water but insoluble in organic solvent

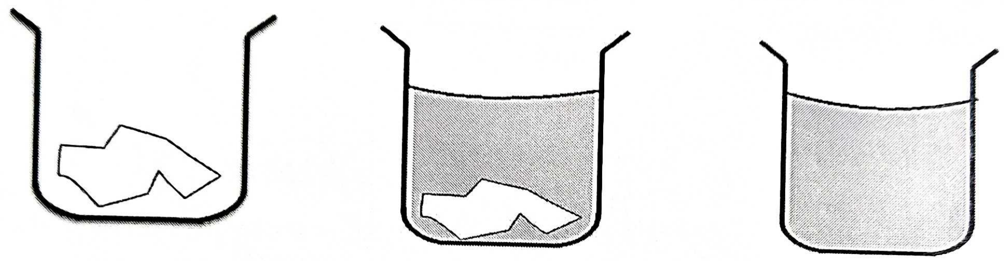
- Ionic compounds are generally soluble in water but insoluble in organic solvent.
- Examples of organic solvent are ethanol, trichloromethane, turpentine, benzene, etc.
- Examples of ionic compounds that are insoluble in water: silver chloride, barium sulfate.
  $AgCl$

Explanation (enrichment):

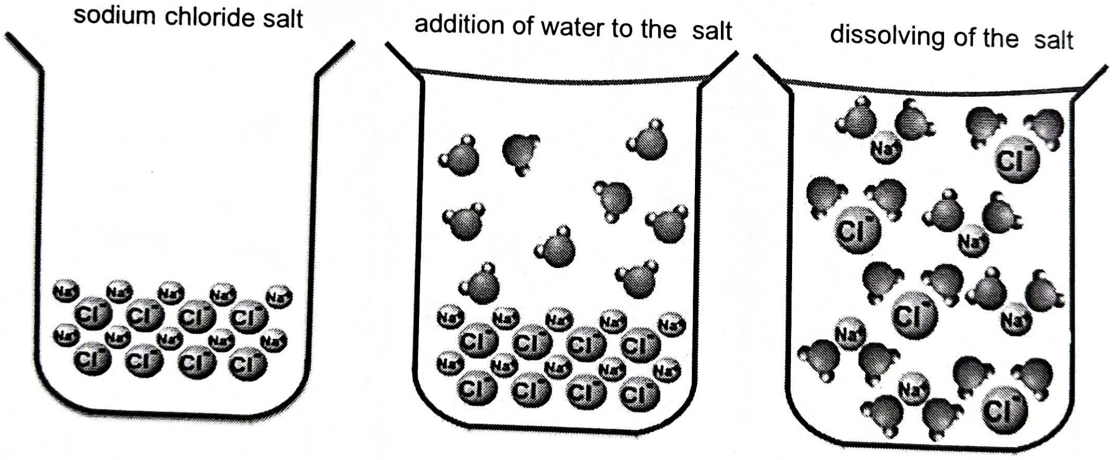
- Water is a polar molecule.
- The partial positive charge formed at the hydrogen ends of water of water molecules will be attracted to anions and the partial negative charge formed at the oxygen ends of water molecules will be attracted to cations.
- Water molecules will pull the ions away from the crystal lattice into the solution and the ionic compound will eventually dissolve into the solution.



water molecule (polar)



sodium chloride salt | addition of water to the salt | dissolving of the salt



B3. Uses of Ionic Compounds

Property	Use
High melting point	• Used as refractory materials • Refractory materials are heat resistant. The melting point of magnesium oxide is 2852°C. It is used to line the inner surface of a high temperature furnace.

not possible for ~~?~~ 4 bond ?

double bond
triple bond
↗ 3

C. Covalent Bonding

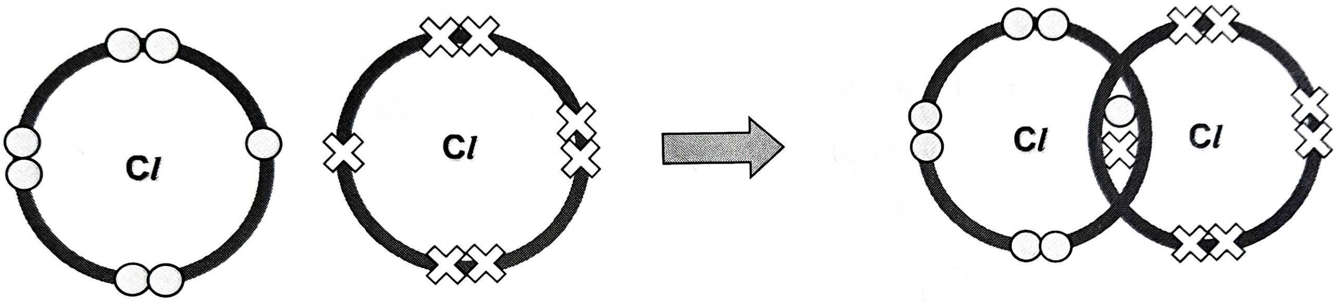
- Covalent bonds are generally formed between non-metal atoms by the sharing of electrons.

  Note: the driving force behind sharing of electrons is that all non-metal atoms want to achieve the stable noble gas electronic configuration.

- The electrons can be shared between atoms of the same kind (in elements) such as H_2 or Cl_2, or between atoms of different kinds (in compounds) such as HCl, NH_3, H_2O and CH_4.

Example 1: chlorine (Cl_2)

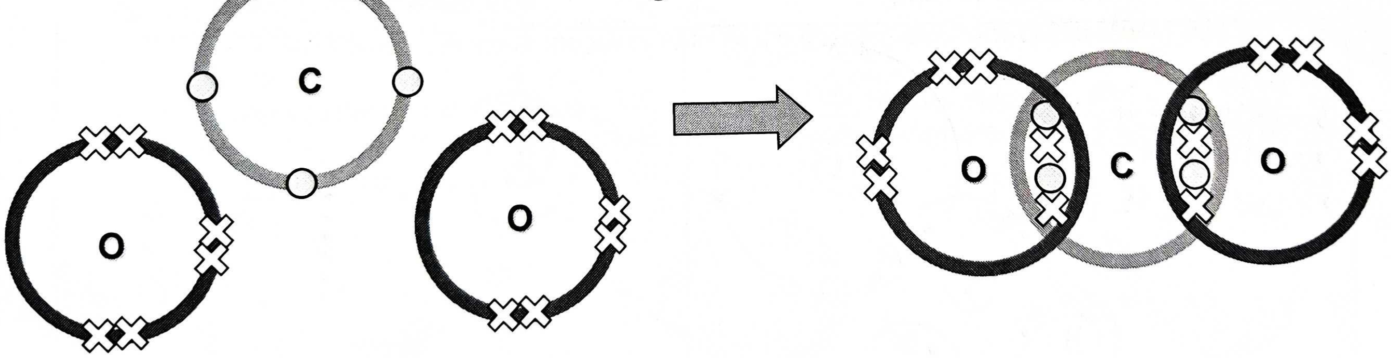
Key:
⊗ electron of Cl
○ electron of another Cl



Chemical formula	Structural formula
Cl_2	Cl - Cl

Example 2: carbon dioxide (CO_2)

Key:
⊗ electron of O
○ electron of C

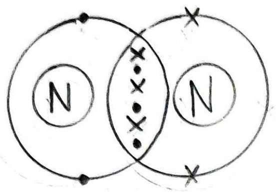
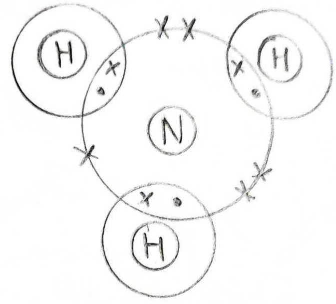
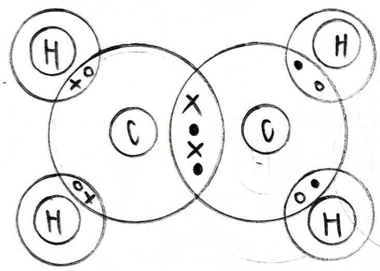
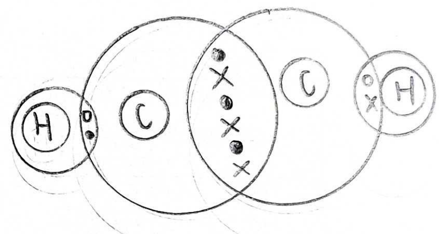
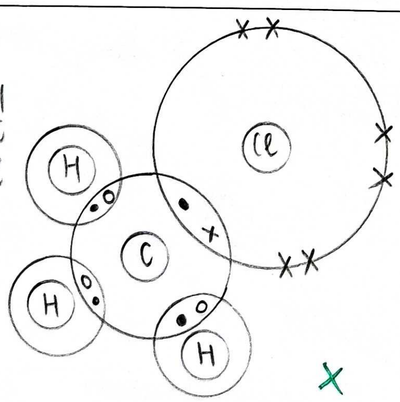
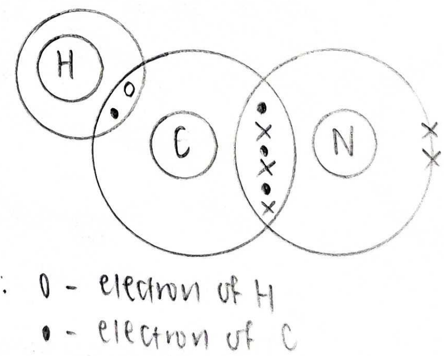


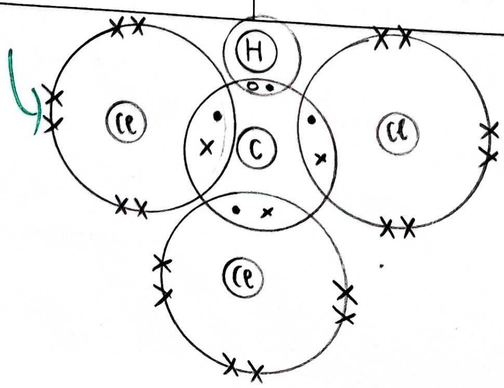
Chemical formula	Structural formula
CO_2	O = C = O

HW

Quick check:

Draw 'dot-and-cross' diagram for the following substances. You only need to show the valence shell electrons.

Nitrogen N_2	Ammonia NH_3
 Key: • - electron of N x - electron of another N ✓	key: x - electron of H • - electron of N  ✓
Ethene (C_2H_4)	**Ethyne (C_2H_2)**
 Key: x - electron of C • - electron of another C o - electron of H ✓	 Key: x - electron of C • - electron of another C o - electron of H ✓
Chloroform ($CHCl_3$)	**Hydrogen cyanide (HCN)**
Key: o - electron of H • - electron of C x - electron of Cl  ✗	 Key: o - electron of H • - electron of C X - electron of N ✓



D. Electronegativity

- Electronegativity refers to the ability of an atom to attract a shared pair of electrons towards itself in a covalent bond.

Periodic Table of Electronegativity using the Pauling scale

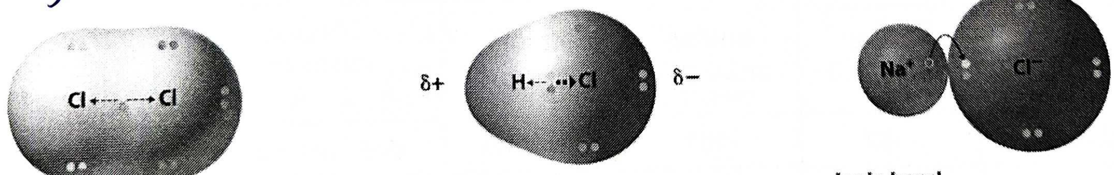
Noble gases

1	H 2.20																	He
2	Li 0.98	Be 1.57											B 2.04	C 2.55	N 3.04	O 3.44	F 3.98	Ne
3	Na 0.93	Mg 1.31											Al 1.61	Si 1.90	P 2.19	S 2.58	Cl 3.16	Ar
4	K 0.82	Ca 1.00	Sc 1.36	Ti 1.54	V 1.63	Cr 1.66	Mn 1.55	Fe 1.83	Co 1.88	Ni 1.91	Cu 1.90	Zn 1.65	Ga 1.81	Ge 2.01	As 2.18	Se 2.55	Br 2.96	Kr 3.00
5	Rb 0.82	Sr 0.95	Y 1.22	Zr 1.33	Nb 1.6	Mo 2.16	Tc 1.9	Ru 2.2	Rh 2.28	Pd 2.20	Ag 1.93	Cd 1.69	In 1.78	Sn 1.96	Sb 2.05	Te 2.1	I 2.66	Xe 2.60
6	Cs 0.79	Ba 0.89	*	Hf 1.3	Ta 1.5	W 2.36	Re 1.9	Os 2.2	Ir 2.20	Pt 2.28	Au 2.54	Hg 2.00	Tl 1.62	Pb 2.33	Bi 2.02	Po 2.0	At 2.2	Rn 2.2
7	Fr 0.7	Ra 0.9	**	Rf	Db	Sg	Bh	Hs	Mt	Ds	Rg	Uub	Uut	Uuq	Uup	Uuh	Uus	Uuo

- Electronegativity increases across a period. In the same Period, F is more electronegative than N.
- Electronegativity decreases down a group. In the same Group, Br is less electronegative than F.
- Flourine is the most electronegative atom.

D1. Non-polar & Polar Covalent Bond

- If the two atoms involved in covalent bond are either the same or have similar electronegativity, a non-polar covalent bond results. The two atoms have equal pull on the shared pair of electrons.
- If the two atoms involved in covalent bonding have different electronegativity values, the pair of shared electrons are not equally shared between the two atoms and a polar covalent bond results.
  - If atom B is more electronegative than A, the bonding electrons are nearer to B in the bond.
- In a polar covalent bond, the more electronegative atom acquires a partial negative charge (denoted by δ⁻) and the less electronegative atom acquires a partial positive charge (denoted by δ⁺).



Nonpolar covalent bond
Bonding electrons shared equally between two atoms.
No charges on atoms.

Polar covalent bond
Bonding electrons shared unequally between two atoms.
Partial charges on atoms.

Ionic bond
Complete transfer of one or more valence electrons.
Full charges on resulting ions.

Increasing difference in electronegativity between the atoms

E. Structures of Covalent Substances

- Covalent substances can be categorised into two different types:

Covalent substances

covalent bonds among few atoms → simple molecular substance

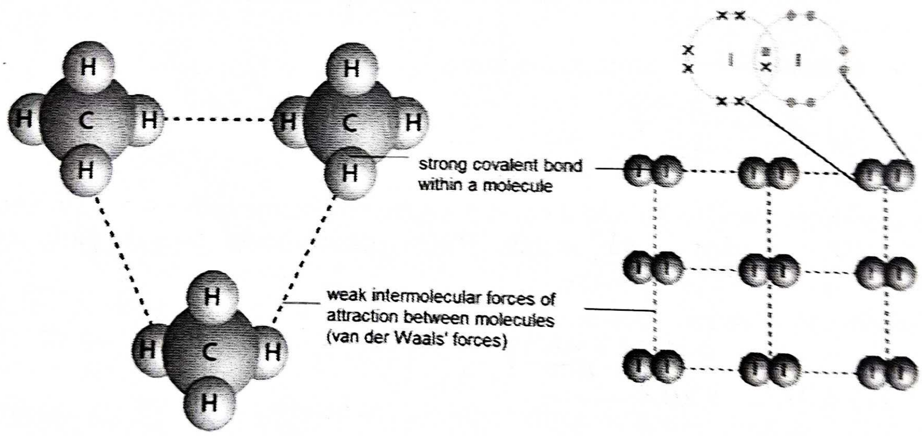
- e.g. H_2, H_2O, NH_3, CH_4, CO_2

covalent bonds among large number of atoms throughout the structure → giant molecular substance

- e.g. diamond, silicon, graphite

F. Structure of Simple Molecular Substances

- Simple molecular substances consist of many simple molecules.
- Within each molecule, the atoms are held together by strong covalent bonds. (does not break)
- However, the molecules are held together by weak intermolecular of attraction.
- The structure of simple molecular substances is known as simple molecular structure.
- Examples of simple molecular substances: water, methane, carbon dioxide, ammonia, iodine, etc.



F1. Properties of Simple Molecular Substances

- Table below shows physical properties of some simple molecular substances.

Substance	Melting point (°C)	Boiling point (°C)	Solubility in water	Electrical conductivity (in liquid state)	Electrical conductivity (in solid state)
Methane	-182	-161	insoluble	does not conduct	does not conduct
Ammonia	-77	-33	soluble	does not conduct	does not conduct
Water	0	100	--	does not conduct	does not conduct
Iodine	114	184	slightly soluble	not usually found in liquid state	does not conduct

Property #1: Low melting point and boiling point

- Simple molecular substances generally have low melting point and boiling point. For example, melting point of water and methane is 0°C and -182°C respectively.
- They generally exist as liquids or gases at room temperature.

Explanation (using methane as example):

- Methane has a simple molecular structure.
- Small amount of energy is required to overcome the weak intermolecular forces of attraction. Therefore, methane has a low melting and boiling point.

Note: When melting or boiling simple molecular substances, we are not breaking the strong covalent bond between the atoms. We are overcoming the weak intermolecular forces of attraction.

Property #2: Non-conductor of electricity in any states

- Simple molecular substances generally do not conduct electricity in any states.

Explanation (using methane as example):

- Methane has a simple molecular structure.
- There are no free-moving valence electrons available to conduct electricity.

Exceptions: hydrogen chloride (HCl), sulfur dioxide (SO_2), ammonia (NH_3) react with water to form solutions that conduct electricity.

Property #3: Insoluble in water but soluble in organic solvent

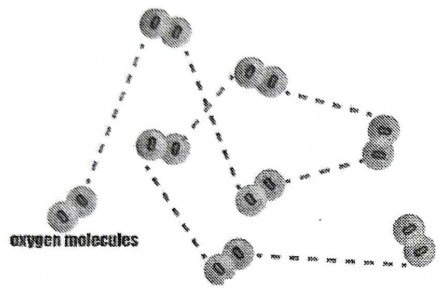
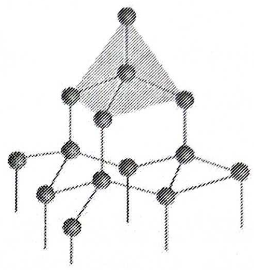
- Simple molecular substances are generally insoluble in water but soluble in organic solvents.
- For example, methane is insoluble in water but can dissolve in organic solvents such as dichloromethane.

F2. Uses of Simple Molecular Substances

property	uses
volatile	• in perfumes and flavourings • in room deodorants • insect repellents, e.g. naphthalene

G. Structure of Giant Molecular Substances

- Besides forming simple molecules, atoms can form a network of covalent bonds throughout the structure
- This will result in the formation of a giant molecular structure.
- Substances with giant molecular structure includes: diamond.
- Comparison between simple molecular structure and giant molecular structures:

	
Simple molecular structure	**Giant molecular structure**

G1. Allotropes of Carbon

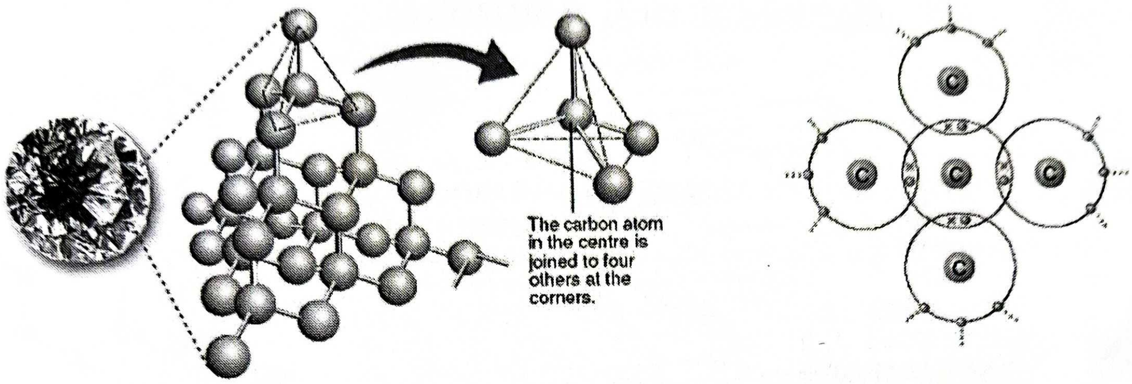
- Allotropes are different forms of the same element. Allotropes may have different properties such as hardness and electrical conductivity
- Two well–known allotropes of carbon are diamond and graphite.
- Table comparing between diamond and graphite:

Property	Diamond	Graphite
Appearance	Transparent colourless crystal	Black, opaque, shiny solid
Density (g/cm^3)	3.5	2.2
Hardness	Very hard	Very soft
Melting and boiling point	Melting point: 3550°C Boiling point: 4827°C	Melting point: 3652°C
Electrical Conductivity	Does not conduct electricity	Conducts electricity.

G2. Diamond

Structure of diamond:

- Diamond has a giant molecular structure.
- In the structure of diamond, each carbon atom is covalently bonded to four other carbon atoms in a tetrahedral arrangement.



Property #1: High melting point

- Diamond has very high melting point; about 3550°C

Explanation:

- Diamond has a giant molecular structure.
- A large amount of energy is required to break strong covalent bonds between carbon atoms. Therefore, diamond has a high melting point.

Property #2: Diamond does not conduct electricity

Explanation:

- Diamond has a giant molecular structure.
- All the four valence electrons of each carbon atom are used for covalent bonding, so there are no free-moving valence electrons present to conduct electricity.

Property #3: Diamond is insoluble in water and organic solvents

Property #4: Diamond is hard

Explanation:

- All the carbon atoms are held by strong covalent bonds throughout the ~~structure~~ structure, hence diamond is hard.
- Due to its hardness, diamond is often used as drill tips and polishing tools.

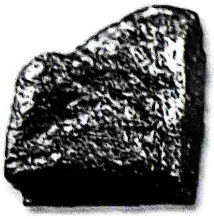
G2.1 Uses of Diamond

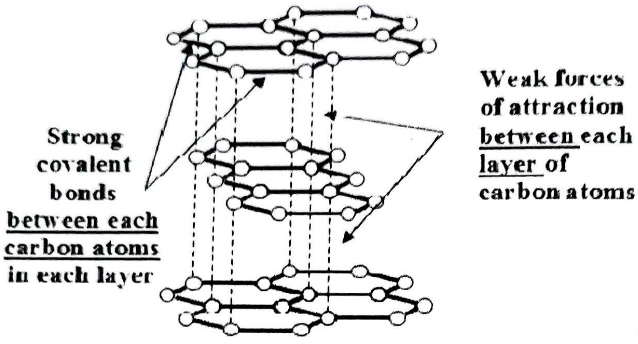
Property	Uses
hard	• tips of cutting, grinding and polishing tools

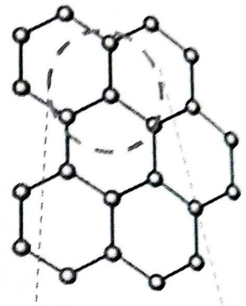
G3. Graphite

Structure of graphite:

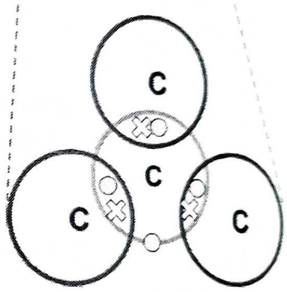
- Graphite has a giant molecular layered structure.
- Graphite is made up of many layers of hexagonal rings of carbon atoms.
- Each carbon atom is covalently bonded to 3 other carbon atoms in hexagonal arrangement
- The carbon atoms are held together by strong covalent bonds but the layers are held together by weak intermolecular forces of attraction.







part of each layer of graphite



Property #1: Graphite has high melting point

- Graphite has very high melting point; about 3650°C

Explanation:

- Graphite has a giant molecular layered ~~covalent bonds~~ ~~strong A~~.
- A large amount of energy is required to overcome the the strong covalent bonds between the carbon atoms. Therefore graphite has a high melting point.

Property #2: Graphite can conduct electricity

Explanation:

- Each carbon atom uses only three out of four valence electrons in bonding. The valence electrons not used in bonding are free-moving. to conduct electricity.
-

Property #3: Solubility of graphite

Graphite is insoluble in water and organic solvents.

Property #4: Graphite is soft and slippery

Explanation:

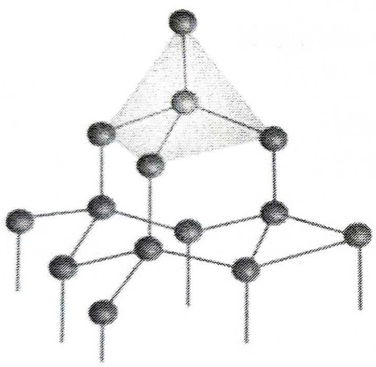
- Graphite has a giant molecular layered structure..
- The layers of carbon atoms in in graphite are held together by weak intermolecular forces of attraction. The layers of atoms are able to slide over one another when a force is applied.

G3.1 Uses of Graphite

Property	Uses
soft and slippery	• in pencil lead. Since it is ~~sot~~ soft, the layers of carbon atoms slide off the pencil onto the paper easily. • as a solid lubricant to reduce friction in machinery
conductor of electricity	• in brushes for electric motors and as inert electrodes.

G4. Silicon and Silicon Dioxide

Structure of silicon: SiO_2



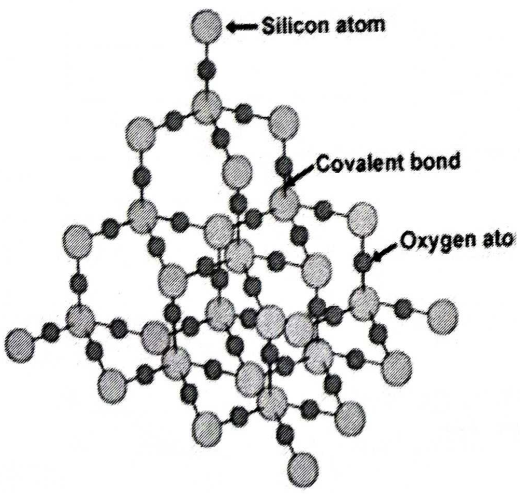
Based on the given structure of silicon,

- state the type of structure that silicon belongs to.

  giant molecular structure

- deduce the following properties of silicon:
  - high / low melting and boiling point.
  - good / non-conductor of electricity.
  - hard / soft solid.
  - soluble / insoluble in water and organic solvent.

Structure of silicon dioxide:



Based on the given structure of silicon dioxide,

- state the type of structure that silicon dioxide belongs to.

  giant molecular structure

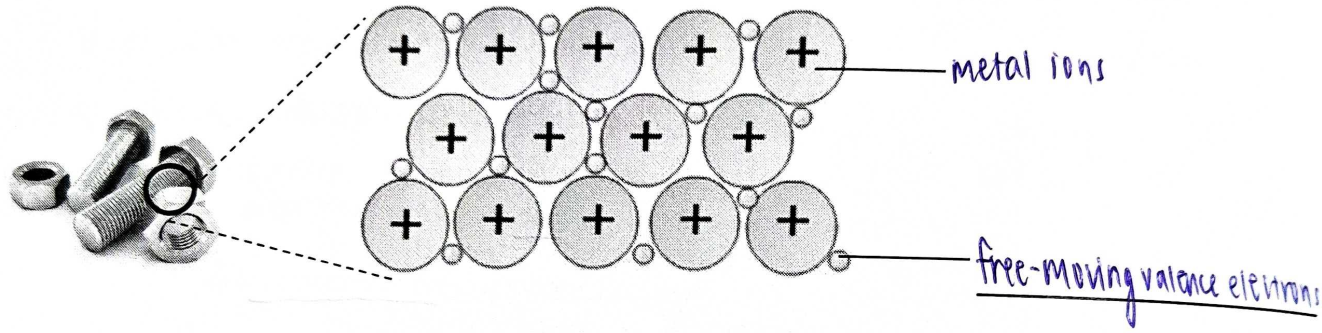
- deduce the following properties of silicon:
  - high / low melting and boiling point.
  - conductor / non-conductor of electricity.
  - hard / soft solid.
  - soluble / insoluble in water and organic solvent.

H. Metallic Bonding

- In any metal, metal atoms are closely packed together to form a giant metallic structure.
- The metal atoms in the giant metallic structure lose their valence electrons and become positive ions.
- The valence electrons are delocalised and can move freely between the metal ions resulting in a 'sea' of free-moving valence electrons.
- A **metallic bond** is the strong electrostatic forces of attraction between the positive metal ions and the 'sea' of delocalised valence electrons.

Note: Metallic bonding exists **within** all metals.

- Diagram below shows the metallic bonding.



H1. Properties of Metals

- Table below shows physical properties of some metals.

Substance	Melting point (°C)	Boiling point (°C)	Electrical conductivity (in liquid state)	Electrical conductivity (in solid state)
magnesium	650	1091	conducts	conducts
copper	1084	2562	conducts	conducts
aluminium	660	2740	conducts	conducts
mercury	-38.8	356	conducts	conducts

Property#1: Metals have high melting point

- Most metals have high melting point.

Explanation:

- Metal has a giant metallic structure.
- A large amount of energy is needed to overcome the strong electrostatic forces of attraction between the positive metal ions and the 'sea' of free-moving valence electrons.
- Therefore metals have high melting points.

Exception: Mercury, which is a liquid at room temperature.

Property #2: Metals can conduct electricity in all states

Explanation:

- Metal has a giant metallic structure.
- There is a 'sea' of free-moving valence electrons present to conduct electricity.

Property #3: Solubility of metals

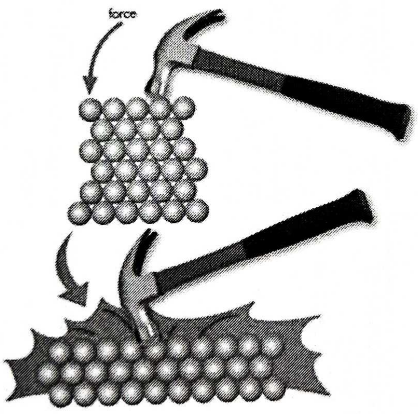
- Metals are insoluble in water and organic solvents.
- *Note:* some metals react with water to form compounds.

Property # 4: Metals are ductile and malleable

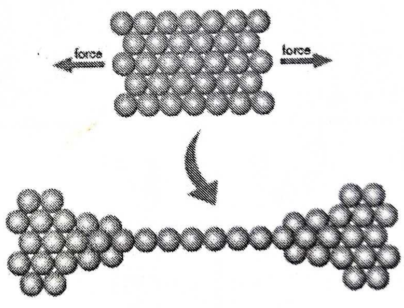
- Ductile – metals can be **stretched into wires** without breaking
- Malleable –metals can be **hammered into different shapes**

Explanation:

- Metal has a **giant metallic structure**.
- Metal ions are arranged orderly in layers. When a force is applied, the layers of metal ions can slide over one another.
- Therefore metals are malleable and ductile.



metals are malleable

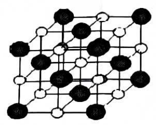
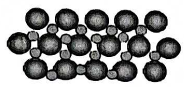
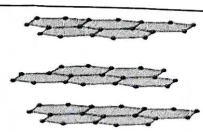
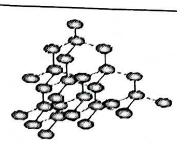
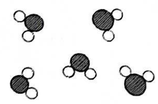


metals are ductile

H2. Uses of Metals

Property	Uses
good conductor of electricity	• in electric wires (e.g. copper) and in electric goods.

★ Summary Table - Different Types of Structure & Physical Properties ★

	Ionic substance	Metallic substance	Covalent substance		
Chemical Structure	**Giant ionic lattice structure**	**Giant metallic lattice structure**	**Giant molecular layered structure**	**Giant molecular structure**	**Simple molecular structure**
Example	NaC*l*, MgO, K_2O, CaF_2, Fe_2O_3, etc.	Na, K, Mg, Ca, Fe, Cu	*Graphite (C) *[below description is for reference to graphite only]*	Diamond (C), Si, SiO_2,	H_2, O_2, N_2, Cl_2, HC*l*, CO_2, SO_3, NH_3,
Particles that make up Substance	Oppositely charged ions (positive metal ions and negative non-metal ions)	Positive metal ions in a 'sea' of delocalised valence electrons	Non-metal carbon atoms	Non-metal atoms	Simple molecules (Non-metal atoms in each molecule)
An Example (Diagram)			 *(Each carbon atom is covalently bonded to 3 other carbon atoms in hexagonal arrangement)*	 *(Each atom is covalently bonded to 4 other atoms in tetrahedral arrangement)*	
Type of Bonds / Forces of Attraction	**Strong electrostatic forces** of attraction (ionic bonds) **between oppositely charged ions** throughout the whole structure.	**Strong electrostatic forces** of attraction (metallic bonds) **between** positive **metal ions** and a 'sea' of free-moving delocalised valence **electrons** throughout the whole structure.	**Strong covalent bonds between** carbon **atoms** in each flat parallel **layer** (but weak intermolecular forces of attraction between layers of atoms)	**Strong covalent bonds between** non-metal **atoms** throughout the whole structure.	**Weak intermolecular forces** of attraction **between** simple **molecules** (but strong covalent bonds between non-metal atoms within each molecule)
Melting / Boiling point	Ionic compounds are solids at r.t.p. and have high melting and boiling points.	Metals are usually solids at r.t.p. and have high melting and boiling points.	Giant molecular layered substances are solids at r.t.p. and have very high melting and boiling points.	Giant molecular substances are solids at r.t.p. and have high melting and boiling points.	Simple molecular substances are usually gases or liquids (solids too, but less common) at r.t.p. and have low melting and boiling points.
	Large amount of energy is needed to overcome the **strong electrostatic forces** of attraction **between oppositely charged ions**	**Large amount** of energy is needed to overcome the **strong electrostatic forces of attraction between the metal ions** and the sea of delocalised valence **electrons**	**Large amount** of energy is needed to overcome the **strong covalent bonds between the atoms** in the layers.	**Large amount** of energy is needed to overcome the **strong covalent bonds between all the atoms** throughout the structure.	**Little amount** of energy is needed to overcome the **weak intermolecular forces** of attraction

	Ionic substance	Metallic substance	Covalent substance		
Chemical Structure	**Giant ionic lattice structure**	**Giant metallic lattice structure**	**Giant molecular layered structure**	**Giant molecular structure**	**Simple molecular structure**
Electrical Conductivity	Non–conductor in solid state but good conductor in molten/ aqueous state	Good electrical conductor in solid & molten state	Good electrical conductor (graphite)*	Non–conductor	Non–conductor Exception: Some simple molecular substances that are soluble and can dissociate in water to form mobile ions, can conduct electricity when in aqueous solution.
	solid: **oppositely charged ions** are **held in fixed positions** by strong electrostatic forces of attraction, hence **ions are not mobile** to conduct electricity **molten / aqueous:** electrostatic forces of attraction between oppositely charged ions are overcome and **ions are mobile** / free moving to conduct electricity	presence of delocalised **mobile / free moving** valence **electrons** to conduct electricity	**Each** carbon **atom** uses only **3 out of 4 valence electrons** for covalent **bonding**. The **valence electrons not** used for bonding along each layer of atoms are **mobile/ free moving** to conduct electricity.	**absence** of **mobile / free** moving valence **electrons** [For Group 14 non-metal element (eg carbon atoms in diamond & silicon atoms) : Each atom uses all its 4 valence electrons for covalent bonding. There are no more mobile valence electrons to conduct electricity.]	**absence** of **mobile / free moving** valence **electrons**
Solubility	Generally soluble in water and insoluble in organic solvents	Generally, insoluble in water and organic solvent, but some metals react with water.	Insoluble in water and organic solvents		Insoluble in water but soluble in organic solvents
Other special properties	-	malleable and ductile — when a force is applied, the layers of ions can easily slide over each other without breaking the metallic bond	soft and slippery • Weak intermolecular forces of attraction between layers of atoms. Hence, layers can easily slide over each other Uses: As a lubricant for machinery	extremely hard • All the atoms are held by strong covalent bonds together throughout the giant molecular structure. Uses: Cutting tool	-