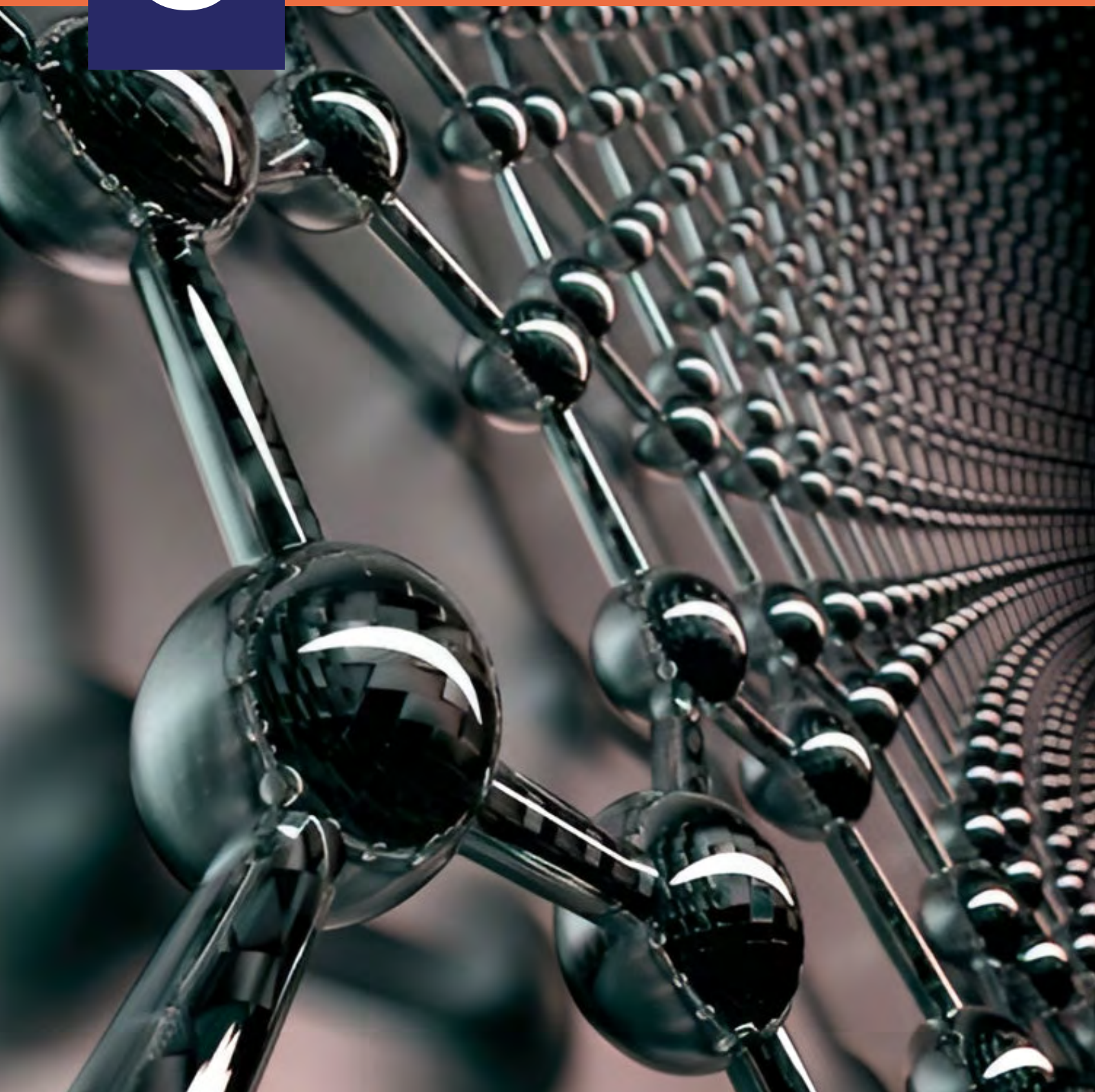
Chemistry Year 1

SECTION 8

INTERMOLECULAR BONDING



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INTRODUCTION

There are different types of intermolecular forces between molecules. These forces arise from the molecular structures of the molecules, and they influence the physical properties of the compounds. In this section, we will delve into explaining how these forces affect the properties of the molecular compounds.

At the end of this section, you will be able to:

- Describe the different types of intermolecular forces and explain how they arise from the structural features of molecules
- Explain how intermolecular forces affect the physical properties of compounds

Key Ideas:

- **Dipoles** - these are pairs of equal and oppositely charged species.
- **Hydrogen bond** - a weak bond between two molecules resulting from an electrostatic attraction between a proton in one molecule and an electronegative atom in the other.
- **Van der Waal Forces** - weak electrostatic forces that attract neutral molecules to one another.
- **Intermolecular forces** - are the attractive and repulsive forces that arise between molecules of a substance.
- **Intra-molecular forces** - Intramolecular forces are the attractive forces that hold atoms together within a molecule.
- **Induced dipole–induced dipole (London Dispersion Forces)** - this is a weak attraction that occurs when a polar molecule causes a dipole to form in an atom or non-polar molecule by disrupting the electron configuration in the non-polar species.

INTERMOLECULAR BONDING

Intermolecular forces (IMF) are the forces that attract or push away molecules in a substance. These forces control how molecules interact with each other. They also help explain many of the physical and chemical properties of different materials.

Intermolecular forces are the attractions that pull molecules together. This is different from **intramolecular forces**, which hold the atoms together inside a molecule, like **covalent bonds**. Covalent bonds are much stronger than intermolecular forces because they keep the molecule itself together.

Intermolecular forces happen because of electric charges, dipoles (molecules with positive and negative ends), and hydrogen bonds. The most common types of intermolecular forces are:

1. Dipole-dipole forces
2. Hydrogen Bonds
3. Induced Dipole–Induced Dipole Forces

Covalent bonds are stronger than intermolecular forces. For example, covalent bonds are usually 50-200 kJ/mol in strength, while intermolecular forces are weaker, usually 1-12 kJ/mol. **Intramolecular forces** keep molecules stable (the atoms making up the molecule remain the same), while **intermolecular forces** affect properties like:

a. **Melting and boiling points**
b. **Solubility**
c. **Viscosity**

To boil a substance, enough energy is needed to completely break the intermolecular forces holding the molecules together, so they can turn into gas. Substances with higher boiling points have stronger intermolecular forces. Those with the highest boiling points have intermolecular forces that are also intramolecular forces e.g. diamond is made up of a network of covalent bonds hence its high boiling point.

Van der Waal Forces

Covalent molecules are usually held together by **Van der Waals forces**, which are forces of attraction between molecules. These forces of attraction come about because of opposite charges that are either permanently present or temporarily present, depending on the atoms in the compound.

There are three types of **Van der Waals forces** based on how the charges are spread in the molecules:

1. **Dipole-Dipole Interactions** are forces that occur between molecules that have positive and negative ends (***dipoles***).
2. **Hydrogen Bonding** is a strong type of dipole interaction that happens when hydrogen is bonded (within the molecule) to highly electronegative atoms like oxygen or nitrogen or fluorine.
3. **Induced Dipole–Induced Dipole (London Dispersion) Forces**: These are weak forces that happen when temporary charges appear in molecules as they get close to each other.

Dipole - Dipole interaction

Dipole-dipole interaction, also called dipolar interaction, is a type of force that happens between two polar molecules. **Polar molecules** have a permanent separation of positive and negative charges. This happens because the atoms in the molecule pull on the shared electrons with different strengths.

Since some atoms in molecules pull harder on the shared electrons, one atom ends up with the shared electrons nearer to it and gets a **partial negative charge**, while the other atom has fewer electrons nearer to it and gets a **partial positive charge**. In dipole-dipole interactions, the positive end of one molecule is attracted to the negative end of another, creating a force that pulls the molecules together.

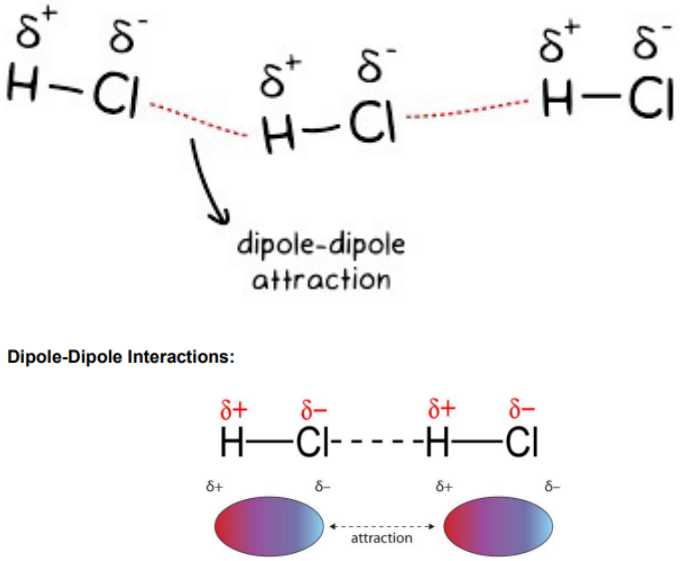

Fig. 8.1: Dipole-dipole interactions

Dipole-dipole interactions are weaker than **covalent bonds** but stronger than **London dispersion forces** (*another type of force that will be explained later*). These interactions are important because they help explain the physical and chemical properties of **polar molecules**.

Dipole-dipole interactions also help determine how easily a polar molecule can dissolve in a **polar solvent** (like water). The attraction between the molecules of the substance and that of the solvent makes the substance more **soluble**. These interactions can also affect the **shape** and **stability** of molecules when they are in solid or liquid forms.

Hydrogen Bond

A hydrogen bond is a special kind of dipole-dipole interaction. It happens when a **hydrogen atom** is bonded to a small but very **electronegative atom** like **oxygen**, **nitrogen**, or **fluorine**. The electronegative atom pulls more on the electrons, creating a **partial negative charge** on itself, while the hydrogen atom gets a **partial positive charge**.

The **partially positively charged hydrogen** is then attracted to a **partially negatively charged electronegative atom** in a nearby molecule. This attraction forms a **hydrogen bond** between the two molecules.

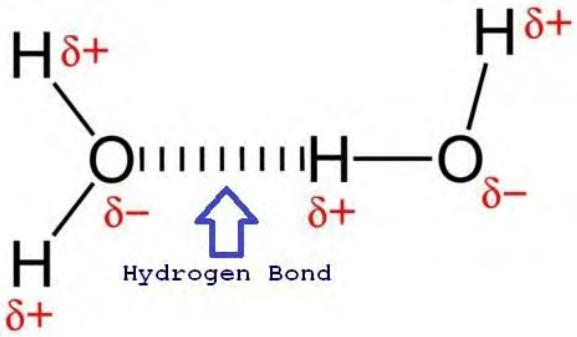

Fig 8.2: Hydrogen bond

Hydrogen bonds are stronger than London dispersion forces (also called induced dipole–induced dipole forces) and dipole-dipole forces, but they are weaker than covalent bonds. Hydrogen bonds are important because they affect the properties of many substances, like water, ice, and biomolecules such as DNA and proteins.

For example, the special properties of water—like its unusually high boiling point, surface tension, and density—are caused by hydrogen bonds between molecules of water. In DNA, hydrogen bonds between base pairs help keep the double helix structure together.

Some common compounds that have their hydrogen atoms bonded to electronegative atoms (like oxygen, nitrogen, and fluorine) include:

Water (H_2O), Ammonia (NH_3), Hydrogen fluoride (HF), Methanol (CH_3OH), Ethanol (C_2H_5OH), Acetic acid (CH_3COOH), Phenol (C_6H_5OH), Sugars (like glucose and fructose), Proteins (like collagen and keratin) and RNA.

These compounds have special properties that make them important in many fields, such as **medicine**, **chemistry**, and **biology**.

Induce dipole–induce dipole (London dispersion) forces

London dispersion forces are types of **intermolecular bonds** that occur between **non-polar covalent molecules**. These forces occur because of small changes in electron density, which cause an uneven distribution of charge.

This uneven charge distribution creates **temporal dipoles** in a molecule, meaning one part of the molecule becomes slightly positive and another part slightly negative. This temporary created dipole can cause a nearby molecule to also form a dipole, and then the two molecules are **attracted** to each other.

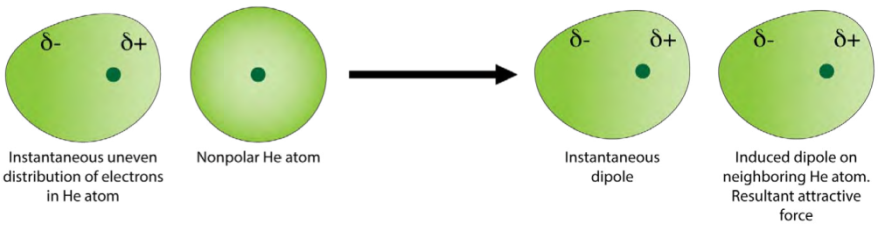

Fig. 8.3: Induce dipole-induce dipole forces

Examples of non-polar molecules which have weakly induced dipole-induced dipole intermolecular forces are diatomic molecules (O_2, H_2, l_2, Br_2); noble gases (He, Ar, Ne): CO_2, CH_4, CCl_4, polythene and rubber.

Activity 8.1

Pair up with your colleague and answer the following questions:

1. In terms of intermolecular forces, explain why the solubility of ethanol in water is greater than the solubility of ether in water.
2. Consider the following compounds: CH_4, CO_2, NH_4Cl. Select the compound capable of undergoing dipole-dipole interactions and explain your answer.

EFFECTS OF INTERMOLECULAR FORCES ON PHYSICAL PROPERTIES OF COMPOUNDS

Intermolecular forces (IMFs) help us understand the physical properties of substances, such as boiling points, melting points, and viscosity. They play a key role in determining how molecules behave in different situations.

1. **Boiling and Melting Points**

   The strength of IMFs affects how much energy is needed to change a substance from a solid to a liquid (melting) or from a liquid to a gas (boiling).

   Substances with stronger IMFs need more energy to melt or boil, so they have higher melting and boiling points. For example, water has strong hydrogen bonds and a high boiling point.

   Substances with weaker IMFs need less energy, so they have lower melting and boiling points. For example, methane has weak forces and a low boiling point.

2. **Solubility**

   Solubility is the ability of one substance to dissolve in another. It depends on the type of intermolecular forces between the solute (the substance being dissolved) and the solvent (the substance doing the dissolving).

   The rule “like dissolves like” means substances with similar types of IMFs dissolve in each other. For example, polar substances dissolve well in polar solvents (like water), while non-polar substances dissolve in non-polar solvents (like oil).

   Hydrogen bonding helps substances like alcohol dissolve in water.

   It is worth noting that this is not the only thing which could affect solubility; temperature and pressure also affect solubility. For example, gases dissolve better at higher pressures.

3. **Surface Tension**

   Surface tension is the property of a liquid’s surface that causes it to behave like a stretched elastic membrane. This phenomenon arises from the cohesive forces between molecules at the surface, which create a tendency for the surface to minimize its area.

   Liquids with stronger IMFs have higher surface tension. Liquids with weaker forces have lower surface tension.

   It is worth noting that this is not the only thing which could affect surface tension; Increasing temperature lowers surface tension because molecules

move faster (and with greater energy) meaning they can more readily overcome the forces at the surface.

4. **Enthalpy of Vaporisation**:

   The enthalpy of vaporisation is the energy needed to change a liquid into a gas. Substances with stronger IMFs need more energy to vaporise, so they have a higher enthalpy of vaporisation.

   Substances with weaker IMFs, like noble gases, have a lower enthalpy of vaporisation because they need less energy to become a gas.

5. **Viscosity**

   Viscosity is how thick or sticky a liquid is and how easily it flows. Liquids with stronger IMFs have higher viscosity because their molecules are held together more, making it harder to flow. For example, honey flows slowly because of strong hydrogen bonds.

   Liquids with weaker IMFs, have lower viscosity and flow easily.

6. **Volatility**

   Volatility refers to how easily a substance evaporates. Substances with stronger IMFs have lower volatility because their molecules are held tightly together, making it harder to evaporate.

   Substances with weaker IMFs have high volatility and evaporate easily. These properties help us understand how substances behave in different situations, from boiling water to the flow of syrup!

Activity 8.2: Intramolecular and intermolecular forces of attraction.

1. Using the internet, watch videos of intramolecular and intermolecular forces by clicking the links below.
   - https://www.youtube.com/watch?v=jucya5UsZz0
   - intermolecular forces-Khan Academy
2. Using this knowledge, define Intramolecular and intermolecular forces of attraction. In pairs, discuss your findings and answers. Make sure to include and refer to a labelled diagram in your discussion, as well as a comparison of all the forces you have found.

Activity 8.3: Hydrogen bond formation

Materials needed: pencil, drawing paper (or marker board and a marker).

1. Using the following molecules (HF, NH_3, CH_4, and H_2O), draw the structural formula of two of the molecules (e.g., ammonia, NH_3, and methane, CH_4).
2. Identify the electronegative atoms and the hydrogen atoms bonded to them.
3. Use different colours for the atoms for identification.
4. Identify how the shared electrons will be influenced by the different atoms on either side of the covalent bond.
5. Show how the molecules approach each other, forming hydrogen bonds.
6. Discuss and compare your results with your friends

Activity 8.4

Study the molecular structure of the following:

Water (H_2O); Ammonia (NH_3); Methanol (CH_3OH); Ethanol (C_2H_5OH); Acetic acid (CH_3COOH

1. Draw the structural formula of a molecule capable of forming hydrogen bonds.
2. Identify the electronegative atom and hydrogen atoms bonded to it.

Extended Activity

1. Compare and contrast the physical properties of ethanol (C_2H_5OH) and methane (CH_4) in terms of their intermolecular forces. Explain why ethanol has a higher boiling point than methane.
2. Design an experiment to investigate the relationship between the strength of intermolecular forces and the surface tension of different liquids. Include a hypothesis, materials list, procedure and expected results.
3. Analyse the impact of intermolecular forces on the solubility of various substances in water. Consider how factors such as molecular structure, polarity and hydrogen bonding influence solubility. Provide examples to support your analysis.

EXTENDED READING

Click on the links below and watch videos on the following forces:

- Dipole-dipole interactions: https://www.youtube.com/watch?v=zOvnu0KYyxo
- Hydrogen bonding: https://www.youtube.com/watch?v=RSRiywp9v9w
- Induced dipole–induced dipole (London dispersion): https://www.youtube.com/watch?v=yFYfP-Azio)

REVIEW QUESTION

Review Questions 8.1

1. Which type of intermolecular force is responsible for the high boiling point of water?

2. Arrange each of the following sets in order of increasing boiling point,

a. HCl, H_2O, SiH_4

b. F_2, Cl_2, Br_2

c. CH_4, C_2H_6, C_3H_8

d. O_2, NO, N_2

3. Deduce the type of intermolecular force present in each of the following compounds:

a. H_2S

b. NH_3

c. CH_4

d. SF_6

e . HF

ANSWERS TO REVIEW QUESTION

Answers to Review Question 8.1

1. Hydrogen bonding

2. **a.** $SiH_4 < HCl < H_2O$

b. $F_2 < Cl_2 < Br_2$

c. $CH_4 < C_2H_6 < C_3H_8$

d. $N_2 < O_2 < NO$

3. **a.** Since S is more electronegative than H, each S-H bond is polarized so H_2S will show dipole-dipole interaction. (Go online and watch a video on it at https://www.youtube.com/)

b. The presence of nitrogen tells us that hydrogen-bonding is present and will be the predominant intermolecular force present.

c. London dispersion forces (also known as dipole-dipole attractions) are present in CH_4 molecules.

d. Dispersion forces are present because it is a non-polar molecule that lacks hydrogen bonding and dipole-dipole interactions.

e. HF is a polar molecule so both dispersion forces and dipole-dipole forces are present. However, because a hydrogen atom is covalently bonded to a fluorine atom, and the same hydrogen atom interacts with a fluorine atom on another HF molecule, hydrogen bonding is possible.

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3. Ryan, L., & Norris, R. (2014). Cambridge International AS and A-level Chemistry Coursebook. University Printing House.

GLOSSARY

- **Melting and boiling points**: the temperature at which a substance will melt (turn into a liquid from a solid) or boil (turn into a gas from a liquid).
- **Solubility:** how easily a substance dissolves.
- **Viscosity:** how thick or runny a liquid is.

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