Chapter 7 – Chemical Bonds

(A) Basic Concepts of Bonding

1. Define bonding.

- Bonding is a process in which an atom transfers electrons to, or shares electrons with, another atom in order to obtain the Octet structure.

2. State and define the two types of bonding.

- Ionic bonding
  - Ionic bonding is the transfer of electrons from a metallic atom to a non-metallic atom so that both obtain the Octet structure.

- Covalent bonding
  - Covalent bonding is the sharing of electrons between two non-metallic atoms so that both obtain the Octet structure.

3(a) What is the Octet structure?

- The Octet structure is one where the outermost electron shell of an atom / ion is completely filled with electrons.

(b) Why is the Octet structure desired by all atoms?

- Because atoms are most stable when they have the Octet structure.

4. The elements in the Periodic Table can be broadly classified into metals and non-metals. State whether ionic and covalent bonding are formed by metals and / or non-metals.

- Ionic bonding: Formed between metals and non-metals.
- Covalent bonding: Formed between non-metals.

5. What are valence electrons?

- Valence electrons are the electrons in the outermost electron shell of an atom.

6. What is valency?

- ❖ Valency is the number of electrons an atom uses to form bonds.

Comments:

√ *Valency is not the same as valence electrons.*
√ *Simply put, the valency of an element is a measure of how it combines with other elements.*
√ *As a general rule, the valency of an atom is equal to the number of its outermost electrons (if it has 4 or less electrons). Otherwise, the valency is equal to 8 minus the number of outermost electrons (if it has more than 4 electrons).*

7. A substance X is in Group III. State the valency of X.

- ❖ 3

8(a) How many valence electrons does a chlorine atom have?

- ❖ 7

(b) What is the valency of chlorine?

- ❖ 1

(c) State two ways how it can achieve such a structure.

- ❖ By receiving an electron through ionic bonding, where the chloride ion (2,8,8) is formed.
- ❖ By sharing a pair of electrons through covalent bonding.

(B) Ionic Bonding: The Transfer of Electrons

9. Why are all atoms electrically neutral?

- ❖ Because they have the same number of protons and electrons.

Comment:

√ *Protons are positively charged, and electrons, negatively charged. When there is an equal number of protons and electrons, the positive and negative charges will cancel off each other.*

10. What is an ion?

- ❖ An ion is a charged particle formed from an atom or a group of atoms by the loss or gain of electrons.

11. Ionic bonding involves the transfer of electrons. State how the following types of ions are formed:

(a) positively charged ions

- Via the loss of electrons.

(b) negatively charged ions

- Via the gain of electrons.

(B1) Cations and Anions

12. What is a:

(a) cation

- A positively-charged ion.

(b) anion?

- A negatively-charged ion.

13. What type of ions do metals and non-metals form?

- Metals form positively charged ions (cations).
- Non-metals form negatively charged ions (anions).

14. In general, how many electrons can atoms of:

(a) metals give away in order to form cations,

- Atoms of metals give away one, two or three electrons.

(b) non-metals gain in order to form anions?

- Atoms of non-metals gain one, two or three electrons.

15. What is the difference in structure between a sodium atom and a sodium ion?

- A sodium atom contains eleven electrons but a sodium ion contains only ten electrons.

Comment:

√ *A sodium ion contains 11 protons and 10 electrons. Thus, it is positively-charged as it contains more protons than electrons.*

16. What is the difference in structure between an oxygen atom and an oxide ion?

- An oxygen atom contains eight electrons but an oxide ion contains ten electrons.

Comment:

√ *An oxide ion is negatively charged as it contains more electrons than protons.*

17. Complete the columns on the formula and charge of the ions in the table below:

Name of Cation	Formula of Cation	Charge of Cation
Hydrogen		
Aluminium		
Iron(III)		
Sodium		
Lithium		
Barium		
Potassium		
Zinc		
Iron(II)		
Silver		
Ammonium		
Magnesium		
Calcium		
Copper(I)		
Copper(II)		
Lead(II)		
Chromium(III)		

Name of Anion	Formula of Anion	Charge of Anion
Fluoride		
Oxide		
Chloride		
Sulphide		
Bromide		
Iodide		

- Answer:

Name of Cation	Formula of Cation	Charge of Cation
Hydrogen	H^+	+1
Aluminium	Al^{3+}	+3
Iron(III)	Fe^{3+}	+3
Sodium	Na^+	+1
Lithium	Li^+	+1
Barium	Ba^{2+}	+2
Potassium	K^+	+1
Zinc	Zn^{2+}	+2
Iron(II)	Fe^{2+}	+2
Silver	Ag^+	+1
Ammonium	NH_4^+	+1
Magnesium	Mg^{2+}	+2
Calcium	Ca^{2+}	+2
Copper(I)	Cu^+	+1
Copper(II)	Cu^{2+}	+2
Lead(II)	Pb^{2+}	+2
Chromium(III)	Cr^{3+}	+3

Name of Anion	Formula of Anion	Charge of Anion
Fluoride	F^-	-1
Oxide	O^{2-}	-2
Chloride	Cl^-	-1
Sulphide	S^{2-}	-2
Bromide	Br^-	-1
Iodide	I^-	-1

(B2) Formation of Ionic Bonds

18. What is an ionic bond?

- ❖ An ionic bond is the strong electrostatic attraction between the positive metallic ion and negative non-metallic ion that holds the oppositely charged ions together.

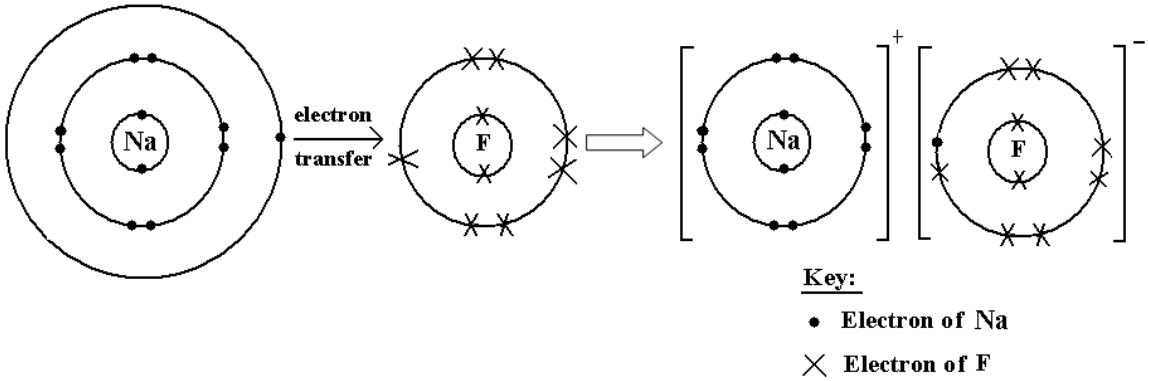
19. When does ionic bonding result?

- ❖ Ionic bonding results when electrons are transferred from a metallic atom to a non-metallic atom, forming positive and negative ions.
- ❖ After the transfer of electrons, the metallic and non-metallic ions obtain the stable octet configuration of a noble gas.
- ❖ The positive and negative ions experience a strong electrostatic attraction that holds them together.

Eg **20. Draw a diagram to illustrate the <u>formation</u> of the ionic bond in:**

(a) Sodium fluoride

- ❖ Answer:

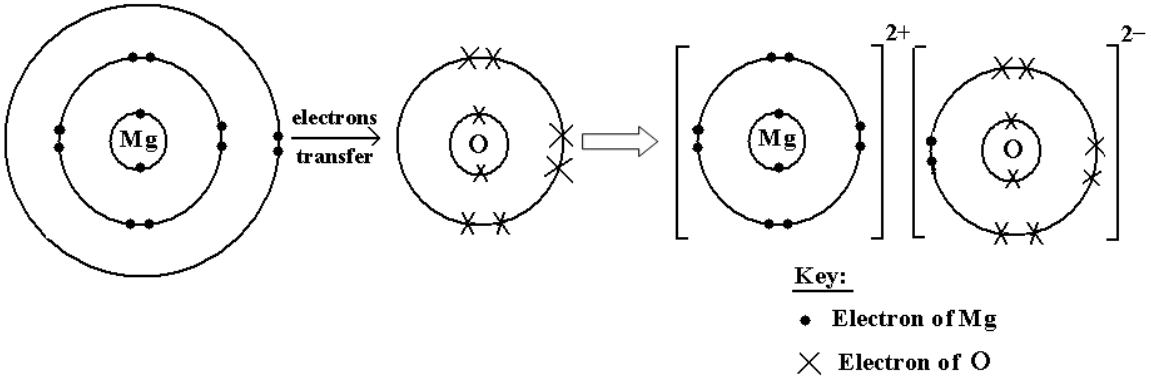


<u>Comment:</u>

√ *The sodium atom has 1 valence electron, and the fluorine atom 7 valence electrons. The electron from the sodium atom will be transferred to the fluorine atom, so that both atoms obtain the Octet structure with 8 outermost electrons. The 2 ions have different charges, and will attract each other.*

(b) Magnesium oxide

❖ Answer:



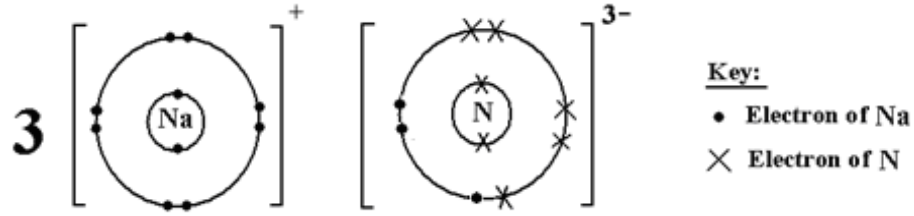
Comment:

√ *The magnesium atom has 2 valence electrons, and the oxygen atom 6 valence electrons. The 2 electrons from the magnesium atom will be transferred to the oxygen atom, so that both atoms will obtain the Octet structure with 8 outermost electrons.*

Eg **21. Draw "dot-and-cross" diagrams to illustrate the bonding in:**

(a) Sodium nitride

❖ Answer:

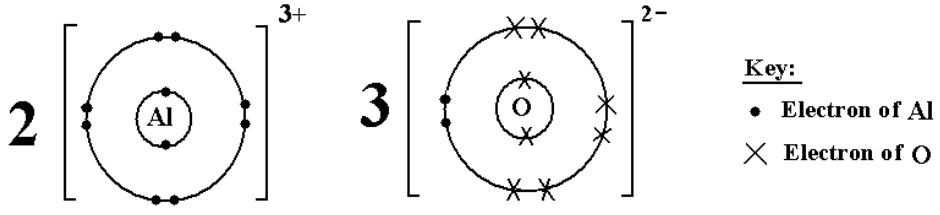


Comment:

√ *The nitrogen atom has 5 valence electrons, and will need 3 more electrons to obtain the Octet structure. Since each sodium atom only has 1 valence electron, we will need 3 sodium atoms to bond with nitrogen to form sodium nitride.*

(b) Aluminium oxide

❖ Answer:



Comment:

√ *Each Al atom can donate 3 electrons, and each O atom can accept 2 electrons. Thus, the simplest ratio is 2 Al atoms to 3 O atoms.*

(B3) Polyatomic Ions

22. Fill in the blank:

Polyatomic ions are a _____ that carry charges.

- ❖ group of atoms

23. Give three examples of polyatomic ions.

- ❖ Ammonium ion
- ❖ Carbonate ion
- ❖ Sulphate ion

24. Complete the columns "Formula of ion" and "Charge of ion" in the table below:

Name of Polyatomic Ion	Formula of Polyatomic Ion	Charge of Polyatomic Ion
Nitrate		
Nitrite		
Sulphate		
Sulphite		
Bisulphate		
Carbonate		
Bicarbonate		
Hydroxide		
Phosphate		
Ammonium		

- ❖ Answer:

Name of Polyatomic Ion	Formula of Polyatomic Ion	Charge of Polyatomic Ion
Nitrate	NO_3^-	-1
Nitrite	NO_2^-	-1
Sulphate	SO_4^{2-}	-2
Sulphite	SO_3^{2-}	-2
Bisulphate	HSO_4^-	-1
Carbonate	CO_3^{2-}	-2
Bicarbonate	HCO_3^-	-1
Hydroxide	OH^-	-1
Phosphate	PO_4^{3-}	-3
Ammonium	NH_4^+	+1

(B4) Structure of Ionic Compounds

25. Sodium chloride is a typical example of an ionic solid. State the structure in which its ions are arranged in.

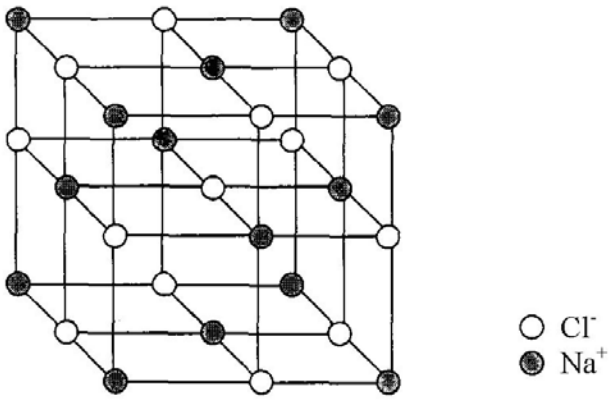
- ❖ Lattice structure

Comments:

- √ *The ions in all ionic compounds are arranged in some forms of a lattice structure.*
- √ *Lattice structure is also known as crystal lattice.*

26. Draw a diagram to show the lattice structure of a sodium chloride crystal.

- ❖ Answer:



Comments:

- √ *The diagram represents only a tiny part of the sodium chloride crystal. The pattern in fact repeats in this way over countless ions.*
- √ *Students will not be required to draw the lattice structure in tests / exams. However, they should be familiar with the structure as related questions could be asked.*

(B5) Properties of Ionic Compounds

27. State three physical properties of ionic compounds.

- ❖ High melting and boiling points.
- ❖ Usually soluble in water but insoluble in organic solvents.
- ❖ Conduct electricity when dissolved in water or when molten.

Comment:

- √ *"Molten" means "melted". Thus, a substance is in the molten state when it is melted and in the liquid state.*

28. Explain why ionic compounds have such high melting points of above 250°C and boiling points of above 500°C.

- ❖ The electrostatic force of attraction between the oppositely-charged ions is very strong.
- ⇨ Thus a large amount of heat energy is needed to break up these bonds, resulting in high melting and boiling points.

29. Ionic compounds have high melting points. Thus, what is their physical state at room temperature?

- ❖ Solids

30. Ionic compounds do not dissolve in organic solvents. Give three examples of organic solvents.

- ❖ Petrol
- ❖ Alcohol
- ❖ Turpentine

31. Explain why ionic compounds conduct electricity only when dissolved in water or when molten.

- ❖ In the solid state, ionic compounds do not conduct electricity. This is because its ions are held in fixed positions, and thus are not free to move about to conduct electricity.
- ❖ When dissolved in water or when molten, ionic compounds dissociate to form ions. These ions are free to move in the molten state or in aqueous solution, and can conduct electricity.

(B6) Formula of Ionic Compounds

32. Fill in the blanks involving the steps used for deducing the formula of an ionic compound:

(a) Write down the _____ of the ions.

- ❖ formula

(b) _____ the charges.

- ❖ Criss-cross

Example:

Step 1: Write down formula

Mg^{2+} Cl^{-}

Step 2: Criss-cross charges

⇨ Formula: $MgCl_2$

Comment:

√ *In writing the formula of ionic compounds, ensure that:*

- o *The subscripts are in the simplest ratio possible, e.g. MgO and not Mg_2O_2.*
- o *The subscript "1" is not written, e.g. NaCl and not Na_1Cl_1*
- o *If there is more than one polyatomic ion in a compound, the polyatomic ion (e.g. OH^-) is written within brackets, e.g. $Cu(OH)_2$ and not $CuOH_2$.*

33. Complete the table below by filling in the blanks:

Name of Compound	Cation	Anion	Formula of Compound
Lead(II) sulphide			
Calcium chloride			
			MgI_2
	Al^{3+}	S^{2-}	
Sodium oxide			
			K_3N
Iron(III) oxide			
Calcium hydroxide			
Ammonium sulphate			
Potassium nitrate			

❖ Answer:

Name of Compound	Cation	Anion	Formula of Compound
Lead(II) sulphide	Pb^{2+}	S^{2-}	PbS
Calcium chloride	Ca^{2+}	Cl^-	$CaCl_2$
Magnesium iodide	Mg^{2+}	I^-	MgI_2
Aluminium sulphide	Al^{3+}	S^{2-}	Al_2S_3
Sodium oxide	Na^+	O^{2-}	Na_2O
Potassium nitride	K^+	N^{3-}	K_3N
Iron(III) oxide	Fe^{3+}	O^{2-}	Fe_2O_3
Calcium hydroxide	Ca^{2+}	OH^-	$Ca(OH)_2$
Ammonium sulphate	NH_4^+	SO_4^{2-}	$(NH_4)_2SO_4$
Potassium nitrate	K^+	NO_3^-	KNO_3

(B7) Uses of Ionic Compounds

34. State one use of the following ionic compounds, and explain why they are used as such.

(a) Magnesium oxide

❖ Used as a refractory material to line the inside of furnaces.
❖ Because it has a high melting point and is heat resistant.

(b) Aluminium oxide

❖ Used to make spark plugs in cars / vehicles.
❖ Because it has a high melting point and is heat resistant.

Comments:

√ *A spark plug is a device inserted in the head of an internal-combustion engine cylinder that ignites the fuel mixture by means of an electric spark.*
√ *Another usage of aluminium oxide is in the making of crucibles.*

(C) Covalent Bond: The Sharing of Electrons

(C1) Formation of Covalent Bonds

35. What is a covalent bond?

- ❖ A covalent bond is the bond formed by the sharing of electrons between two non-metallic atoms.

Comment:

√ *Covalent bonds can be formed between atoms of the same element (e.g. in the molecules H_2 and Cl_2) or between atoms of different elements (e.g. in the molecules CH_4 and H_2O).*

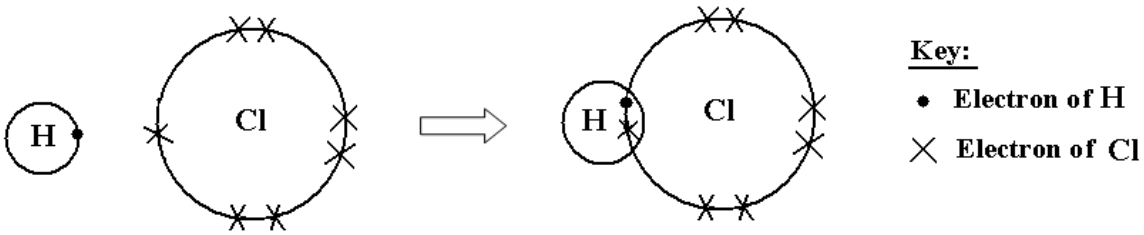
36. When does covalent bonding result?

- ❖ Covalent bonding results when electrons are shared between two non-metallic atoms.
- ❖ Upon the sharing of electrons, the two atoms obtain the stable octet configuration of a noble gas.

Eg **37. Draw a diagram, showing only outermost electrons, to illustrate the formation of the covalent bond in the following molecules:**

(a) Hydrogen chloride

- ❖ Answer:



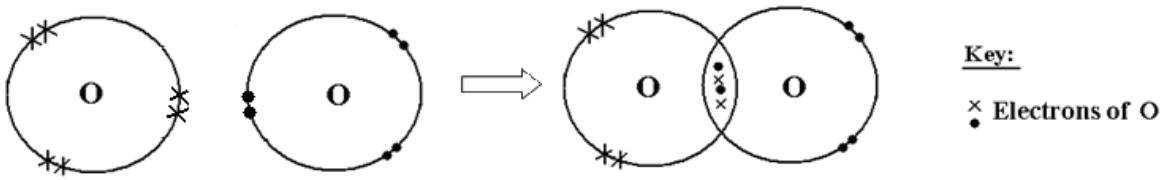
Comments:

√ *Hydrogen has 1 valence electron and need one more electron to obtain a full outermost shell of 2 electrons. Chlorine has 7 valence electrons and need one more electron to obtain a full outermost shell of 8 electrons. Thus, by sharing electrons, the two atoms will be able to achieve a complete outermost shell.*

√ *The bond formed between the hydrogen and chlorine atoms comprises 2 electrons. Such a covalent bond is known as a single bond.*

(b) Oxygen gas

- Answer:

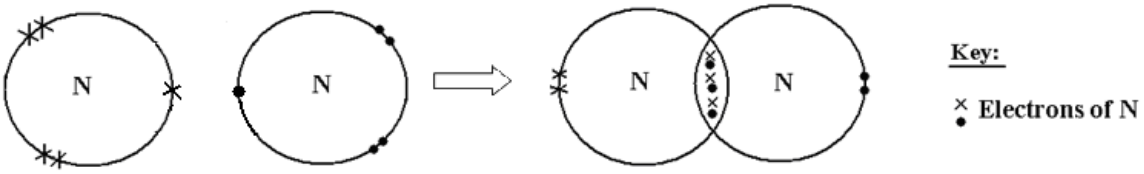


Comment:

√ *The bond formed between the two oxygen atoms comprises 4 electrons. Such a covalent bond is known as a double bond.*

(c) Nitrogen gas

- Answer:



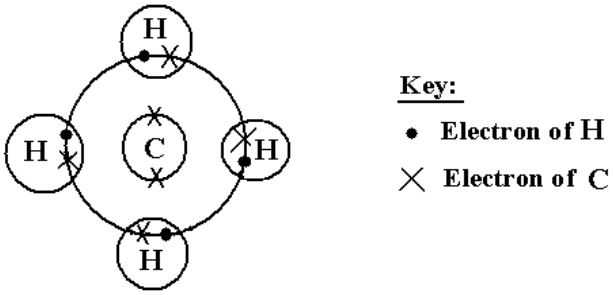
Comment:

√ *The bond formed between the two nitrogen atoms comprises 6 electrons. Such a covalent bond is known as a triple bond.*

Eg **38. Draw "dot-and-cross" diagrams to illustrate the bonding in:**

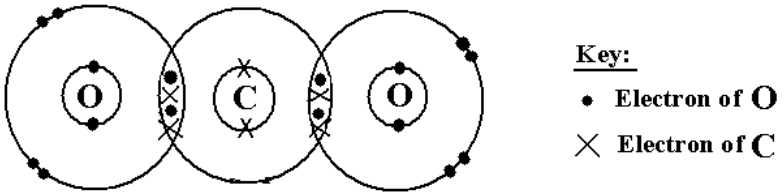
(a) Methane

- Answer:



(b) Carbon Dioxide

- Answer:



(C2) Structure of Simple Molecular / Covalent Compounds

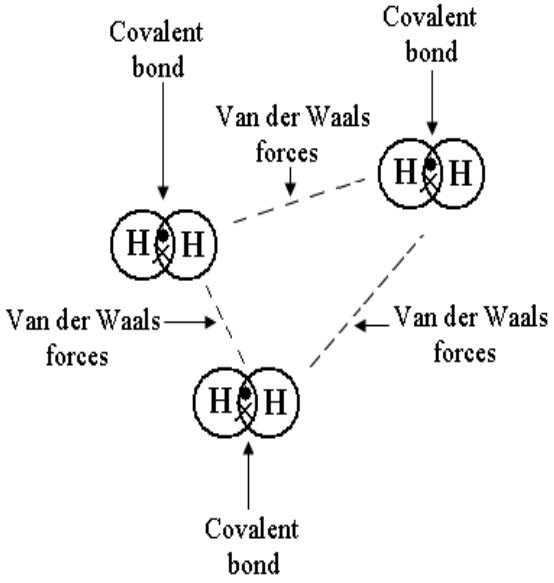
39. Describe the structure of simple molecular compounds.

- ❖ Consist of simple, discrete molecules.
- ❖ Within the molecule, the atoms are joined together by strong covalent bonds.
- ❖ Between the molecules, weak intermolecular forces known as Van der Waals forces exist.

Comment:

√ *"Simple, discrete" molecules mean that the molecules "exist separately, and are not covalently bonded to other molecules".*

40. With regards to simple molecular compounds, state the type of force found



(a) between its atoms

- ❖ Covalent bonds

(b) between its molecules

- ❖ Intermolecular forces (Van der Waals forces)

Eg **41(a) What type of molecule is iodine?**

- ❖ A simple discrete molecule.

(b) What type of structure does it have?

- ❖ Simple molecular structure.

(c) What type of bonds is found <u>within</u> the iodine molecules?

- ❖ Strong covalent bonds.

(d) What type of forces is found <u>between</u> the iodine molecules?

- ❖ Weak Van der Waals' forces.

(C3) Properties of Simple Molecular Compounds

42. State three physical properties of simple molecular compounds.

- ❖ Low melting and boiling points.
- ❖ Usually soluble in organic solvents but insoluble in water.
- ❖ Do not conduct electricity in any state (except HCl and HS when dissolved in water).

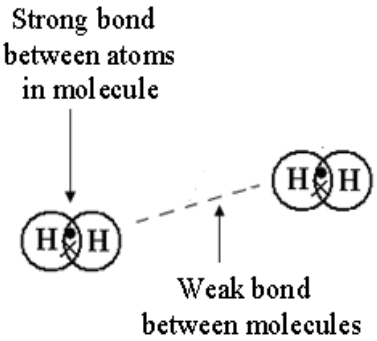
43. Explain why simple molecular compounds have low melting and boiling points.

- ❖ The Van der Waals forces between the molecules are weak.
- ⇨ Thus very little amount of heat energy is needed to break up these intermolecular forces, resulting in low melting and boiling points.

44. Fill in the blanks:

When a simple molecular compound melts / boils, only the weak _____ break; the strong _____ inside each molecule are not broken.

- ❖ Van der Waals forces
- ❖ covalent bonds



Comment:

√ *Two hydrogen molecules are shown on the right. Note that the strong covalent bond between atoms is not broken during melting / boiling; only the weak Van der Waals (intermolecular) forces are broken.*

45. Simple molecular compounds have low melting points.
Thus, what is typically their physical state at room temperature?

- ❖ Liquids or gases

Comment:

√ *Many simple covalent molecules are liquids or gases at room temperature because they melt or boil below room temperature. As the molecules increase in size, the force of attraction becomes stronger. Hence, larger molecules are solids at room temperature.*

46. Explain why covalent compounds do not conduct electricity.

- ❖ Because covalent compounds do not contain ions or free electrons to conduct electricity.

(C4) Formula of Covalent Compounds

47. What does the molecular formula for a covalent compound show?

- ❖ The types and number of atoms in the covalent compound.

48. What can be inferred from the molecular formula of carbon dioxide, CO_2?

- ❖ Each carbon dioxide molecule contains two oxygen atoms joined to one carbon atom.

Comment:

√ *For ionic compounds, you have to write down the formula of the ions and then criss-cross the charges. In contrast, the formulas of covalent compounds are more straight-forward because there are no charges involved. For example, the formula of carbon dioxide is simply CO_2, carbon monoxide is CO, and water is H_2O.*