Delta Science Education

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HKDSE CHEMISTRY

Section 2: Microscopic World I

Part 2

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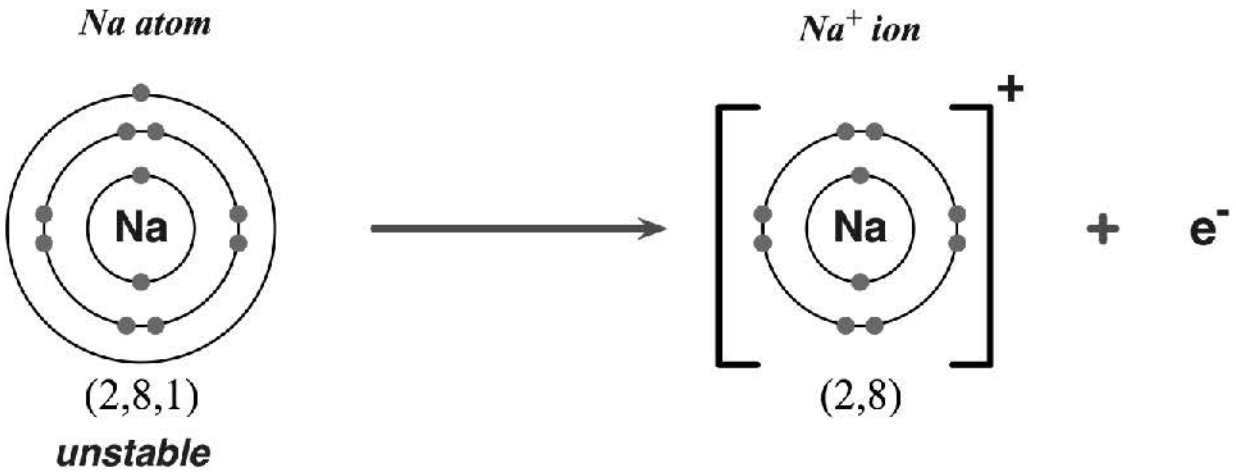
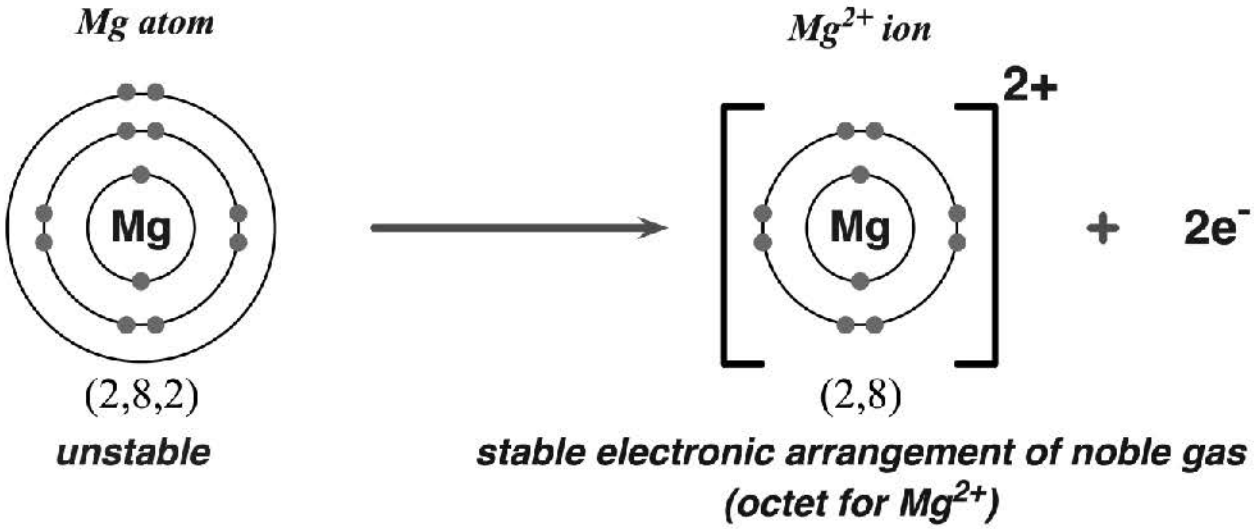
3. Ionic Bond and Giant Ionic Structure

A. Formation of cations from atoms

- **Cation:** the **positive** ion
- **Metal cation:** a **metal** atom [ ] one or more electrons to form a positive ion or cation.





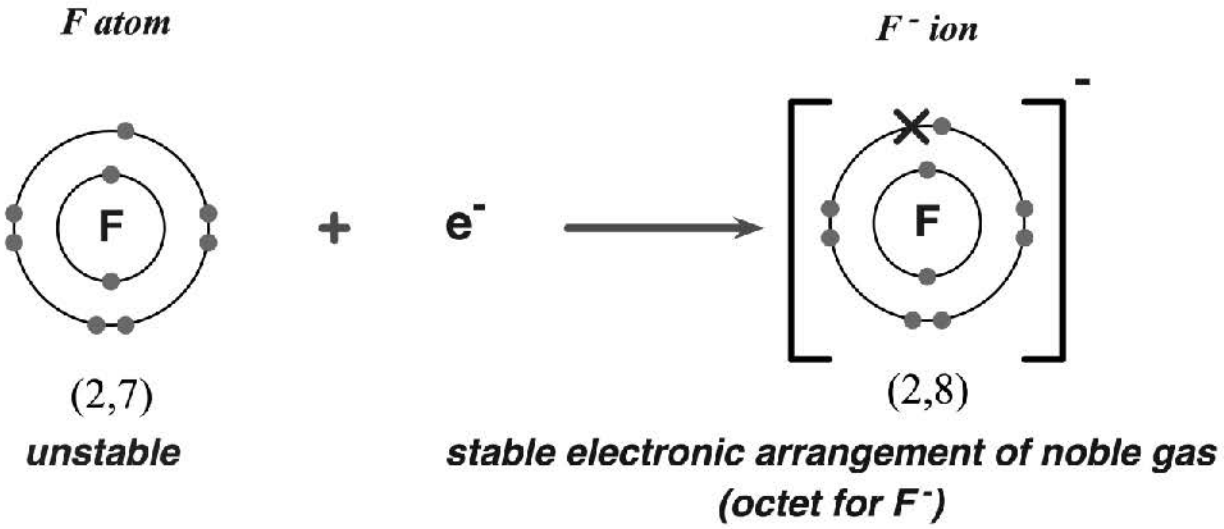
Why do the metal atoms tend to form cations?

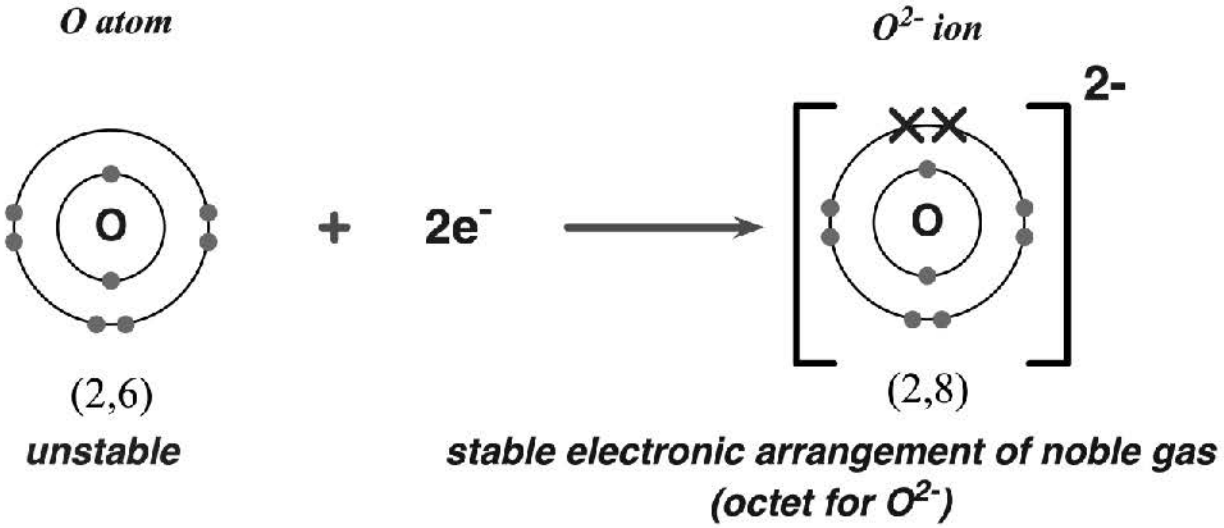
When a **metal atom loses** its outermost shell electron(s)

- a [ ] **of noble gas (octet or duplet) can be obtained**
- the cation is relatively more stable than the atom

B. Formation of anions from atoms

- **Anion:** the negative ion
- **Non-metal cation:** a **non-metal** atom [ ] one or more electrons to form a negative ion or anion.





Why do the non-metal atoms tend to form anions?

When a **non-metal atom gains** electron(s)

- **a stable electronic arrangement of noble gas (octet or duplet) can be obtained**
- the anion is relatively more stable than the atom

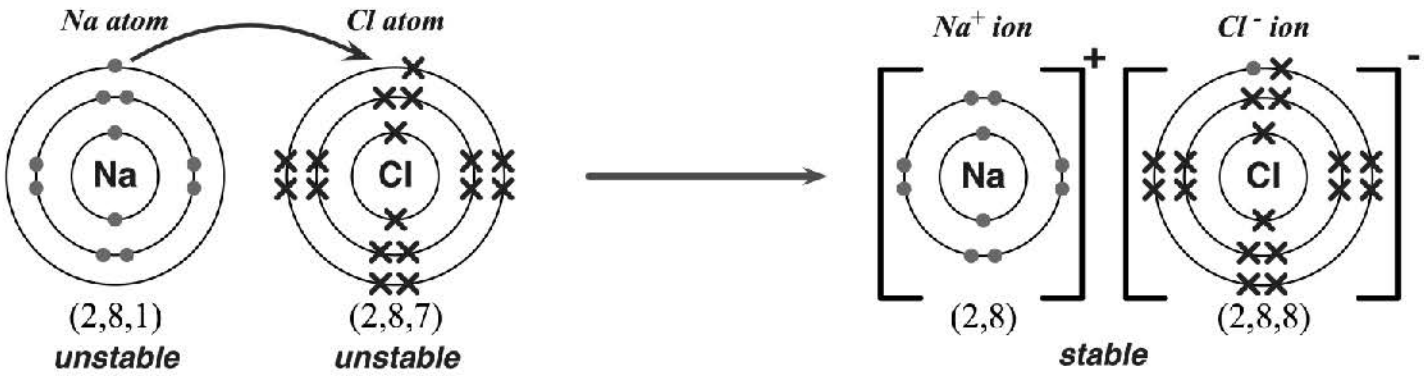
C. Common cations and anions

Cation	Name	Colour in water
Li^+ / Na^+ / K^+	Lithium ion / Sodium ion / Potassium ion	Colourless
Mg^{2+} / Ca^{2+}	Magnesium ion / Calcium ion	
Al^{3+}	Aluminium ion	
Ag^+ / Hg^+	Silver ion / Mercury(I) ion	
Zn^{2+} / Pb^{2+} / Hg^{2+}	Zinc ion / Lead(II) ion / Mercury(II) ion	
Cu^+	Copper(I) ion	Free Cu^+ does not exist in water
Cu^{2+}	Copper(II) ion	(Greenish) blue
Fe^{2+}	Iron(II) ion	Green
Fe^{3+}	Iron(III) ion	Yellow
Ni^{2+}	Nickel(II) ion	Green
Cr^{3+}	Chromium(III) ion	Green
Mn^{2+}	Manganese(II) ion	Very pale pink or colourless
NH_4^+	***Ammonium ion***	***Colourless***
H^+	*Hydrogen ion*	Colourless

Anion	Name	Colour in water
F^- / Cl^- / Br^- / I^- / H^-	Fluoride ion / Chloride ion / Bromide ion / Iodide ion / Hydride ion	Colourless
O^{2-} / S^{2-}	Oxide ion / Sulphide ion	Do not exist in water
N^{3-}	Nitride ion	
OH^-	Hydroxide ion	Colourless
NO_2^- / NO_3^-	Nitrite ion / Nitrate ion	
SO_3^{2-} / SO_4^{2-}	Sulphite ion / Sulphate ion	
HSO_3^- / HSO_4^-	Hydrogensulphite ion / Hydrogensulphate ion	
CO_3^{2-}	Carbonate ion	
HCO_3^-	Hydrogencarbonate ion	
PO_4^{3-}	Phosphate ion	
MnO_4^-	Permanganate ion	Deep purple
$Cr_2O_7^{2-}$	Dichromate ion	Orange
CrO_4^{2-}	Chromate ion	Yellow

D. Ionic bond and ionic compound

- When metal atoms react with non-metals atoms, there is [ ] **of electrons** from metal atoms to non-metal atoms, forming cations and anions.
- **Ionic bond:** the strong electrostatic attraction between cation and anions.
- Ionic bond is [ ].
- **Example 1: formation of Sodium Chloride:**



- **Example 2: formation of Lithium Oxide:**

Examples that you must fully understand

Draw the electron diagrams of the following ionic compounds, show only the outermost shell.

(a) Al and Br

(b) Al and O

(c) Al and N

(d) Ca and F

(e) Mg and S

(f) Li and N

(g) K and H

E. Formula, name and relative formula mass of ionic compounds

- The total charge of an ionic compound must be **ZERO**:

Sodium and Chlorine ⇒

Magnesium and Sulphur ⇒

Lithium and Sulphate ion ⇒

Aluminium and Oxygen ⇒

Iron and Oxygen ⇒ Fe^{2+} & O^{2-} ⇒ FeO

Iron and Oxygen ⇒ Fe^{3+} & O^{2-} ⇒ Fe_2O_3

NH_4^+ & PO_4^{3-} ⇒ [Ammonium phosphate]

Al^{3+} & CO_3^{2-} ⇒ [Aluminium carbonate]

Cu^{2+} & SO_4^{2-} & $5H_2O$ ⇒ [Copper(II) sulphate or Copper(II) sulphate-5-water]

Cu^{2+} & SO_4^{2-} ⇒ $CuSO_4$ [Copper(II) sulphate]

- **Relative formula mass of an ionic compound** = sum of the relative atomic masses of all elements present in a simplest unit of the ionic compound.

RAM of H = 1.0; N = 14.0; O = 16.0; Na = 23; Al = 27.0; S = 32.0; K = 39.0; Cl = 35.5; Fe = 55.8; Cu = 63.5

$NaCl$ ⇒

K_2SO_4 ⇒

Al_2O_3 ⇒

FeO ⇒

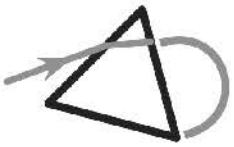
Fe_2O_3 ⇒

$CuSO_4 \cdot 5H_2O$ ⇒

Examples that you must fully understand

1. Write down the chemical formulae of the following ionic compounds and calculate the relative formula masses:

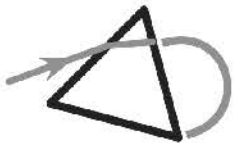
Ionic compound	Chemical formula
sodium hydroxide	
potassium sulphide	
calcium chloride	
aluminium oxide	
calcium oxide	
magnesium sulphate	
zinc nitrate	
potassium phosphate	
calcium carbonate	
copper(II) sulphate	
potassium permanganate	
sodium hydrogencarbonate	
iron(III) chloride	
magnesium nitrate	
aluminium sulphate	
ammonium sulphate	
copper(I) oxide	
lead(II) carbonate	
Iron(II) oxide	
magnesium nitride	
silver chromate	



Examples that you must fully understand

2. Write down the chemical name of the following ionic compounds:

Chemical formula	Ionic compound
KOH	
LiF	
$Al(NO_3)_3$	
$CuCO_3$	
$K_2Cr_2O_7$	
$AgCl$	
$FeSO_4$	
$NiCO_3$	
$Zn(NO_3)_2$	
Fe_2O_3	
CuI	
$NaHCO_3$	
$KHSO_4$	
NH_4Cl	
Na_2SO_3	
$MgBr_2$	
$CoCl_2$	
$BaSO_4$	
Mg_3N_2	
$Na_2Cr_2O_7$	
$HgCl_2$	



Examples that you must fully understand

3. Element X and Y have atomic numbers of 16 and 20 respectively. The formula for the compound formed between X and Y would be:

   A. YX

   B. Y_2X

   C. YX_2

   D. Y_2X_3

4. Q is an element in the third period of the Period Table. Q forms a sulphate which has a formula of $Q_2(SO_4)_3$. The formula of the nitrate of Q is

   A. QNO_3

   B. $Q(NO_3)_2$

   C. $Q(NO_3)_3$

   D. $Q_2(NO_3)_3$

5. The atomic number of element X is 20. X reacts with element Y to form an ionic compound with formula XY_2. To which Group of the Periodic Table does Y belong?

   A. *Group IV*

   B. *Group V*

   C. *Group VI*

   D. *Group VII*

6. Statement one-two:

   Statement 1: All ionic compounds contain metal.

   Statement 2: Metal tends to lose electrons and form cations.

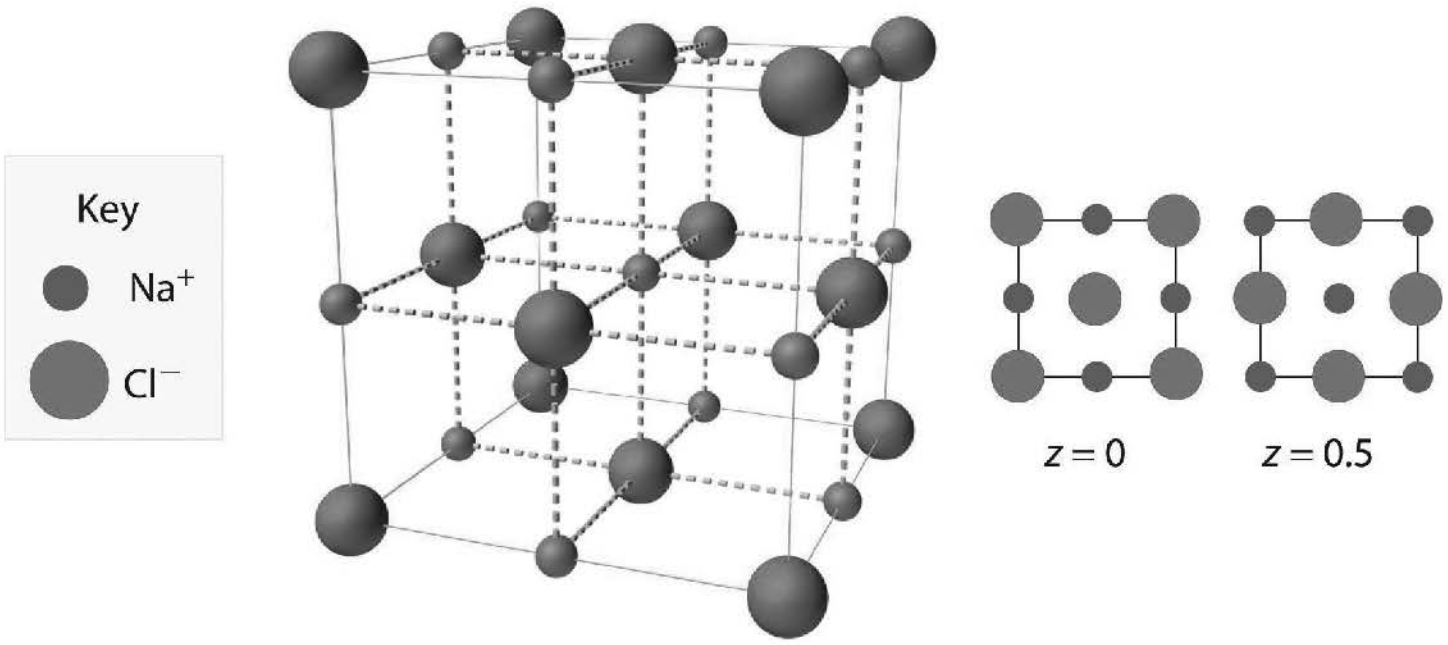
F. Strength of Ionic bond

- Generally, **smaller** the size of ions >> [ ] ionic bond
  - LiCl > NaCl > KCl
- Generally, **more the charges** of ions >> [ ] ionic bond
  - $AlCl_3$ > $MgCl_2$ > NaCl

G. Giant Ionic Structure

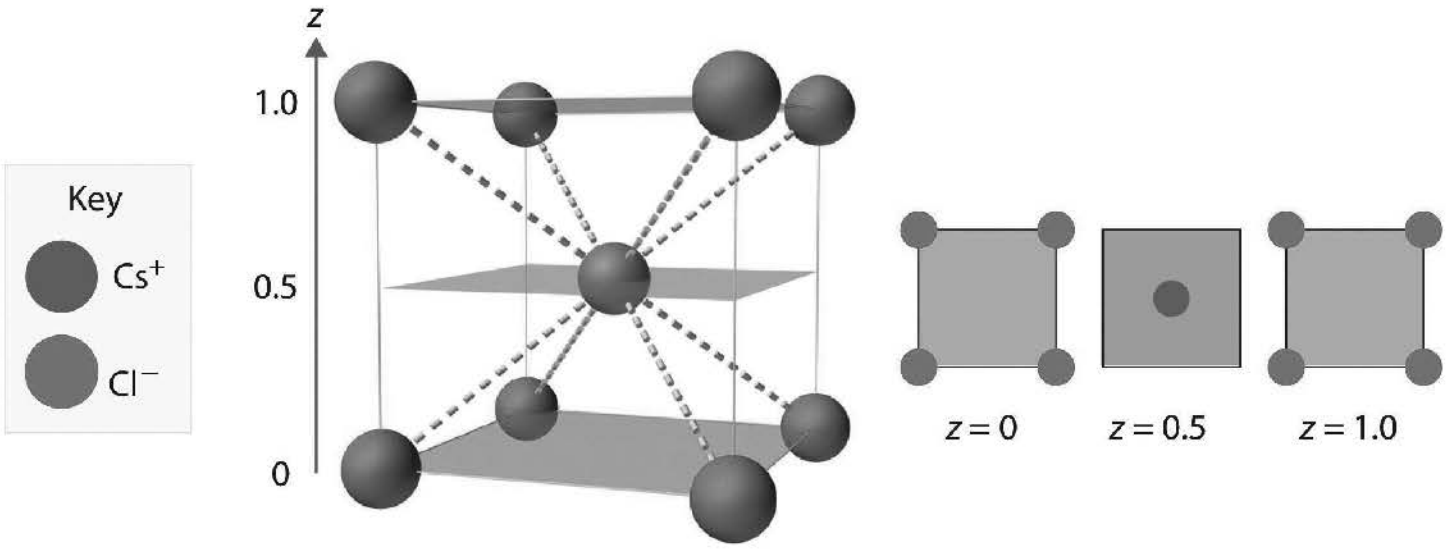
- The physical properties of a substance mainly depend on its structure.
- Ionic compound has a **crystal** structure, in which the cations and anions are **regularly arranged** to form a giant ionic structure.

Structure of Sodium Chloride (NaCl)



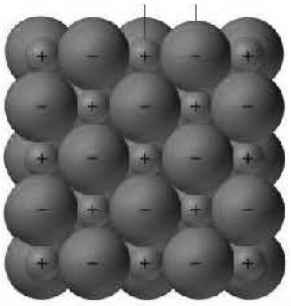
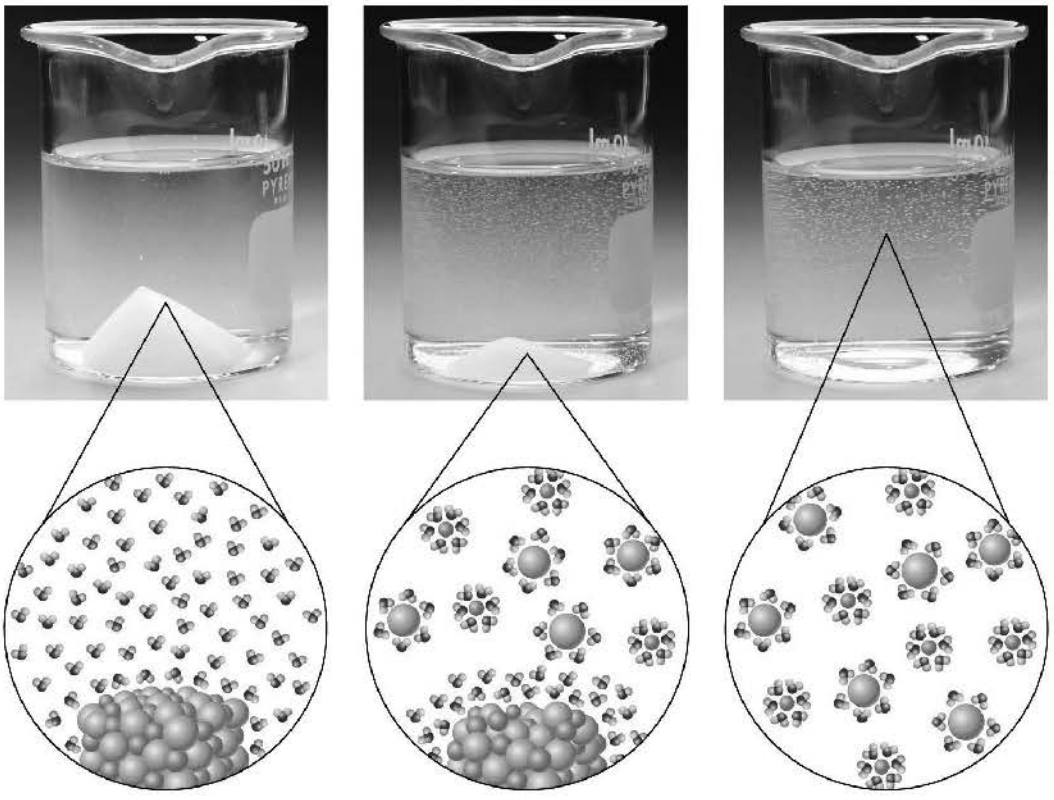
- **Every Na^+ is surrounded by ☐ Cl^- while each Cl^- is surrounded by ☐ Na^+.**

Structure of Caesium Chloride (CsCl)



- **Every Cs^+ is surrounded by ☐ Cl^- while each Cl^- is surrounded by ☐ Cs^+.**

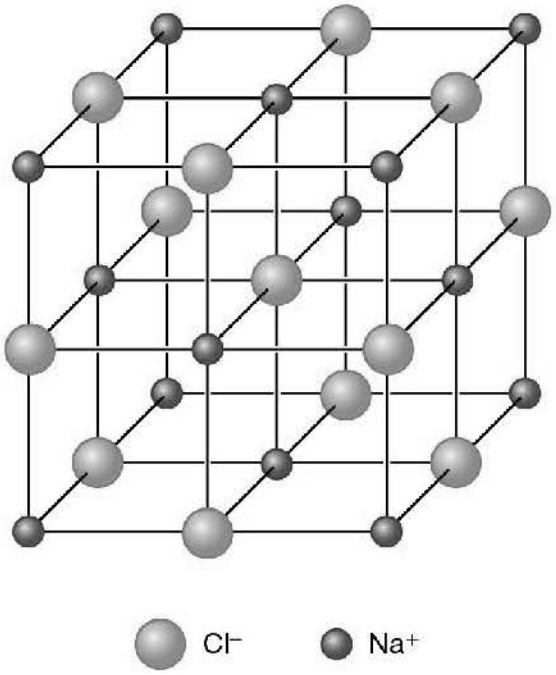
General properties of substance with Giant Ionic Structure

High melting point (mp) and boiling point (bp)	• There is **strong ionic bond** between **cations and anions.** • Lots of energy is required to break this bond.
Hard but brittle	• Cations and anions are held by strong ionic bond. Therefore, it is hard to break the crystal. • However, once the ionic crystal has been broken apart by external forces, the [ ] between the layers of ions make the broken parts separate. 
Soluble in water but not in organic solvent (e.g. CCl4/tetrachloromethane , 1,1,1-trichloromethane, methylbenzene, etc)	• The strong attraction between ions and water can [ ] the attraction between water molecules and the ionic bond between the ions.  • The [ ] between ions and organic solvent molecule cannot overcome the ionic bond between the ions
Good electrical conductivity in (l) or (aq) but poor in (s) and (g)	• The **ions** become [ ] to conduct electricity in **molten** or **aqueous** state. • There are **no mobile ions** or **mobile electrons** in solid and gas state.

Examples that you must fully understand

1. Briefly describe the bonding and structures of sodium chloride.

(NaCl)



Sodium chloride has a [ ].

In the crystal of sodium chloride, each sodium ion is surrounded by six chloride ions while each chloride ion is surrounded by six sodium ions.

There is [ ] between the sodium ions and chloride ions.

2. Consider the following table:

Solid	Melting point	Electrical conductivity	Solubility in water
P	Low	Non-conducting	Soluble
Q	Very high	Non-conducting	Insoluble
R	High	Good	Insoluble
S	High	Non-conducting	Soluble

Which of the above solids is likely to be an ionic compound?

3. Which of the following statements about solid sodium carbonate is INCORRECT?
(RAM of C = 12.0; O = 16.0; Na = 23.0)

A. *Its relative formula mass is 106.*

B. *It is soluble in water.*

C. *It does not conduct electricity because it does not contain ions.*

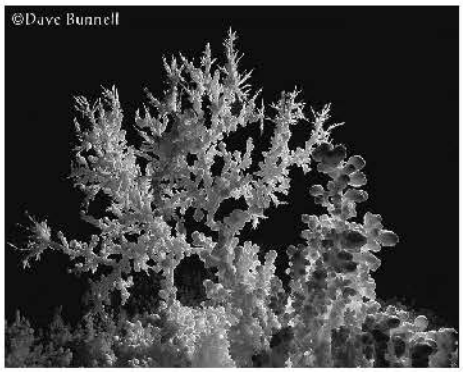
D. *It has a giant ionic structure.*

4. Statement one-two:

Statement 1: All ionic compounds are soluble in water.

Statement 2: There are strong attraction between the dissolved ions and water molecules.

5. This question is about Aragonite, a carbonate mineral.
Aragonite is one of the two common crystalline forms of calcium carbonate occurring naturally (the other one is calcite). It is formed by biological and physical processes which include the precipitation from marine skeleton. Aragonite has a melting point of around 600°C. Aragonite decomposes to form a white powdery brittle solid and carbon dioxide upon strong heating.



(a) Explain why aragonite has a high melting point.

[ ] are held by strong ionic bond. Lots of energy is required to break the bonding.

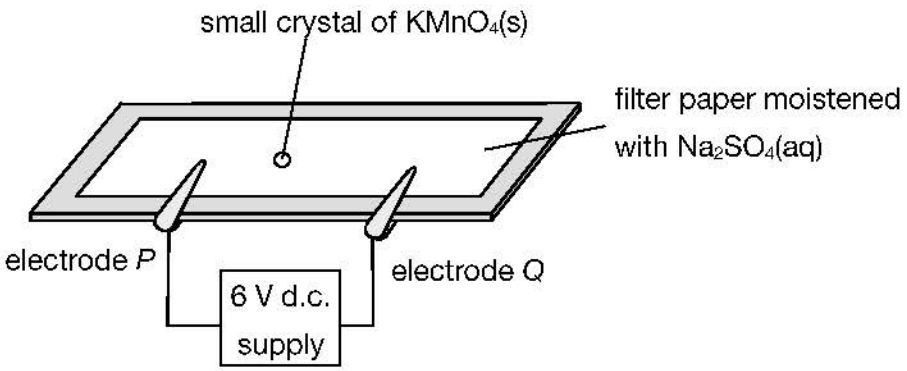
(b) What is the chemical of the white powdery brittle solid? Explain why it is brittle.

[ ]. It has a giant ionic structure, in which the [ ] are arranged in a regular and alternating manner.

When a force is applied to this structure, ions of [ ] charge are brough into alignment and [ ] one another, which causes the [ ] of the giant ionic structure.

Examples that you must fully understand

6. In the setup below, a small crystal of potassium permanganate was placed at the centre of a piece of filter paper soaked with sodium sulphate solution.



(a) Could the wet filter paper be replaced with a dry one (i.e. without soaking with sodium sulphate solution)? Explain your answer.

The wet filter paper [ ] be replaced with a dry one because sodium sulphate has to dissolve in water to give a solution with [ ] and [ ].

(b) Could the filter paper be soaked with copper(II) sulphate solution instead of sodium sulphate solution? Explain your answer.

[ ]. Copper(II) ions are [ ], and the colour would [ ] the colour observation.

(c) A purple spot was later found on the filter paper closer to electrode *Q*. What is it?

The purple spot is the [ ] ions.

(d) Deduce with reason the polarity of electrode *Q*.

Permanganate ion is [ ]. The ion will move towards the [ ] electrode. So electrode *Q* is the [ ] electrode.

(e) Something was migrating towards electrode *P* but we could not see it. Why?

We cannot see any colour movement because potassium ions are [ ].

(f) Can the movement of the purple spot due to diffusion?

[ ]. Since diffusion of substance is along the [ ], the purple spot should be spreading [ ] instead of towards [ ].

(g) What would happen if the polarities of the two electrodes were reversed?

The purple spot would migrate towards the [ ] direction.

4. Covalent Bond and Simple Molecular Structure

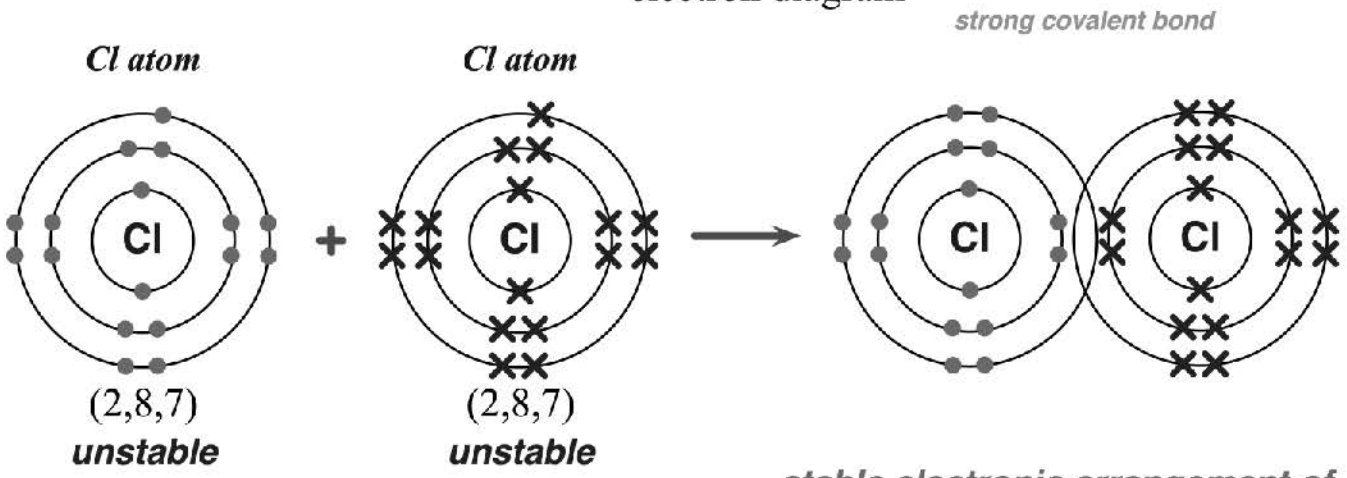
A. Formation of Covalent bond in a molecule

- A non-metal atom can achieve stable electronic arrangement of noble gas by:

Method 1: Gaining e^-	Method 2: Sharing of e^-
• e^- are **transferred** from metal atoms to non-metal atoms forming cation and anion • both [ ] are bonded together by **strong ionic bond**	• One non-metal atom [ ] electron(s) with another non-metal atom • both [ ] are bonded together by forming **strong** [ ] **bond**

- **Covalent bond:** the strong electrostatic attraction between the [ ] **and the two positively charged** [ ] **of the bonded atoms.**
- Covalent bond is [ ].
- **Example 1: formation of Chlorine gas molecule (Cl_2):**
  - [ ] is formed between two Cl atoms (= [ ] bond pair), producing a **Cl_2 molecule**.

electron diagram

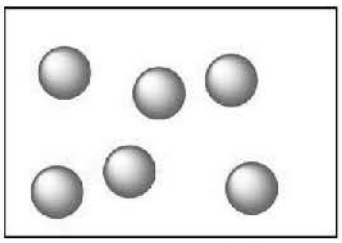


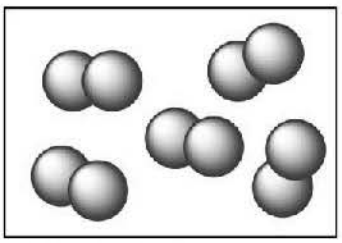
'dot and cross' diagram

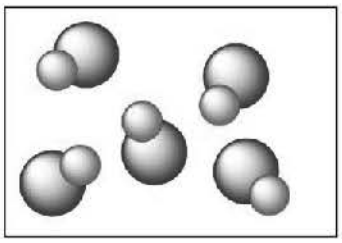
structural formula —

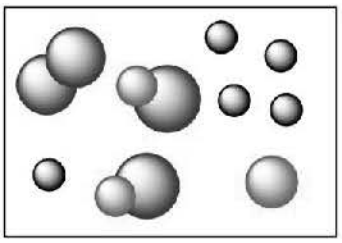
molecular formula

- **Molecule:** a **neutral** and discrete particle of **at least two** non-metallic atoms holding together by **covalent bonds:**
  - [ ] **molecule** (= atom of noble gas): He, Ne, Ar, Kr, Xe and Rn
    - ➢ The atom of noble gas has already the **stable electronic arrangement.** They don't need to form covalent bond.
  - **Diatomic molecule**: Cl_2, H_2, O_2, HCl, etc.

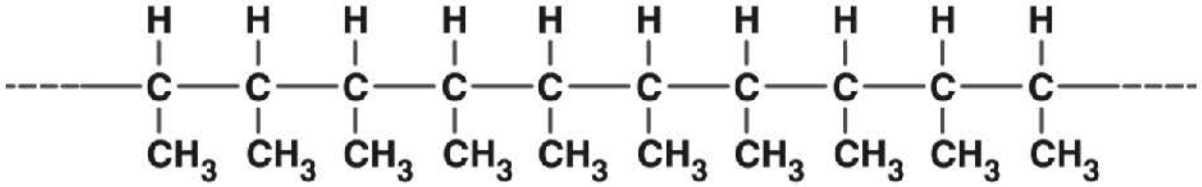

Atoms of a monatomic element

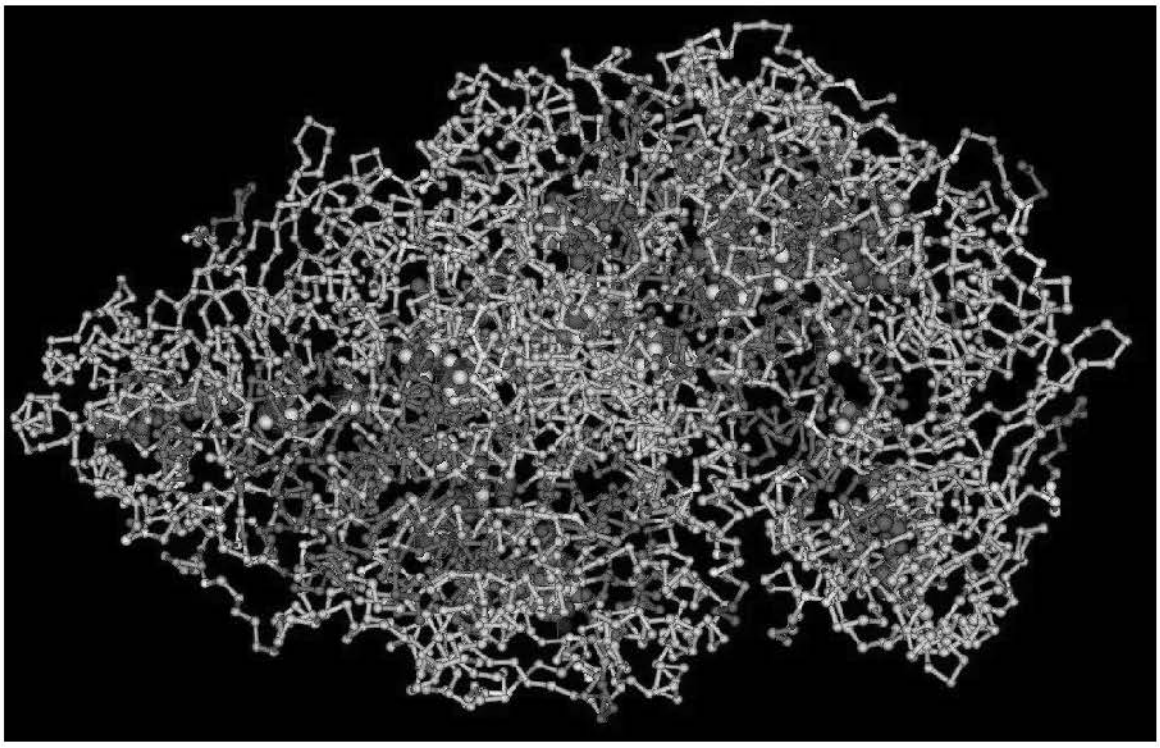

Molecules of a diatomic element

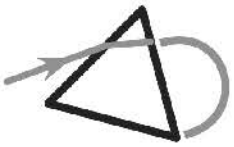

Molecules of a diatomic compound


A mixture

- **Polyatomic molecule:** CO_2, NH_3, H_2O, CH_4, etc.
- **Macromolecules** (usually polymers): plastic, DNA, proteins, etc.

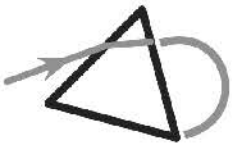






- **Example 2a: Oxygen gas molecule (O_2):**
  - ☐ is formed between two O atom (= ☐ bond pairs), producing a **O_2 molecule.**

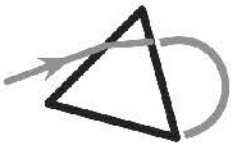
- **Example 2b: Oxygen and Hydrogen:**
  - ☐ are formed between O atom and 2 H atoms (= ☐ bond pairs), producing a ☐ **(water) molecule.**



- **Example 3a: Nitrogen gas molecule (N_2):**
  - [ ] is formed between N atoms (= [ ] bond pairs), producing a **N_2 molecule.**

- **Example 3b: Nitrogen, Oxygen and Cl:**
  - [ ] between N and Cl and [ ] between N and O (= [ ] bond pairs), producing a [ ] **molecule**.

- **Example 3c: Nitrogen and Hydrogen:**
  - [ ] between N and 3 H atoms (= [ ] bond pairs), producing a [ ] **(ammonia) molecule**.

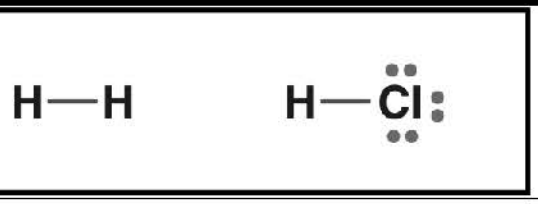
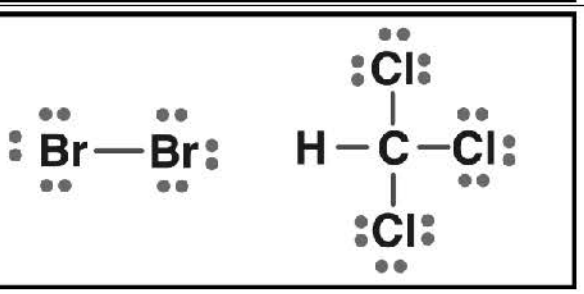
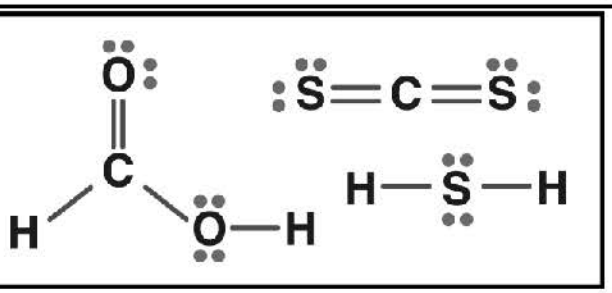
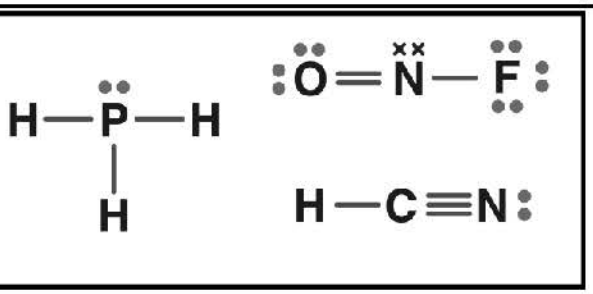
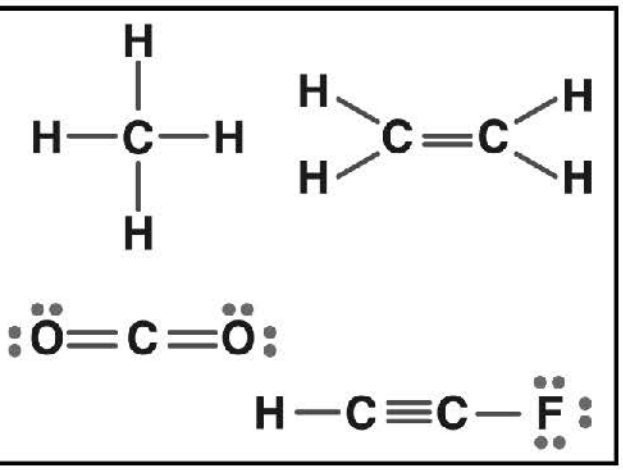


■ **Example 4:**

4a: Carbon, Nitrogen and Hydrogen:	4d: Carbon and Oxygen:
• **Triple bond** between C and N atom and **single bond** between C and H atom (= ☐ bond pairs), producing a ☐ **(hydrogen cyanide) molecule.**	• **TWO double bonds** between C and 2 O atoms (= ☐ bond pairs), producing a ☐ **(carbon dioxide) molecule**.

4c: Carbon, Oxygen and Hydrogen:	4d: Carbon and Hydrogen:
• **Double bond** between C and O atom and **TWO single bonds** between C and 2 H atoms (= ☐ bond pairs), producing a ☐ **(methanal) molecule**.	• **FOUR single bonds** between C and 4 H atoms (= ☐ bond pairs), producing a ☐ **(methane) molecule.**

B. Summary of different bonding atoms

Bonding atoms	No. of e- / BP needed	Common pattern	No. of LP	Examples
H			0	
Gp VII (F, Cl, Br, I)			3	
Gp VI (O, S)			2	
Gp V (N, P)			1	
Gp IV (C)			0	

■ **Note:** elements of **period 3 or above do not necessarily obey the octet rule**. They can form more bonds than expected.

Examples that you must fully understand

Draw the electron diagram / dot and cross diagram (showing the outermost shell electrons only) for the following molecules:

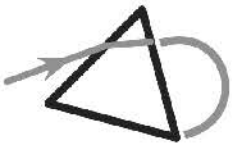
(a) Hydrogen gas, Fluorine gas, Chlorine gas, Bromine liquid, Iodine solid

(b) Oxygen gas

(c) Nitrogen gas

(d) Compound between H and Cl, H and Br, F and I

(e) Compound between C and O, C and S

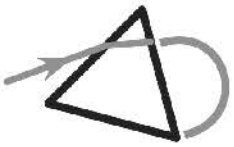


(f) Compound between H and O, O and Cl, S and F

(g) H_2O_2 (hydrogen peroxide) and S_2Cl_2

(h) Compound between N and H, N and F, P and I

(i) Compound between C and H, C and Cl, Si and F, CH_2Cl_2



(j) Hydrogen cyanide

(k) NOF

(l) N_2H_4

(m) CH_2NH

C. Naming a molecule

- **The more electronegative element is usually listed after the more electropositive element:**
  - HCl >> Hydrogen chloride
  - CO_2 >> Carbon dioxide
- **Similar to ionic compound, the name of the second element needs to be changed.**
- **Add prefixes where necessary:**
  - One atom of the element >> **mono- (usually omitted)**
  - Two atoms of the element >> **di-**
  - Three atoms of the element >> **tri-**
  - Four atoms of the element >> **tetra-**
  - Five atoms of the element >> **penta-**
  - Six atoms of the element >> **hexa-**

Common names:

H_2O >> ____

H_2O_2 >> ____

NH_3 >> ____

CH_4 >> ____

- **The "o" and "a" endings of the prefixes are dropped when they are attached to vowels.**
  - CO >> Carbon ____
  - N_2O_4 >> Dinitrogen ____

Molecular Formula	Name	Molecular Formula	Name
HF	Hydrogen fluoride	**Cl_2O**	Dichlorine monoxide
HCl	Hydrogen chloride	**ClO_2**	Chlorine dioxide
HBr	Hydrogen bromide	**NF_3**	Nitrogen trifluoride
HI	Hydrogen iodide	**PH_3**	Phosphorus trihydride
CO	Carbon monoxide	**CCl_4**	Tetrachloromethane
CO_2	Carbon dioxide	**IF_5**	
NO		**SF_6**	Sulphur hexafluoride
NO_2		**N_2O_3**	
SO_2	Sulphur dioxide	**N_2O_4**	Dinitrogen tetroxide
SO_3	Sulphur trioxide	**S_2Cl_2**	

Examples that you must fully understand

1. Which of the following molecules has only one lone pair of elections:

   A. C_2H_4

   B. PH_3

   C. H_2O

   D. HCl

2. Which of the following molecules has the smallest number of lone pairs of electrons?

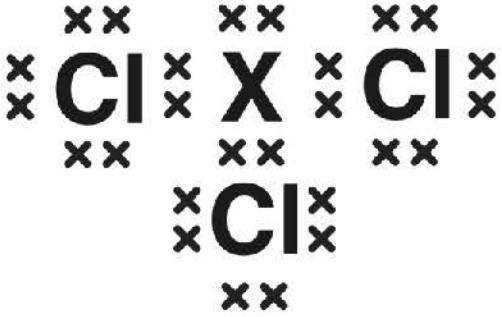
   A. ***Water***

   B. ***Hydrogen fluoride***

   C. ***Ammonia***

   D. ***Methane***

3. The electronic structure of a compound formed between an element X and chlorine is shown below. (Only electrons in the outermost shells are shown.)
   What would be the formula of the compound formed between X and magnesium?



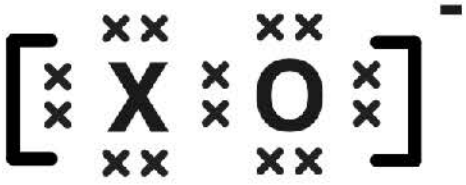
   A. MgX

   B. MgX_2

   C. Mg_2X_3

   D. Mg_3X_2

4. The electronic structure of a negatively charged compound formed between an element X and oxygen is shown below: (Only the outermost shell electrons are shown.)



   What would be the formula of the compound formed between X and Mg?

   A. MgX

   B. MgX_2

   C. Mg_2X_3

   D. Mg_3X_2

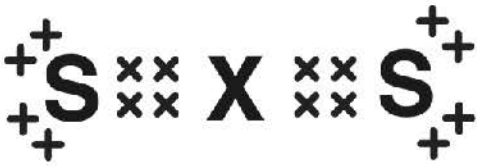
5. A compound formed from element X and sulphur has the following electronic structure: (Only electrons in the outermost shells are shown.) How many electrons are there in the outermost shell of an atom of X?

A. 2

B. 4

C. 6

D. 8



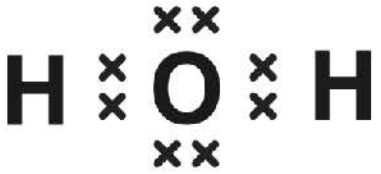
6. Below shows the electron diagram of a water molecule: (Only electrons in the outermost shells are shown.) How many electrons are there in one molecule of water?

A. 8

B. 10

C. 12

D. 14



7. Refer to the particles in the table below and choose the letter(s) representing:

Particle	Number of		
	protons	neutrons	electrons
A	*7*	*7*	*7*
B	*12*	*12*	*10*
C	*17*	*18*	*18*
D	*7*	*8*	*7*
E	*11*	*12*	*11*
F	*17*	*18*	*17*
G	*20*	*12*	*20*

(a) An atom of a metal.

(b) An atom of a non-metal.

(c) A pair of isotopes.

(d) A positively charged ion.

(e) A negatively charged ion.

(f) The formula of the compound formed between A and E:

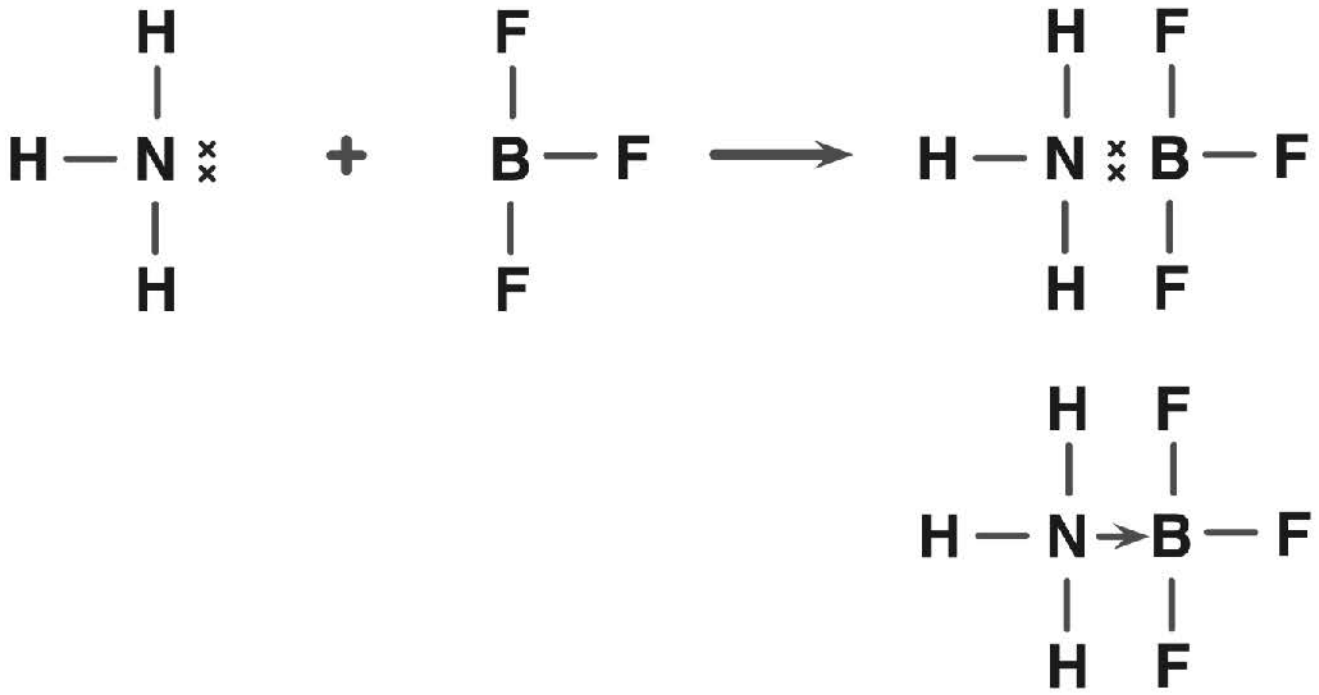
(g) The formula of the compound formed between A and F:

(h) The particle that is not possible:

D. Dative covalent bond

- **Dative covalent bond**: a kind of covalent bond in which the two shared electrons are supplied by the [ ] atom.

- **Example 1: NH_3BF_3:**



- **Example 2: Hydronium ion (H_3O^+):**

Examples that you must fully understand

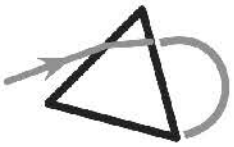
Draw the structural formula for the chemical species below. All of them contain dative covalent bond.

(a) Carbon monoxide (CO):

(b) Ozone (O_3):

(c) Nitrous oxide (N_2O):

(d) Nitrogen dioxide (NO_2):



(e) Nitric acid (HNO_3):

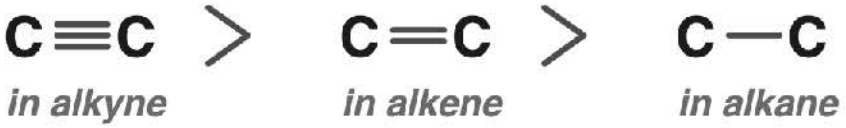
(f) Ammonium ion (NH_4^+):

(g) Al_2Cl_6:

(h) BF_4^-:

E. Strength of covalent bond

- Generally, **triple bond** is the **strongest** and *single bond* is the *weakest*:



- Generally, covalent bond formed by atoms with [ ] **radius** is **stronger**:
  - N-H bond in NH_3 > P-H bond in PH_3
  - C-O bond > Si-O bond
  - O-H bond in H_2O > S-H bond in H_2S

H. Relative molecular mass of molecules

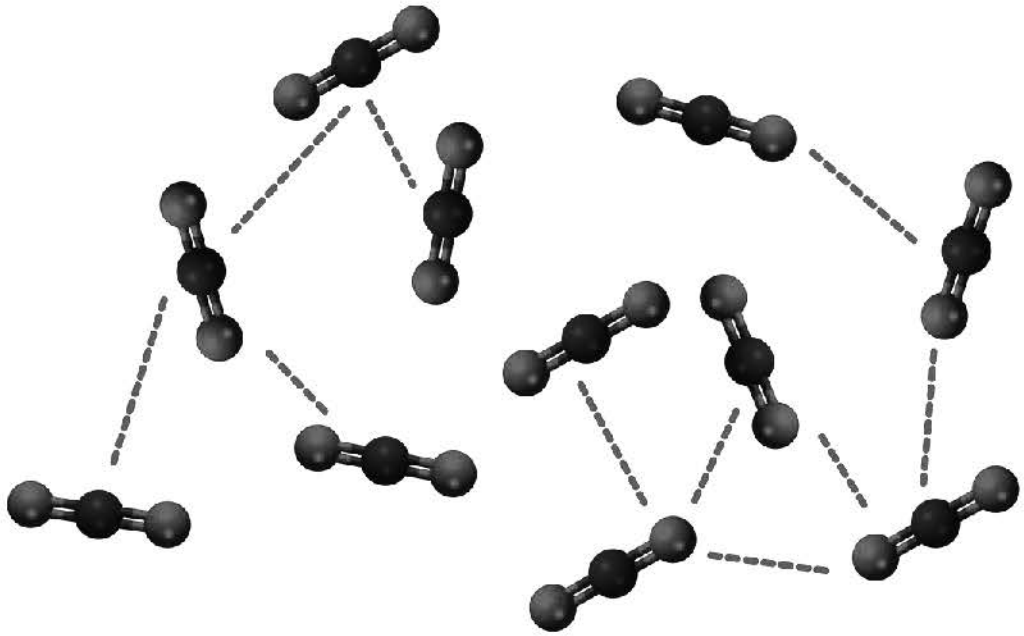
- **Relative molecular mass of a molecule** = sum of the relative atomic masses of all atoms present in the molecule

RAM of H = 1.0; C = 12.0; N = 14.0; O = 16.0; S = 32.0; Cl = 35.5;

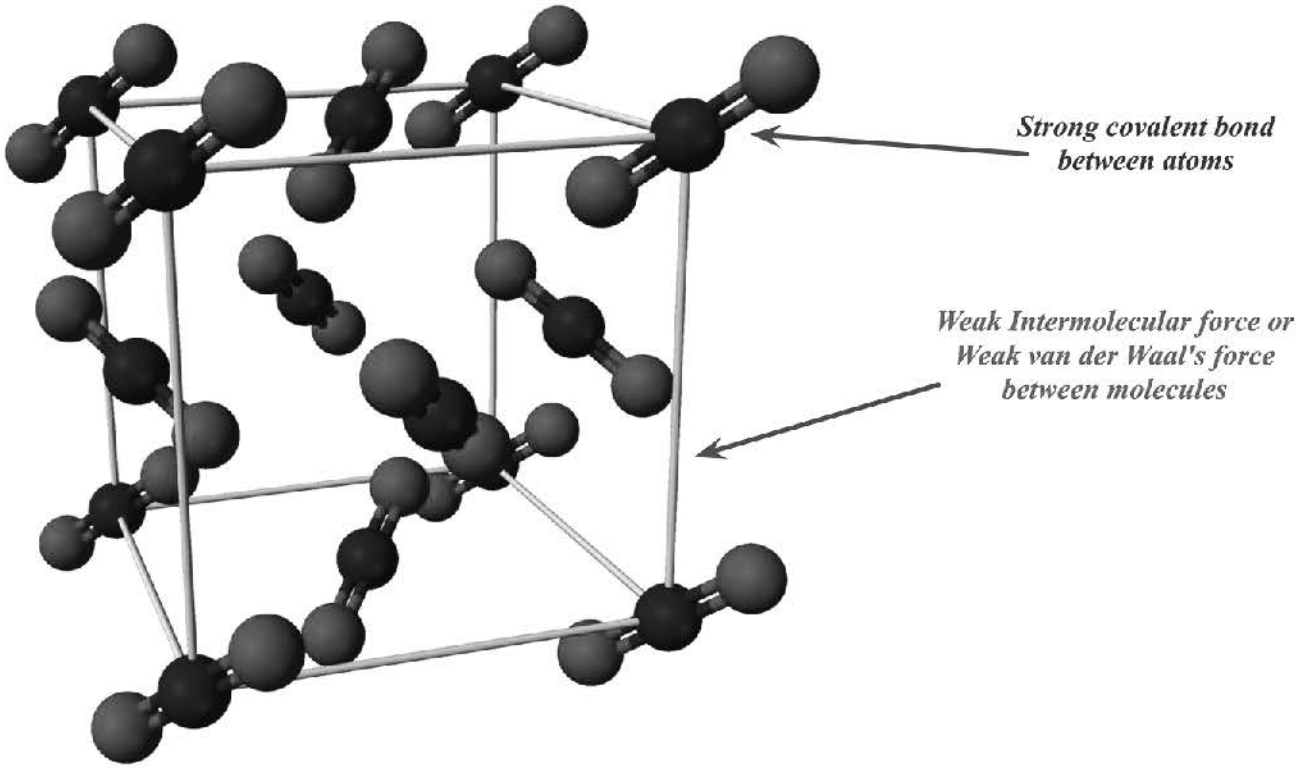
$O_2 \Rightarrow$
$H_2O \Rightarrow$
$CO_2 \Rightarrow$
$NH_3 \Rightarrow$
$C_6H_{12}O_6 \Rightarrow$
$HCl \Rightarrow$
$H_2SO_4 \Rightarrow$

I. Simple molecular structure

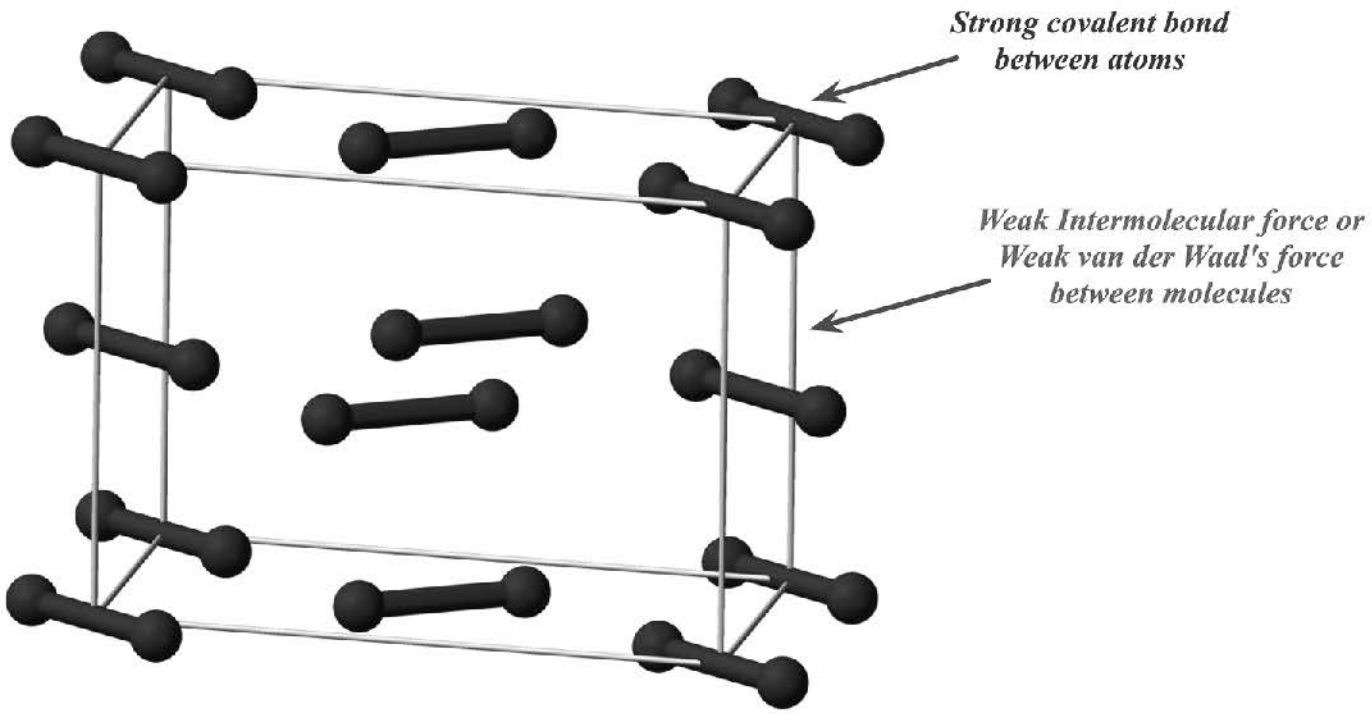
- The [ ] of are holding each other, resulting in the **simple molecular structure:** e.g. CO_2



- When the temperature is low enough, the molecules will arrange themself regularly forming [ ] [ ] / crystalline structure (solid): e.g. Dry ice (solid CO_2)



- Molecular crystal of solid I_2:



General properties of substance with Simple Molecular Structure	
Low mp, bp and low sublimation temperature (e.g. for CO_2(s) and I_2(s)) **Soft**	• There is **weak intermolecular/van der Waals' force** between [ ]. • Little energy can overcome the weak force. • Easy to separate the molecules apart or break the substance.
Generally insoluble in water but **soluble in organic solvent**	• The attraction between the substance and H_2O [ ] **overcome** the **relatively strong** attraction between H_2O molecules. • The attraction between the substance/solute and the organic solvent **can** [ ] the attraction between solvents.
Non-conductor in all states	• There are no mobile [ ] nor delocalized [ ]. • Except those molecular substances which can dissolves in water to form acids and ammonia. The solutions can conduct electricity due to the presence of mobile ions.

Examples that you must fully understand

(Di)hydrogen disulphide exists as a yellow liquid at room temperature and pressure. H_2S_2 has a low solubility in water and its boiling point is 70.7°C.

It has an irritating odour and it can cause dizziness and even unconsciousness in high concentration.

(a) Draw the electron diagram of dihydrogen disulphide.

(b) Explain why the solubility of dihydrogen disulphide is low in water.

(c) Describe the bonding and structure of dihydrogen sulphide.

H_2S_2 has a [ ].

There are [ ] within H_2S_2 molecules.

There is [ ] holding the H_2S_2 molecules together.

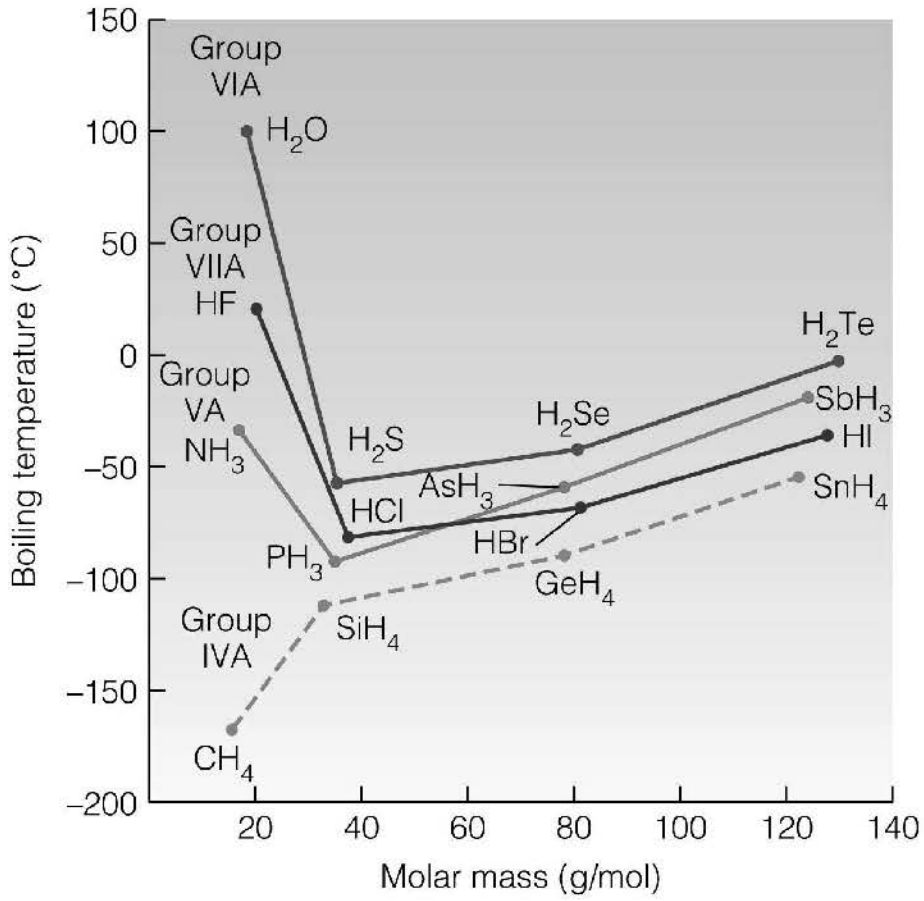
(d) Hence, explain why the boiling point of dihydrogen disulphide is low.

Since the H_2S_2 molecules are held together by weak van der Waal's force, little energy is required to overcome this weak force and separate the H_2S_2 molecules apart.

J. Effect of molecular size on strength of van der Waals' force

Molecules	Molecular mass	Boiling point (oC)
Helium	4	-269
Neon	20	-246
Argon	40	-286
Fluorine	38	-188
Chlorine	71	-34.7
Bromine	160	58.8
Methane	16	-162
Ethane	30	-88.6
Propane	44	-42.2

*Generally speaking, **larger the molecular size** (mass), **stronger** the van der Waals' force, leading to **higher** mp, bp, density and hardness*



Examples that you must fully understand

1. Which one has a higher bp? CO_2 or CS_2? Why?

   [ ] has a higher boiling point.
   Since the molecular size of [ ] is [ ] than that of [ ].
   The van der Waals' force between [ ] molecules is [ ] than that between [ ] molecules, leading to a higher boiling point.

2. Which of the following statements is/are true?

   (1) A molecule must be a covalent substance.

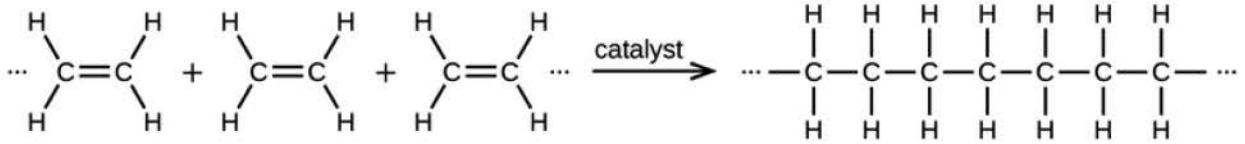
   (2) All covalent substances are compounds.

   (3) Covalent substances have lower bp than ionic compounds since ionic bonds are stronger than covalent bonds.

   (4) All covalent substances exist as discrete molecules.

   (5) Since the molecular size of H_2S is larger than that of H_2O, the boiling point of H_2S is higher.

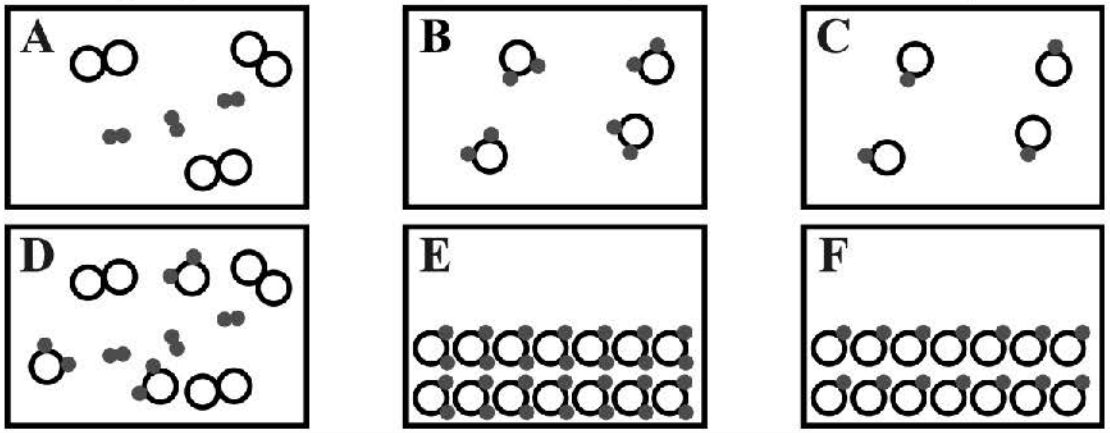
3. Polymer is a kind of macromolecule made up of a lot of monomers. E.g. polyethene is formed by the polymerization of thousands of ethene molecules.



   Compare the boiling point of polyethene and ethene.

   The boiling point of polyethene is [ ] than that of ethene.
   It is because the molecular size of polyethene is [ ] than that of ethene.
   There is [ ] van der Waals' force between polyethene molecules than that between ethene molecules.

4. Which of the following diagrams represent the particles of the product between H and Se (atomic no. = 34)?

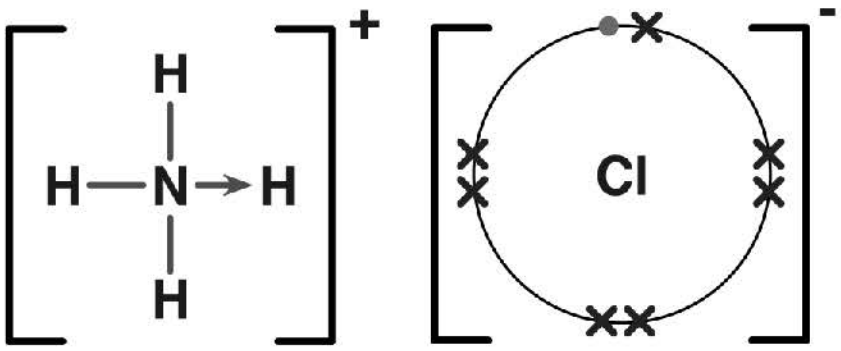


5. Consider the following information related to the four substances:

Substance	Melting point /°C	Electrical conductivity at room temperature
A	733	Poor
B	298	Good
C	62	Poor
D	-32	Poor

Which substance exists as discrete molecules and is a solid at room temperature?

6. Which of the following attractive force(s) can be found in ammonium chloride?



(1) Covalent bond

(2) Ionic bond

(3) Strong electrostatic attraction between ions

(4) Van der Waals' force

5. Covalent Bond and Giant Covalent Structure

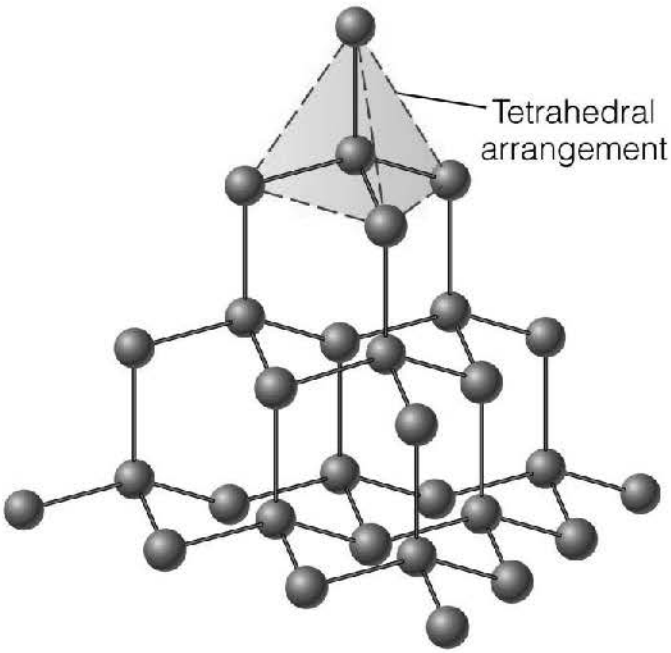
A. Covalent substance not forming molecules

- Not all covalent substances are simple molecules.
- Some covalent substances have their atoms in the whole solid bonded by strong covalent bonds, resulting in a **giant covalent networks**.
- **Examples:** Diamond, graphite, quartz, silicon and silicon carbide

B. Diamond (a form of the element carbon) and Quartz (SiO_2)

Diamond (an allotrope of pure Carbon):

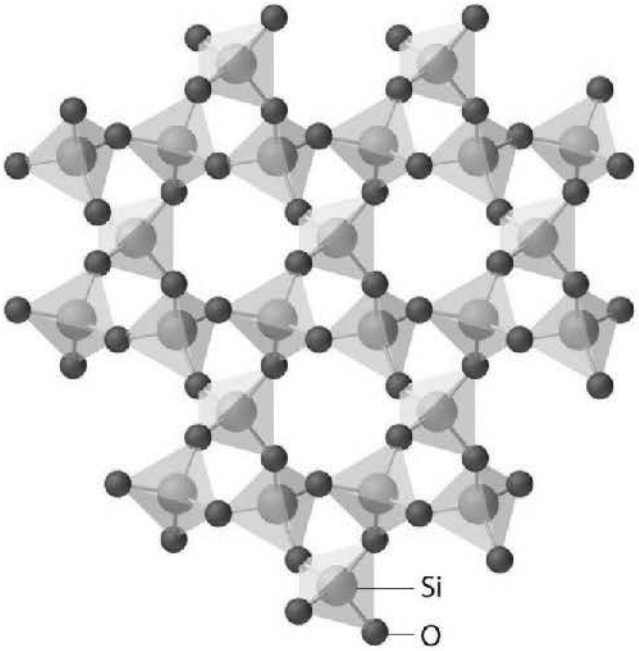
- **Diamond** is one of the naturally occurring **allotropes** of carbon (the other is graphite).
- **All C atoms in diamond are bonded to FOUR other C atoms by strong covalent bonds** ☐.



- Silicon crystal has a similar structure as diamond.

Quartz (Silicon dioxide, SiO_2):

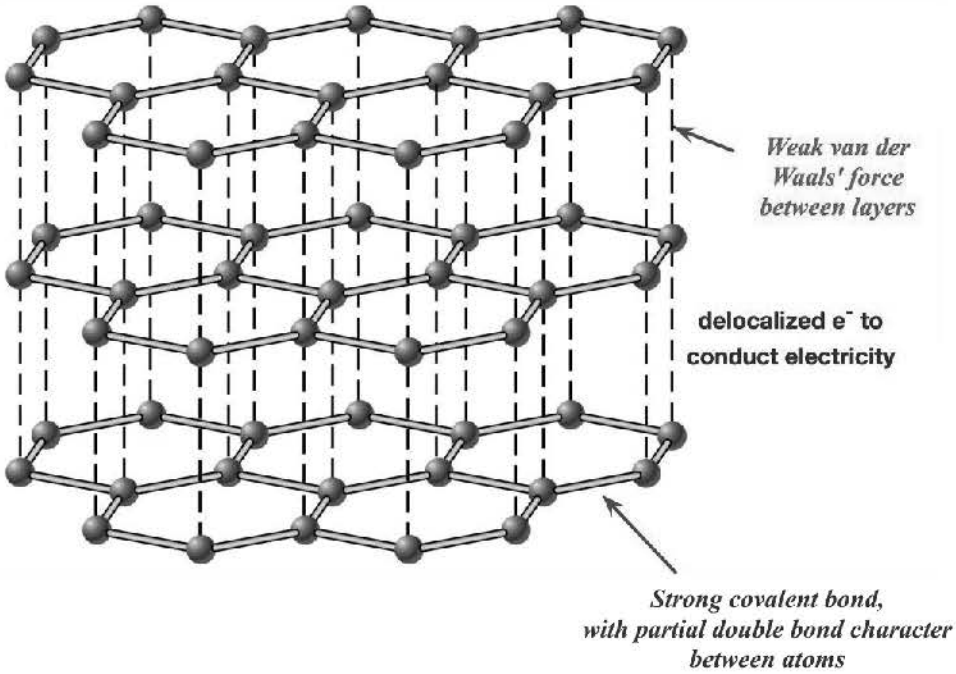
- In **quartz (silicon(IV) oxide or silicon dioxide)**, all Si and O atoms are bonded by strong covalent bonds.
- **Each Si atom is bonded to FOUR O atoms while each O atom is bonded to TWO Si atoms.**



General properties of Diamond and Quartz (Giant Covalent Structure)	
High mp, bp (Diamond > Quartz)	In the **giant covalent network of atoms**, the atoms are bonded together with [ ] • A lot of energy is required to break these strong bonds in melting (or boiling) or cutting or dissolving in any solvent.
Hard (Diamond > Quartz)	
Not soluble in water and most solvents	
Non-conductor in all states	• There are **no mobile ions nor delocalized electrons**.

C. Graphite (another allotrope of pure C)

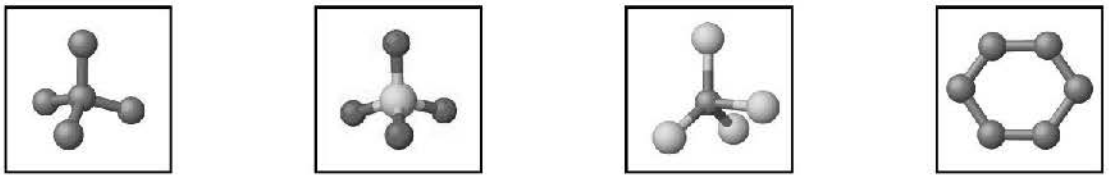
- **Graphite** is another naturally occurring **allotropes** of carbon.
- **All C atoms in graphite form strong covalent bond with the other THREE C atoms, resulting in layered structure. The layers (graphene) are attracted together by weak van der Waals' force.**

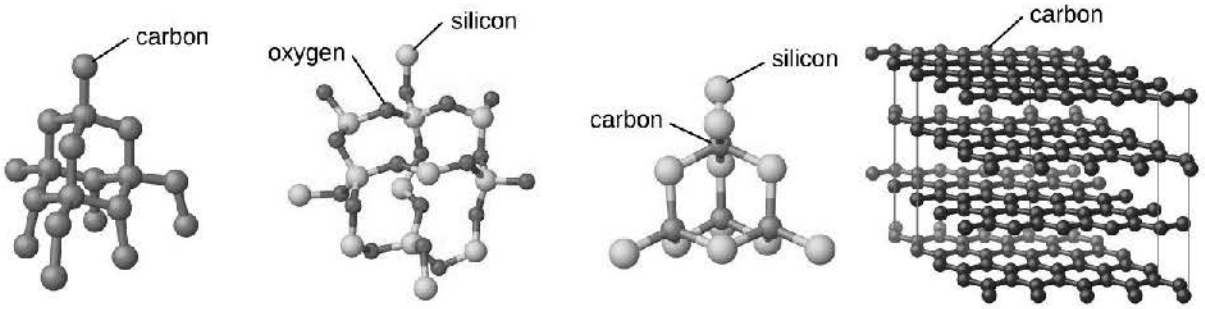


General properties of Graphite (Giant Covalent Structure)	
High mp, bp (similar to Diamond)	• In the **giant covalent network of atoms**, the atoms are bonded together with [ ].
Not soluble in water and most solvents	• A lot of energy is required to break these strong bonds in melting (or boiling) or dissolving in any solvent.
Soft and slippery	• There is only **weak van der Waals' force** between [ ]. • Layers of graphite can **slip over** each other (can be used as [ ]).
Good conductor in (s)	• There are **delocalized electrons** within each layer.

Section 2

Microscopic World Part 2





diamond | silicon dioxide | silicon carbide | graphite

Examples that you must fully understand

1. Which of the following statements about diamond is correct?

   (1) It is a covalent compound.

   (2) It has a giant covalent structure.

   (3) It is very hard because all C atoms are bonded with strong covalent bond.

2. Which of the following can be found in both quartz and graphite?

   (1) Carbon atom

   (2) Ionic bond

   (3) Delocalized electrons

   (4) Van der Waals' force

   (5) Covalent bond

3. Both diamond and graphite have a giant covalent structure. However, graphite is much softer than diamond, why?

   Diamond is very hard since the [ ] are held together by [ ] to form a giant network. [ ] of the atoms is restricted.

   Graphite is [ ] since it has a [ ] structure with [ ] between layers. Layers can [ ] each other.

4. Compare and contrast CO_2 and SiO_2.

	CO_2	SiO_2
Bonding		
Structure		
MP BP Hardness		

5. Which of the following statement(s) is / are true?

(1) All substances with giant covalent structure have higher melting points than all substances with simple molecular structure.

(2) A volatile substance cannot be in giant ionic or giant covalent structure.

(3) It a substance is soluble, it must be an ionic compound.

(4) All ionic compounds are soluble in water.

(5) When a molecular substance is melted, covalent bonds within the substance are broken.

(6) Solid ionic compounds have high electrical conductivity.

(7) Substances with simple molecular structure are insoluble in water.

(8) A substance which can conducts electricity in solid state must be a metal.

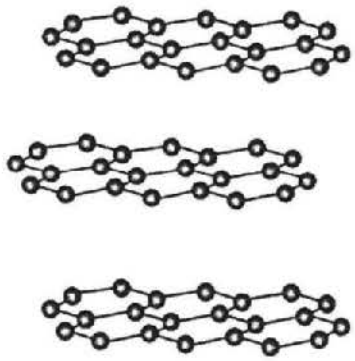
(9) No aqueous state of molecular substance can conduct electricity.

6. Which of the following statement(s) is / are true?

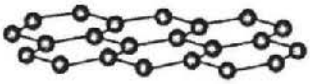
(1) Graphite is softer than diamond and the melting point of graphite is also much lower than that of diamond.

(2) No molecular substance at room temperature is a solid.

7. Graphite is a form of carbon and has a layer structure. Graphene is an individual single layer of graphite. Their structures are shown below:



graphite



graphene

(a) Thin sheets of graphene can be easily peeled off from graphite using adhesive tape.

(i) Explain why graphene can be easily peeled off.

Layers of graphite are _____

(ii) Explain whether graphene can conduct electricity.

Graphene can conduct electricity because _____

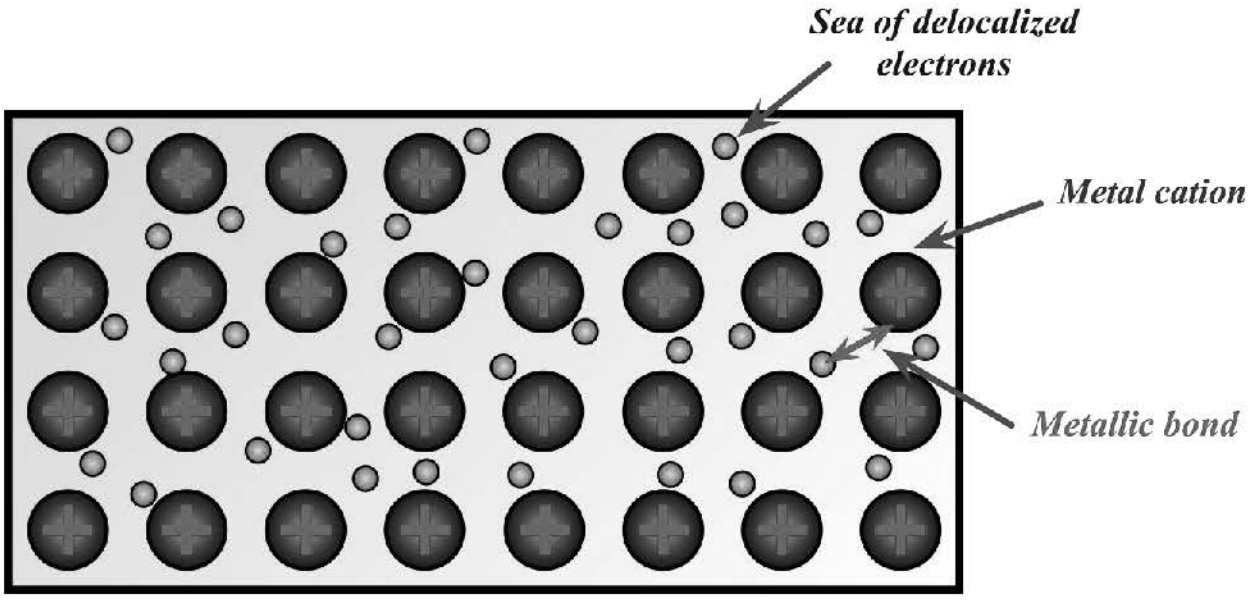
(iii) Draw the electron diagram for a molecule of the compound formed by complete combustion of graphene, showing electrons in the outermost shells only.

(b) Based on the fact that graphene can be easily peeled off from graphite, a student concluded that graphite should have a low melting point due to its layer structure. Explain whether you agree with this conclusion.

6. Metallic bond and Giant Metallic Structure

A. Formation of Metallic Bond and the Giant Metallic Structure

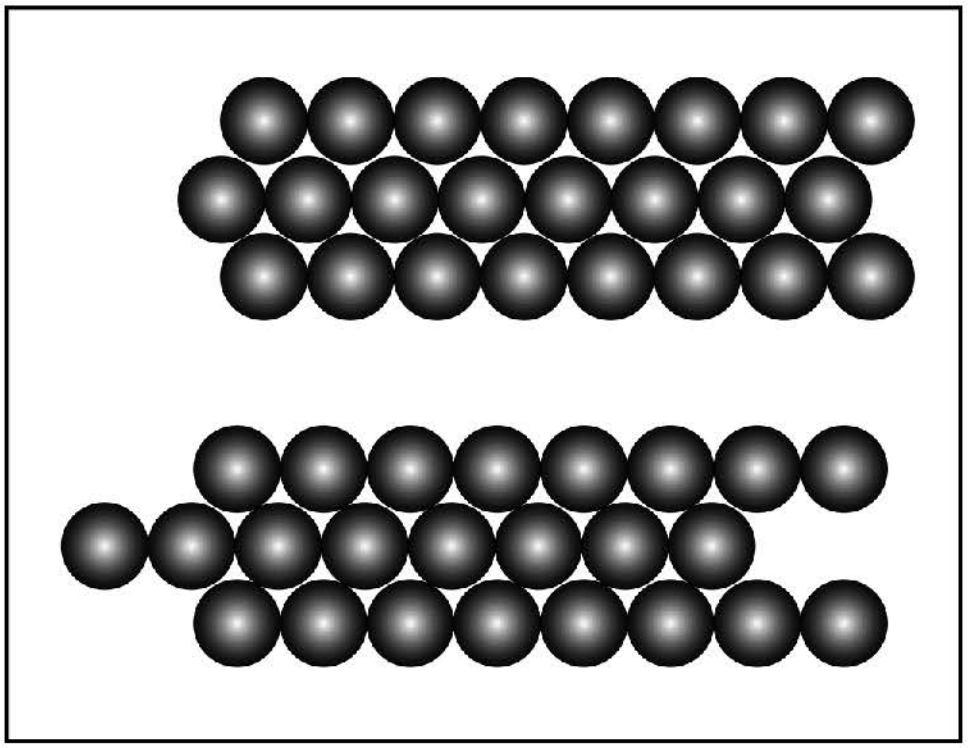
- A piece of metal consists of a large number of **metal atoms packed in a regular and close way**.
- Each of the **metal atom loses its outermost electron(s) to become a metal** [ ]. The lost electrons form the **sea of delocalized electrons.**
- Metallic bond: the **strong**, **non-directional** electrostatic attraction between the **metal cations and the sea of delocalized electrons**.
- **Giant metallic structure: a giant lattice of a larger number of metal cations surrounded by the sea of delocalized electrons.**



General properties of Metal (Giant Metallic Structure)	
High mp, bp and Strong (high strength)	• Metal **cations and sea of delocalized electrons** are bonded together with **strong metallic bond**.
Not soluble in water and most solvents	• A lot of energy is required to break these strong bonds in melting (or boiling) or dissolving in any solvent.
Good electrical & thermal conductor in (s) & (l)	• There are **delocalized electrons** in solid and liquid states.

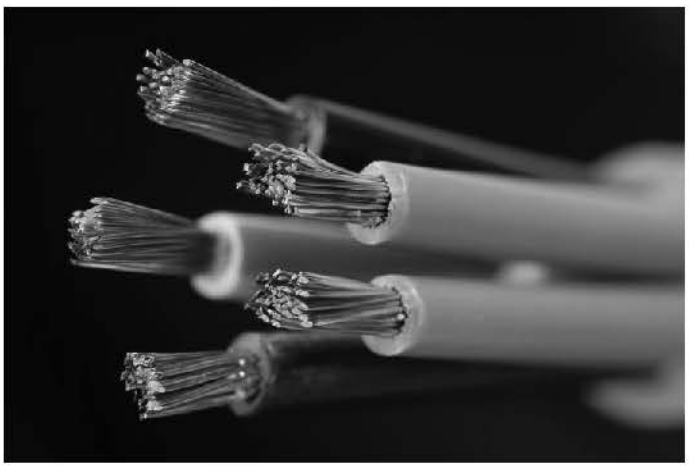
Malleable and ductile

- Metallic bond is non-directional and the metal cations are packed tightly in layers.
- When metal is hammered or pulled, the metal cations can [ ] each other to new positions and the metallic bonds are only [ ].
- The non-directional metallic bonds [ ] the atoms together.



Malleable (e.g. Al foil)

Ductile (e.g. Cu wire)



B. Factors affecting the strength of metallic bond

- Generally, the [ ] **the atomic radius** of metal atoms, the **stronger** the metallic bond is:
  - E.g.: mp of Group I metals decreases down the group
- Generally, the [ ] the outermost electron of a metal atom, the **stronger** the metallic bond is:
  - E.g.: mp of Group II metals > Group I metals of the same period

Examples that you must fully understand

1. The melting point and boiling point of substance X are 280°C and 670°C respectively. It its molten state, X conducts electricity without decomposition. X is most likely

   A. A giant covalent network substance

   B. A simple molecular substance

   C. An ionic compound

   D. A metal

2. Which of the following statements is/are true?

   (1) A substance which is a liquid of a gas at 25oC must be in simple molecular structure.

   (2) All metals at room temperature must be solid.

   (3) An electrical non-conductor solid with high boiling point must be in giant covalent structure.

3. Which of the following description about Iron and Iron(III) fluoride are correct?

	Iron	***Iron(III) fluoride***
A.	***Has a high melting point***	***Has a low melting point***
B.	***Ductile and malleable***	***Ductile and malleable***
C.	***Conducts electricity in solid state***	***Conducts in solid state***
D.	***Conducts electricity in liquid state***	***Conducts electricity in liquid state***
E.	***Brittle***	***Brittle***
F.	***Molten state can be decomposed by electricity***	***Molten state can be decomposed by electricity***
G.	***Shiny***	***Shiny***

7. Comparing the bonds and structures

A. Comparison of strength

Generally: Covalent Bond > Ionic Bond > Metallic Bond >>> van der Waals' force

*Generally, **covalent bond**:*
1. smaller atomic radius = stronger covalent bond
2. triple bond > double bond > single bond

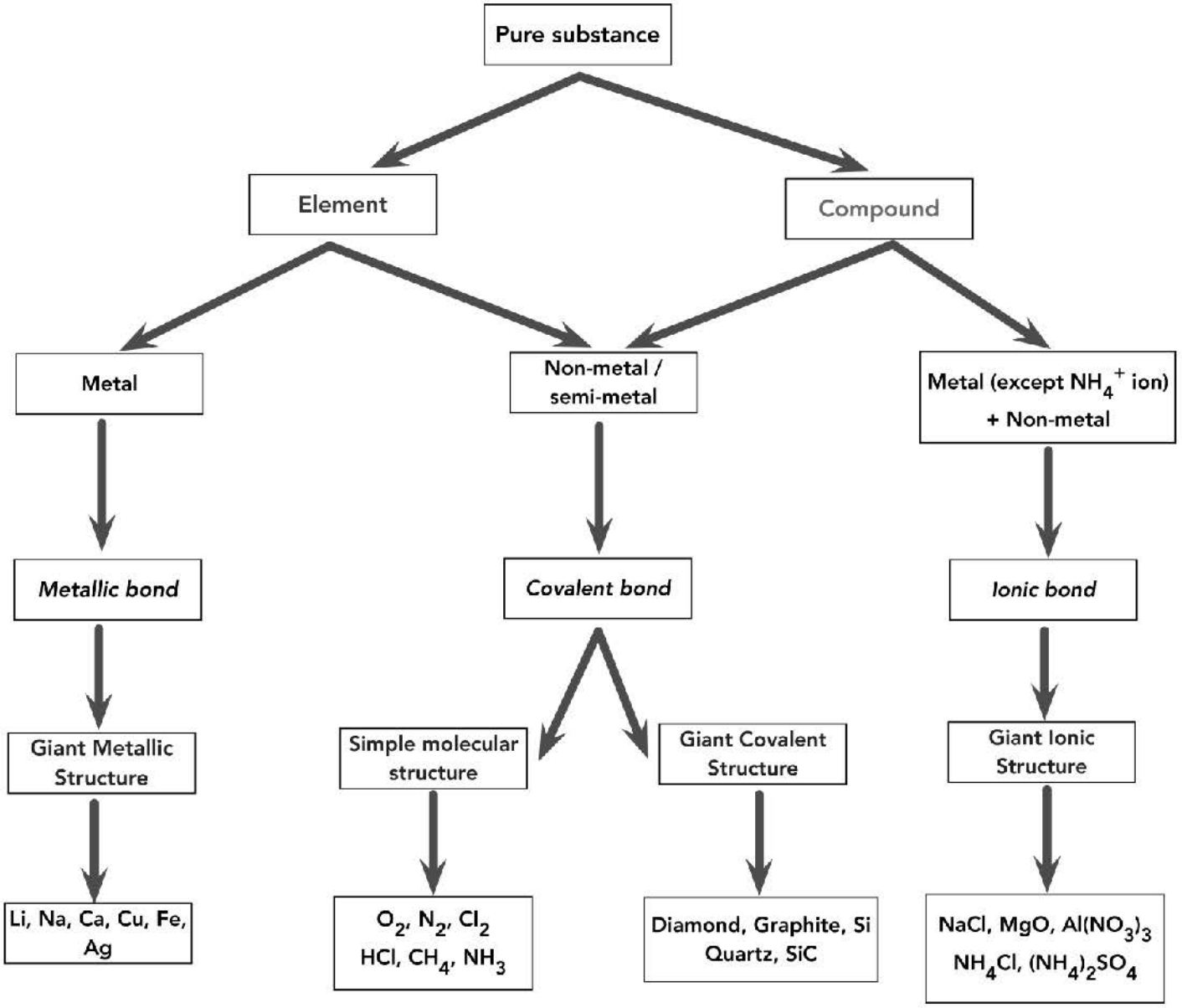
*Generally, **ionic bond**:*
1. smaller ionic radius = stronger ionic bond
2. more charge of the ion = stronger ionic bond

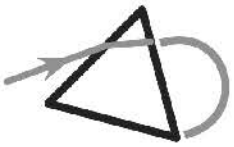
*Generally, **metallic bond**:*
1. smaller atomic radius = stronger metallic bond
2. more the outermost shell electrons = stronger metallic bond

*Generally, **van der Waals' force**:*
the larger the molecular size = stronger van der Waals' force (to be continued...)

	Substance	Attractions between?	Melting point/ °C
(1)	Diamond		4 000
(2)	Quartz		1 670
(3)	Na_2O		1 132
(4)	NaCl		801
(5)	KCl		770
(6)	Al		660
(7)	Na		97.8
(8)	K		63.5
(9)	I_2		113.7
(10)	Br_2		-7.2

B. Classification of pure substance

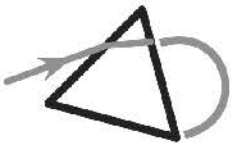




C. Summary

	Ionic compounds	Covalent substance (elements or compounds)		Metallic elements
Constituent elements	Metal (except NH_4^+) + non-metals	Non-metals		Metals
Structure	Giant Ionic Structure	Simple Molecular Structure	Giant Covalent Structure	Giant Metallic Structure
Formation of bonding	e^- transfer from metal to non-metal producing cation and anion	Sharing of e- between non-metal and/or semi-metal atoms.		Metal loses outermost e- to form cation and the sea of delocalized e^-
Bonding	Strong ionic bond = Strong electrostatic attraction between cations and anions	Strong covalent bond = Strong electrostatic attraction between the shared e^- and the nuclei of boding atoms (except noble gas)		Strong metallic bond = Strong electrostatic attraction between the metal cations and the sea of delocalized e^-
Directional bonding?	Non-directional	Directional		Non-directional
Particles	Cations and anions	Molecules (for noble gas, atoms)	Atoms	Cations and sea of delocalized e^- (or atoms)
Type of force	Strong ionic bond between ions	Weak van der Waals' force between molecules Strong covalent bond within molecules	Strong covalent bond between atoms (for graphite, weak van der Waals' force between layers)	Strong metallic bond between cations and sea of delocalized e- (or atoms)

	Ionic compounds	Covalent substance (elements or compounds)		Metallic elements
Examples	NaCl, CsF, CaO, NH_4Cl, $CuSO_4$	H_2O, CH_3OH, CO_2, CCl_4, P_4, S_8, He, Ar, polymers (macromolecules)	Diamond, graphite, Si, SiO_2, SiC	Na, Mg, Cu, Ag, K
State at room temperature	Solid	Mainly liquid or gas; Some solid	Solid	Solid (except Hg)
Mp, bp	Very high (usually mp > 300°C)	Low (usually mp < 300°C)	Very very high (usually mp > 1000°C)	High
Hardness of solid	Hard & brittle	Soft	Very hard but brittle	Hard (except Group I) Malleable and ductile
Conductivity	Conducting in (l) & (aq), due to mobile ions; Non-conducting in (s) & (g)	Non-conducting Except aqueous solutions of HCl, Cl_2, NH_3, CO_2…as they react/ionize to give mobile ions in water	Non-conducting Except graphite: conducting in (s) due to delocalized e-; non-conducting in (l) & (g); no (aq)	Conducting in (s) & (l) due to delocalized e^-; Non-conducting (g) and no (aq)
Solubility in water	Usually soluble, except $CaSO_4$, $MgCO_3$…	Usually insoluble (except HCl, Cl_2, alcohol…)	Insoluble	Insoluble (but some metal can react with H_2O)
Solubility in organic solvent	Insoluble	Usually soluble (except H_2O)	Insoluble	Insoluble



Examples that you must fully understand

1. Complete the following table with the use of the substances below:

$CuSO_4$, H_2, I_2, H_2SO_4, Fe, Al, HNO_3, $MgCl_2$, Graphite, NaCl, SiO_2, CO_2, CaO, NH_3, MgO, CCl_4, CH_3OH, Au

Structure	GMS	GCS	SMS	GIS
Substances				
State at 25°C				
Solubility in water				
Solubility in trichloromethane				
Electrical conductivity in Solid state				
Electrical conductivity in Liquid state				
Electrical conductivity in Aqueous state				

2. Predict which one in the following pairs of substances has a higher boiling point. Explain briefly.

(a) NaCl vs Cl_2

NaCl has a [ ]. There [ ]. A lot of energy is needed to break the bonds.

Cl_2 has a [ ]. There are [ ] [ ] between [ ]. Little amount of energy is needed to overcome the force.

Therefore, the boiling point of NaCl is higher.

(b) SiO_2 vs CO_2

SiO_2 has a [ ]. There are strong covalent bonds between [ ]. A lot of energy is needed to break the bonds.

CO_2 has a simple molecular structure. There are weak van der Waals' forces / intermolecular forces between molecules. Little amount of energy is needed to overcome the force.

Therefore, the boiling point of SiO_2 is higher.

(c) Al vs I_2

Al has a giant metallic structure. There are strong metallic bonds between [ ] [ ]. A lot of energy is needed to break the bonds.

I_2 has a simple molecular structure. There are weak van der Waals' forces / intermolecular forces between molecules. Little amount of energy is needed to overcome the force.

Therefore, the boiling point of Al is higher.

(d) CH_4 vs CCl_4

Both of them are in [ ]. There are weak van der Waals' force / intermolecular force between their molecules.

However, the [ ] of van der Waals' forces in CCl_4 is [ ] due to its [ ] [ ].

Therefore, the boiling point of CCl_4 is higher.

3. Predict which one in each of the following pairs of substance has a higher boiling point.

(a) $MgCl_2$ vs CCl_4

(b) N_2 vs Br_2

(c) Ca vs PH_3

(d) HCl vs HI

(e) SiO_2 vs CO_2

(f) C vs Si

(g) $MgCl_2$ vs NaCl

(h) KCl vs LiCl

(i) K vs Na

(j) Mg vs Na

4. Statement one-two:

Statement 1: The melting point of diamond is higher than that of iron.

Statement 2: The covalent bond is stronger than the metallic bond.

5. The atomic number of elements X and Y are 9 and 19 respectively. Which of the following statements concerning the compound formed between X and Y is INCORRECT?

A. ***One formula unit of compound contains 28 electrons.***

B. ***This compound has a very high melting point.***

C. ***This compound is soluble in water.***

D. ***Pure substance of this compound is a conductor at 25°C.***

6. A compound called silicon carbide can be formed between C and Si. Its structure is similar to diamond.

(a) Write down the chemical formula of silicon carbide.

(b) Draw the crystal structure of silicon carbide.

7. Give the formula and name of the compound formed between:

	Elements	Formula	Name	Ionic/covalent?
(a)	Ca & S			
(b)	Cs & N			
(c)	B & Cl			
(d)	Si & O			
(e)	P & Cl			
(f)	N & H			
(g)	O & F			
(h)	Al & S			
(i)	Br & Cl			
(j)	Si & Cl			
(k)	C & H			

8. Which of the following statements is/are true?

(1) NaCl cannot conduct electricity because there are no ions in it.

(2) NaCl has a higher bp than that of CCl_4 because the ionic bond in NaCl is stronger than the covalent bond in CCl_4.

(3) Chlorine and bromine are in the same group of the Periodic Table because they have similar chemical properties.

(4) HCl can dissolve in water producing H^+ and Cl^- is an ionic compound.

(5) When dry ice sublimes at room temperature and pressure, the covalent bonds are broken.

(6) When an ionic compound or a metal is melted, all of the ionic bonds are broken.

9. X, Y and Z are three elements in the Periodic Table. The sum of their atomic numbers equals to 38. It is known that both X and Y belong to Group VII and the atomic number of X is the smallest.

(a) What are X, Y and Z?

X: [ ]; Y: [ ]; Z: [ ]

(b) Draw the electronic diagram of the compound formed between X and Y and the compound formed between X and Z, showing the outermost electrons only.

(c) Compare and explain the electrical conductivity of the two compounds in (b).

The compound formed between X and Y does not conduct electricity since it has [ ] [ ].

The compound formed between X and Z can conduct electricity in [ ] since the ions in the compound become [ ].

(d) Suppose element T also belongs to Group VII and the electronic arrangement of T is 2, 8, p, q. What is the number of p and q?

10. Statement one-two:

Statement 1: Oxygen gas and Neon gas are both non-metals.

Statement 2: There are covalent bonds in both of the substances.

11. Which of the following exist as discrete molecules at room temperature and pressure?

(1) Graphite
(2) Argon gas
(3) Silicon dioxide
(4) Carbon dioxide
(5) Calcium chloride

12. Argon exists as a gas at room temperature and pressure because

A. *Argon is monatomic molecule.*
B. *Argon is chemically inert.*
C. *The outermost electron shell of an argon atom is octet.*
D. *The attractive force between argon molecules is weak.*
E. *There is no covalent bond in Argon gas.*

13. X and Y are two elements. The melting points of their chlorides are:

MP of Chloride of X = 772°C; MP of Chloride of Y = -68°C

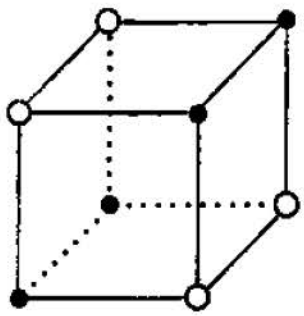
Which of the following statements is/are correct?

(1) Both X and Y are metals.
(2) The chloride of Y is a solid at room temperature.
(3) The chloride of X conducts electricity in solid state.
(4) The chloride of Y is a covalent compound.

14. Which of the following diagrams best represents a part of the giant lattice of sodium chloride crystal?

(In these diagram, • represent Na^+ ion and o represent Cl^- ion.)

A.



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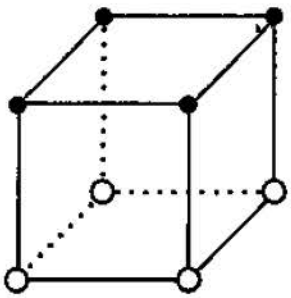
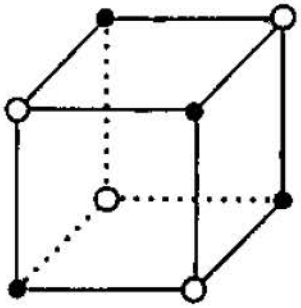
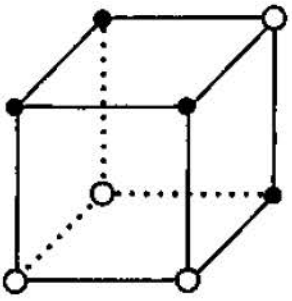


C.

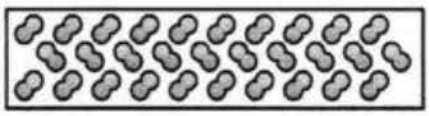


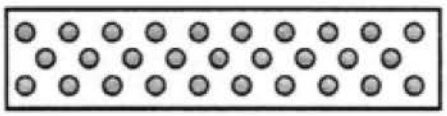
D.

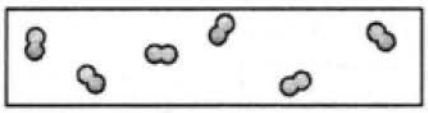


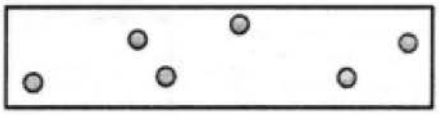
15. Draw the crystal structure of solid Bromine. Represent the Br_2 molecule with a ball.

16. Which of the following diagrams best represents the arrangement of particles in a sample of astatine at room temperature and pressure?

A. 

B. 

C. 

D. 

17. Which of the following groups of ions/ atoms has the same number of electrons?

A. K^+, Ca^{2+}

B. Cl^-, S

C. H^+, He

D. O^{2-}, Ar

18. X, Y and Z are three consecutive elements in the Periodic Table. X forms a stable anion X^-, while Z forms a stable cation Z^+. Which of the following statements about X, Y and Z is correct?

A. X, Y and Z are elements in the same period of the Periodic Table.

B. Y tends to form Y^+ cation.

C. Y reacts with Z readily.

D. X^- and Z^+ have the same electronic arrangement.

HKDSE-CHEM

PERIODIC TABLE

GROUP

(1 = atomic number; H; 1.0 = relative atomic mass)

I	II											III	IV	V	VI	VII	0
				1 **H** 1.0													2 **He** 4.0
3 **Li** 6.9	4 **Be** 9.0											5 **B** 10.8	6 **C** 12.0	7 **N** 14.0	8 **O** 16.0	9 **F** 19.0	10 **Ne** 20.2
11 **Na** 23.0	12 **Mg** 24.3											13 **Al** 27.0	14 **Si** 28.1	15 **P** 31.0	16 **S** 32.1	17 **Cl** 35.5	18 **Ar** 40.0
19 **K** 39.1	20 **Ca** 40.1	21 **Sc** 45.0	22 **Ti** 47.9	23 **V** 50.9	24 **Cr** 52.0	25 **Mn** 54.9	26 **Fe** 55.8	27 **Co** 58.9	28 **Ni** 58.7	29 **Cu** 63.5	30 **Zn** 65.4	31 **Ga** 69.7	32 **Ge** 72.6	33 **As** 74.9	34 **Se** 79.0	35 **Br** 79.9	36 **Kr** 83.8
37 **Rb** 85.5	38 **Sr** 87.6	39 **Y** 88.9	40 **Zr** 91.2	41 **Nb** 92.9	42 **Mo** 95.9	43 **Tc** (98)	44 **Ru** 101.1	45 **Rh** 102.9	46 **Pd** 106.4	47 **Ag** 107.9	48 **Cd** 112.4	49 **In** 114.8	50 **Sn** 118.7	51 **Sb** 121.8	52 **Te** 127.6	53 **I** 126.9	54 **Xe** 131.3
55 **Cs** 132.9	56 **Ba** 137.3	57 * **La** 138.9	72 **Hf** 178.5	73 **Ta** 180.9	74 **W** 183.9	75 **Re** 186.2	76 **Os** 190.2	77 **Ir** 192.2	78 **Pt** 195.1	79 **Au** 197.0	80 **Hg** 200.6	81 **Tl** 204.4	82 **Pb** 207.2	83 **Bi** 209.0	84 **Po** (209)	85 **At** (210)	86 **Rn** (222)
87 **Fr** (223)	88 **Ra** (226)	89 ** **Ac** (227)	104 **Rf** (261)	105 **Db** (262)													

*	58 **Ce** 140.1	59 **Pr** 140.9	60 **Nd** 144.2	61 **Pm** (145)	62 **Sm** 150.4	63 **Eu** 152.0	64 **Gd** 157.3	65 **Tb** 158.9	66 **Dy** 162.5	67 **Ho** 164.9	68 **Er** 167.3	69 **Tm** 168.9	70 **Yb** 173.0	71 **Lu** 175.0
**	90 **Th** 232.0	91 **Pa** (231)	92 **U** 238.0	93 **Np** (237)	94 **Pu** (244)	95 **Am** (243)	96 **Cm** (247)	97 **Bk** (247)	98 **Cf** (251)	99 **Es** (252)	100 **Fm** (257)	101 **Md** (258)	102 **No** (259)	103 **Lr** (260)