5072 CHEMISTRY (NEW PAPERS WITH SPA)
TOPIC 2: THE PARTICULATE NATURE OF MATTER

5067 CHEMISTRY (NEW PAPERS WITH PRACTICAL EXAM)
TOPIC 2: THE PARTICULATE NATURE OF MATTER

SUB-TOPIC 2.3 TO 6
STRUCTURE AND PROPERTIES OF MATERIALS; IONIC BONDING; COVALENT BONDING; METALLIC BONDING

LEARNING OUTCOMES
SUB-TOPIC 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 molecular substances, e.g. poly(ethene); sand (silicon dioxide); diamond; graphite in order to deduce their properties c) Compare the bonding and structures of diamond and graphite in order to deduce their 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 SUB-TOPIC 2.4: IONIC BONDING a) Describe the formation of ions by electron loss/gain in order to obtain the electronic configuration of a noble 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) 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 SUB-TOPIC 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 a noble gas b) 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 c) Deduce the arrangement of electrons in other covalent molecules d) Relate the physical properties (including electrical property) of covalent substances to their structure and bonding SUB-TOPIC 2.6: METALLIC BONDING a) Describe metals as a lattice of positive ions in a 'sea of electrons' b) Relate the electrical conductivity of metals to the mobility of the electrons in the structure

A Introduction

- Substances that make up matter consists of three things:
  - Elements
    - Elements are divided into metals and non-metals:

	Appearance	Physical state	Melting/ Boiling Point	Density	Malleability/ Ductility	Heat & Electrical Conductivity
Metals	Shiny surface (lustrous)	Solid	High	High	Malleable & Ductile	Good
Non-Metals	Dull surface (non-lustrous)	Gas/ Liquid	Low	Low	Brittle & Non-Ductile	Poor

    - When two or more metals mix together, a mixture called an alloy is formed. An alloy is a mixture of a metal with other elements. This other element can be a metal or even a non-metal and is introduced to make the parent metal harder and stronger.
  - Compounds
  - Mixtures
    - A mixture is formed by physically mixing two or more substances. There are a few types:

Type	**Element + Element**	**Element + Compound**	**Compound + Compound**
Example	Pewter	Air	Seawater
Constituents	Tin, Copper, Antimony	Oxygen, Nitrogen, Carbon Dioxide, etc	Salt, Water

- The following table lists the differences between Elements, Compounds and Mixtures:

	Formation	Composition	Properties	Separation
Elements	Simplest form of matter	Contains only one type of atom	NA	Cannot be decomposed by chemical means into simpler substances
Compounds	Consists of two or more different types of elements chemically joined together, involves heat changes	Contains two or more different types of atoms in fixed proportion.	Different from the properties of constituents	Can be decomposed by chemical means into simpler substances
Mixtures	Consists of two or more different types of elements and/ or compounds physically mixed together.	Contains two ore more different types of atoms/ substances in varied proportions	Same as the properties of constituents	Can be separated by physical means

B Ions and Ionic Bonds

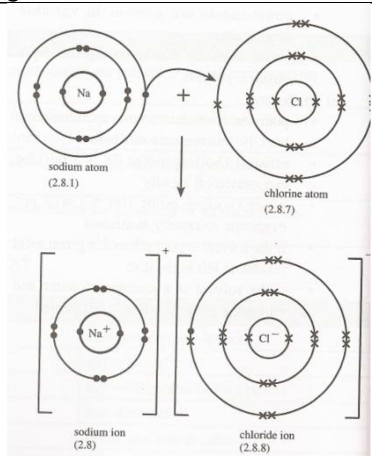
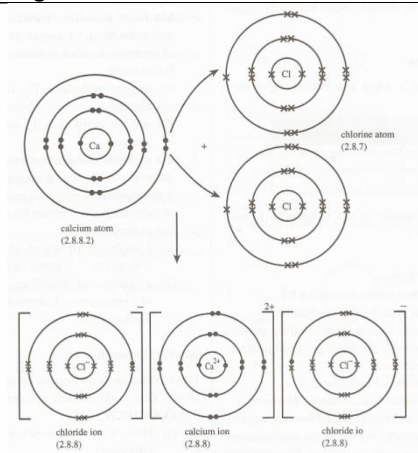
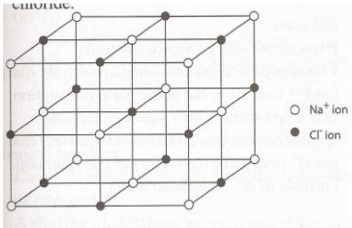
- Ions are charged particles, formed when an atom loses or gains electrons.

- Atoms lose or gain electrons in order to achieve a noble gas configuration.

	Metals	**Non-Metals**
Valency	Metal atoms lose their valence electrons to achieve a noble gas configuration	Non-Metal atoms gain electrons to achieve a noble gas configuration
Ions	A positive ion, cation, is formed	A negative ion, anion, is formed
E.g. 1	Group I They lose 1 valence electron to form ions with charge of +1 Li (2, 1) → Li^+ (2) Na (2, 8, 1) → Na^+ (2, 8) K (2, 8, 8, 1) → K^+ (2, 8, 8)	Group VII They gain 1 electron to form ions with charge of -1 F (2, 7) → F^- (2, 8) Cl (2, 8, 7) → Cl^- (2, 8, 8) Br (2, 8, 18, 7) → Br^- (2, 8, 18, 8)
E.g. 2	Group II They lose 2 valence electrons to form ions with charge of +2 Be (2, 2) → Be^{2+} (2) Mg (2, 8, 2) → Mg^{2+} (2, 8) Ca (2, 8, 8, 2) → Ca^{2+} (2, 8, 8)	Group VI They gain 2 electrons to form ions with charge of -2 O (2, 6) → O^{2-} (2, 8) S (2, 8, 6) → S^{2-} (2, 8, 8)
E.g. 3	Group III They lose 3 valence electrons to form ions with charge of +3 Al (2, 8, 3) → Al^{3+} (2, 8) Ga (2, 8, 18, 3) → Ga^{3+} (2, 8, 18)	

- Ionic bonds are formed between metal atoms and non-metal atoms.
- A transfer of electrons from a metal atom to a non-metal atom enables both to achieve the stable noble gas configuration.
- The resulting oppositely-charged ions formed then attract each other via strong electrostatic forces of attraction.
- Take for example, the formation of Sodium Chloride and Calcium Chloride:

	Sodium Chloride	**Calcium Chloride**
Constituents	Sodium Chloride is formed when a Sodium atom combined with a Chlorine atom. Na (g) + Cl (g) → NaCl (s)	Calcium Chloride is formed when a Calcium atom combines with two Chlorine atoms. Ca (g) + 2Cl (g) → $CaCl_2$ (s)
Cation	Each Sodium atom loses 1 electron to form a positively charged ion, Na^+, so as to achieve the noble gas configuration similar to neon. This electron is transferred to a Chlorine atom. Na (2, 8, 1) → Na^+ (2, 8) + e^-	Each Calcium atom loses 2 electrons to form a positively charged ion, Ca^{2+}, so as to achieve the noble gas configuration similar to Argon. The two electrons are transferred to 2 Chlorine atoms. Ca (2, 8, 8, 2) → Ca^{2+} (2, 8, 8) + $2e^-$
Anion	Each Chlorine atom gains 1 electron from Sodium to form a negatively charged ion, Cl^-, so as to achieve the noble gas	Each Chlorine atom gains 1 electron to form a negatively charged ion, Cl^- so as to achieve the noble gas configuration

	configuration similar to Argon. Cl (2, 8, 7) + e^- → Cl^- (2, 8, 8)	similar to Argon. Cl (2, 8, 7) + e^- → Cl^- (2, 8, 8)
Bonding	The oppositely charged ions, Na^+ and Cl^- are then held together by strong electrostatic forces and form an ionic bond.	The oppositely charged ions, Ca^{2+} and Cl^- are then held together by strong electrostatic forces and form an ionic bond.
Diagram		
Crystal Lattice	In a crystal of Sodium Chloride, the ions are arranged in a regular lattice structure with each Na^+ ion surrounded by 6 Cl^- ions and each Cl^- ion surrounded by 6 Na^+ ions. 	-

- Ionic Compounds have a few properties:

Melting/ Boiling Points	<u>Ionic compounds have high melting and boiling points</u> The oppositely charged ions are held together by very strong electrostatic forces of attraction which require a lot of energy to overcome. Therefore, ionic compounds are difficult to melt, This ability to withstand high temperatures makes ionic compounds (e.g. Magnesium Oxide) suitable for use as lining for furnaces.
Electrical	<u>Ionic Compounds conduct electricity only when molten or dissolved in water</u>

Conductivity	In the solid state, the ions are bonded together by strong electrostatic attractions and can only vibrate about a fixed point. In the molten or aqueous state, the ions are free to move to carry an electric current.
Solubility	Ionic compounds readily dissolve in water but not in organic solvents Ions are readily hydrated by water but not by organic solvents.

C Molecules and Compounds

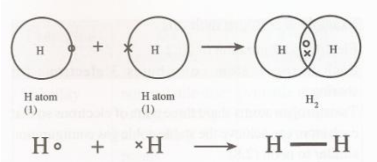
- When two or more atoms are chemically bonded together, a molecule is formed.
- A molecule is a group of atoms chemically bonded together.
- Most non-metallic elements are found in the molecular form, i.e. two or more of the same type of atoms are bonded together.
  - ➢ Oxygen molecules, O_2, contain 2 Oxygen atoms.
  - ➢ Sulphur molecules, S_8, contain 8 Sulphur atoms.
- If a molecule is made up of atoms of two or more different elements, a compound is formed. A compound is a substance made by combining two or more elements together by a chemical reaction.
  - ➢ A molecule of Water, H_2O, is made up of 2 elements: 2 atoms of Hydrogen and 1 atom of Oxygen.
  - ➢ A molecule of Chloroform, $CHCl_3$, is made up of 3 elements: 1 atom of Carbon, 1 atom of Hydrogen and 3 atoms of Chlorine.

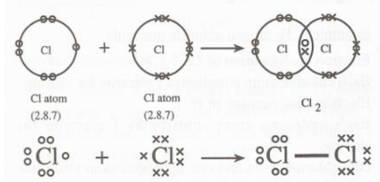
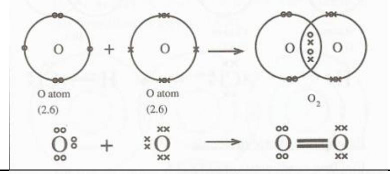
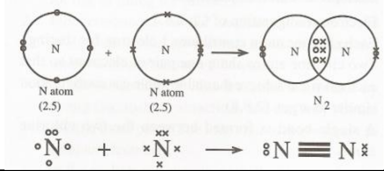
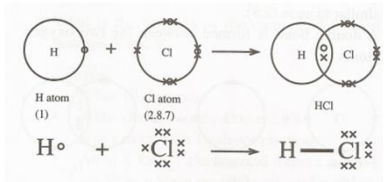
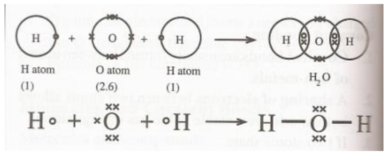
D Simple Covalent Bonding

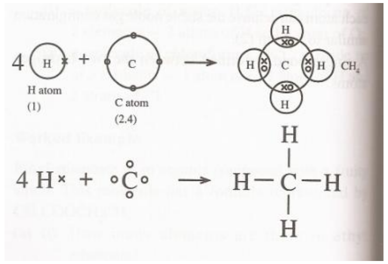
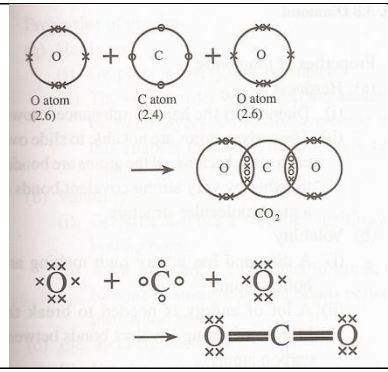
- Covalent bonds are usually formed between atoms of non-metals.
- A sharing of electrons between two atoms allows both to achieve a suitable noble gas configuration.

Number of atoms shared	Type of Bond	Example
1	Single	H – H
2	Double	O = O
3	Triple	N ≡ N

- Each atom contributes an equal number of electrons for sharing.
- In the following examples, only the outermost electrons are shown:

Compound	Atoms involved	Formation, Type of Bond	Diagram
Hydrogen molecule H_2	Hydrogen (1) Each Hydrogen atom contributes 1 electron for sharing.	2 Hydrogen atoms share 1 pair of electrons so that each atom can achieve the stable noble gas configuration similar to Helium (2) A single bond is formed.	

Chlorine molecule Cl_2	<u>Chlorine (2,8,7)</u> Each Chlorine atom contributes 1 electron for sharing.	2 Chlorine atoms share 1 pair of electrons so that each atom can achieve the stable noble gas configuration similar to Argon (2,8,8) A single bond is formed.	
Oxygen molecule O_2	<u>Oxygen (2,6)</u> Each Oxygen atom contributes 2 electrons for sharing.	2 Oxygen atoms share 2 pairs of electrons so that each atom can achieve the stable noble gas configuration similar to Neon (2,8) A double bond is formed.	
Nitrogen molecule N_2	<u>Nitrogen (2,5)</u> Each Nitrogen atom contributes 3 electrons for sharing.	2 Nitrogen atoms share 3 pairs of electrons so that each atom can achieve the stable noble gas configuration similar to Neon (2,8) A triple bond is formed.	
Hydrogen Chloride molecule HCl	<u>Hydrogen (1)</u> Each Hydrogen atom contributes 1 electron for sharing. <u>Chlorine (2,8,7)</u> Each Chlorine atom contributes 1 electron for sharing	1 Chlorine atom and 1 Hydrogen atom share one pair of electrons so that each atom can achieve the stable noble gas configuration: Hydrogen achieves Helium (2), while Chlorine achieves Argon (2,8,8). A single bond is formed.	
Water molecule H_2O	<u>Hydrogen (1)</u> Each Hydrogen atom contributes 1 electron for sharing. ∴ Each 2 Hydrogen atoms are needed to contribute to a total of 2 electrons for sharing. <u>Oxygen (2,6)</u> Each Oxygen atom contributes 2 electrons for sharing.	1 Oxygen atom and 2 Hydrogen atoms share two pairs of electrons so that each atom can achieve the noble gas configuration: Hydrogen achieves Helium (2), while Oxygen achieves Neon (2,8) 2 single bonds are formed.	

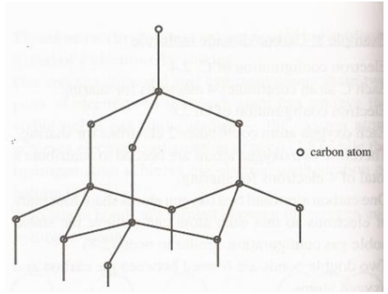
Methane molecule CH_4	<u>Carbon (2,4)</u> Each Carbon atom contributes 4 electrons for sharing. <u>Hydrogen (1)</u> Each Hydrogen atom contributes 1 electron for sharing. ∴ Each 4 Hydrogen atoms are needed to contribute to a total of 4 electrons for sharing.	1 Carbon atom and 4 Hydrogen atoms share 4 pairs of electrons so that each atom can achieve the noble gas configuration: Carbon achieves Neon (2,8), while Hydrogen achieves Helium (2). 4 single bonds are formed.	
Carbon Dioxide molecule CO_2	<u>Carbon (2,4)</u> Each Carbon atom contributes 4 electrons for sharing. <u>Oxygen (2,6)</u> Each Oxygen atom contributes 2 electrons for sharing. ∴ Each 2 Oxygen atoms are needed to contribute to a total of 4 electrons for sharing.	1 Carbon atom and 2 Oxygen atoms share 4 pairs of electrons so that each atom can achieve the noble gas configuration similar to Neon (2,8) 2 double bonds are formed.	

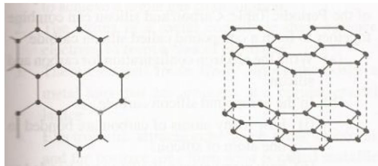
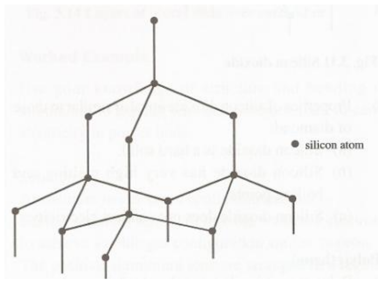
- Covalent compounds have certain properties:

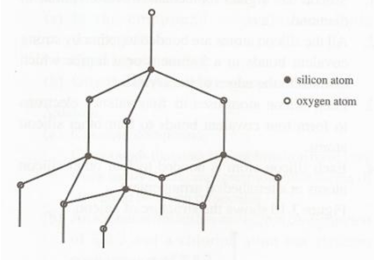
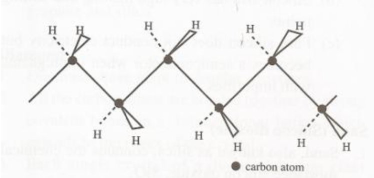
Melting/ Boiling Points	<u>Covalent compounds have low melting and boiling points</u> The molecules are held together by very weak van der Waals' forces of attraction. Very little energy is required to overcome these weak intermolecular forces of attraction.
Electrical Conductivity	<u>Covalent Compounds do not conduct electricity</u> Molecules in covalent compounds do not carry charges, i.e. there are no ions in covalent compounds.
Solubility	<u>Covalent Compounds dissolve in organic solvents but not in water</u> Covalent molecules are not readily hydrated by water molecules.

E Macromolecules/ Giant Covalent Molecules

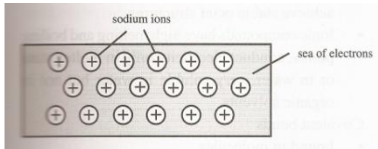
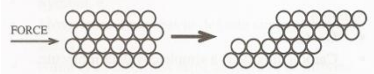
- Some substances consist of extremely large molecules or even giant molecules. These molecules are called macromolecules.
- Large molecules have thousands of atoms per molecule, while giant molecules contain billions of atoms per molecules.
- Poly(ethene) is an example of a large molecule.
- Examples of giant molecules include diamond, graphite and silica.

Compound	Description	Properties	Diagram
Diamond	- Diamonds have a giant molecular structure. - All the Carbon atoms are bounded together by strong covalent bonds in a 3-dimensional lattice which extends to the edges of the crystal. - Each single crystal of a diamond is one giant molecule. - Each Carbon is bonded to 4 other Carbon atoms in a tetrahedral arrangement. - Each Carbon atom uses all of its 4 valence electrons to form 4 covalent bonds to 4 other Carbon atoms.	- Diamond is the hardest substance known. The Carbon atoms are not able to slide over each other because all the atoms are bonded together by very strong covalent bonds in a giant molecular structure. - A diamond has a very high melting and boiling point. A lot of energy is needed to break the billions of strong covalent bonds between Carbon atoms. - Diamonds do not conduct electricity. Each Carbon atom uses all its 4 valence electrons for bonding. Hence it has no 'free' electrons to conduct electricity.	

Graphite	- Graphite is another crystalline form of Carbon. - Graphite also has a giant molecular structure. - Graphite has a layered structure consisting of millions of layers of Carbon atoms - In each layer, ➢ All the Carbon atoms are bonded together by strong covalent bonds in a 2-dimensional lattice which extends to the edges of the crystal. Each layer becomes one giant molecule. ➢ Each Carbon atom is bonded to 3 other Carbon atoms in a hexagonal arrangement to form rings of regular hexagons. ➢ Each Carbon atom uses only 3 valence electrons to form 3 covalent bonds to 3 other Carbon atoms. - The different layers of Carbon atoms are held together by weak van der Waals' forces of attraction.	- Graphite is a very soft substance. The weak van der Waals' forces of attraction between layers are easily overcome and this enables the layers to slide over each other. - Graphite also has a very high melting and boiling point. A lot of energy is required to break the billions of strong covalent bonds between the Carbon atoms. - Graphite conducts electricity. Each Carbon atom uses only 3 out of 4 valence electrons for bonding. Hence it has 1 'free' electron to conduct electricity parallel to the layers.	 Fig. 3.9 Graphite
Silicon	- Silicon has a giant molecular structure similar to diamond. - All the silicon atoms are bonded together by strong covalent bonds in a 3-dimensional lattice which extends to the edges of the crystal. - Each silicon atom uses its 4 valence electrons to form 4 covalent bonds to 4 other Silicon atoms. - Each Silicon atom is bonded to 4 other	- Silicon is a hard substance though not as hard as diamond. - Silicon also has very high melting and boiling points. - Pure Silicon does not conduct electricity but becomes a semiconductor when impregnated with impurities.	

	Silicon atoms in a tetrahedral arrangement.		
Sand/ Silicon Dioxide/ Silica/ SiO_2	- Silicon Dioxide has a giant molecular structure similar to diamond. - Each silicon atom is bonded to 4 other Oxygen atoms in a tetrahedral arrangement. - Each Silicon atom forms 4 covalent bonds to 4 Oxygen atoms.	- Silicon Dioxide is a very hard solid. - Silicon Dioxide has very high melting and boiling points. - Silicon Dioxide does not conduct electricity.	 Fig. 3.11 Silicon dioxide
Poly (ethene)	- Poly(ethene) is a large molecule. It is a polymer. - A polymer is a long chain molecule made by joining thousands of small repeated units (monomers) together. - The repeated unit in Poly(ethene) is the ethene molecule, C_2H_4.	- Poly(ethene) has high melting points. - Poly(ethene) does not conduct electricity.	 Fig. 3.12 Poly(ethene)

F Metallic Bonding

- Metals are electropositive elements, ie. Metals have a tendency to lose their outermost electrons in order to achieve a noble gas configuration. - The atoms in a metal contribute to their valence electrons to form a 'sea of electrons'. - These electrons move freely amongst the positive metal ions that are arranged in a regular crystal lattice. - Electrostatic attraction between these electrons and the positive ions form what is called metallic bonding. - The sea of electrons help to cement the positive ions together to give metals a giant metallic structure.	 Fig. 3.13 Bonding in metal
<u>Metals conduct electricity in the solid and molten states, Metals conduct heat</u> This is because they have mobile electrons to carry electricity and heat energy. <u>Most Metals have high melting and boiling points (Excluding Mercury)</u> This is because of the very strong electrostatic forces of attraction between the sea of electrons and the positive metal ions.	 Fig. 3.14 Layers of atoms slide over each other

<u>Metals are malleable and ductile</u> This is due to the orderly packing of metal atoms. They layers of atoms can easily slide over each other whenever a force is applied.	

G In Summary

Characteristic	Ionic Compound	Covalent Compound		Metals
		Simple Molecule	Macromolecule	
Atoms involved	Metals and Non-Metals	Non-Metals	Non-Metals	Metals
Particles	Ions (Cations & Anions)	Molecules	Atoms	Fixed positive ions in a “sea of delocalised e^-“
State at r.t.p.	Solid	Gas/ Volatile Liquid	Solid	Solid
Melting/ Boiling Point	High	Low	High	High (Exc. Hg)
	Strong electrostatic forces of attraction between oppositely charged ion. A large amount of heat energy is required to overcome it.	Weak intermolecular (Van der Waals’) forces between molecules. A small amount of heat energy is required to overcome it.	Exists as macromolecule with strong covalent bonds between atoms. A large amount of heat energy is required to overcome it.	Strong metallic bond between positively charged ions and delocalised electrons. A large amount of heat energy is required to overcome it.
Electrical Conductivity	Molten and Aqueous only	-	- (Exc. Graphite)	Solid and Molten only
	In molten and aqueous states, ions are mobile and able to conduct electricity. In solid state, ions are held rigidly in fixed positions and are unable to move thus unable to conduct electricity.	Exists as neutral molecules. Absence of mobile charged particles.	Absence of charged particles in diamond, silicon and silica. Graphite can conduct electricity due to the presence of mobile electrons which can carry electrical charges.	Presence of electron cloud which are able to carry electrical charges.
Solubility	Soluble in Water, Insoluble in organic solvents	Soluble in organic solvents, insoluble in water	Insoluble in water and almost all solvents	Insoluble in water
Example	Sodium Chloride	Chlorine	Diamond	Magnesium