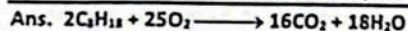


Q.13 How many moles of CO_2 can be produced from burning one mole of octane (mass of octane is 114)?



Number of moles of octane = 2 moles

Number of moles of CO_2 = ?

2 mole of octane gives CO_2 = 16 moles

1 mole of octane gives CO_2 = 8 moles



SELF-ASSESSMENT Chapter # 04

Total Mark: 30

Q.1 Encircle the correct option.

(1 × 6 = 6)

- (i) Which one of the following has maximum mass?
A. 0.5 mol of N_2 B. 0.5 mol of NH_3 C. 0.5 mole of He D. 0.5 mol of CO
- (ii) Which of the following represents Avogadro's number?
A. $6.022 \times 10^{23} \text{ mol}^{-1}$ B. $6.022 \times 10^{-23} \text{ mol}^{-1}$ C. $3.011 \times 10^{23} \text{ mol}^{-1}$ D. $1.008 \times 10^{24} \text{ mol}^{-1}$
- (iii) If 2 moles of H_2 react with 1 mole of O_2 , what is the limiting reagent?
A. H_2 B. O_2 C. H_2O D. None
- (iv) A sample of nitrogen gas (N_2 , molar mass = 28.0 g mol^{-1}) has a mass of 14.0 g. How many nitrogen atoms are present in this sample?
A. 3.01×10^{23} atoms B. 6.02×10^{23} atoms C. 1.20×10^{24} atoms D. 2.40×10^{24} atoms
- (v) If a gas has a density of 1.43 g/L at STP, what is its molar mass?
A. 14.3 g/mol B. 22.4 g/mol C. 32.0 g/mol D. 28.6 g/mol
- (vi) The number of molecules in 2 moles of CO_2 is:
A. 3.01×10^{23} B. 1.20×10^{24} C. 6.02×10^{23} D. 2.00×10^{23}

Q.2 Write short answers of the following questions.

(2 × 8 = 16)

- (i) Calculate the number of molecules in 0.5 mol of O_2 .
- (ii) Do you think that 1 mole of H_2 and 1 mole of NH_3 at 0°C and 1 atm will have Avogadro's number of particles?
- (iii) Calculate the molar mass of CO_2 from its density (1.96 g/L) at STP.
- (iv) Define stoichiometry. Give the basic assumptions of stoichiometric calculations.
- (v) Differentiate theoretical and actual yields. How is the percentage yield of a reaction calculated?
- (vi) Calculate the theoretical yield of water when 4 g of H_2 reacts with excess O_2 .
- (vii) The reaction produced 9 g of product when the theoretical yield was 10 g. Calculate percentage yield.
- (viii) How is stoichiometry important in medicine dosage?

Q.3 Extensive Questions.

(2 × 4 = 8)

- (a) When iron(III) oxide (Fe_2O_3) reacts with carbon monoxide (CO) in a blast furnace, iron metal (Fe) is produced according to the following equation:
- $$\text{Fe}_2\text{O}_3(s) + 3\text{CO}(g) \longrightarrow 2\text{Fe}(s) + 3\text{CO}_2(g)$$
- (b) If 1.00 kg of iron(III) oxide is reacted with excess carbon monoxide, and 650 g of iron is obtained, what is the percentage yield of iron? (A, of O = 16.0, Fe = 55.8)



STATES AND PHASES OF MATTER

Student Learning Outcomes

After studying this chapter, students will be able to:

- Describe the physical properties of gases (including compressibility, expandability, and pressure exerted by gases). (Understanding)
- Origin of pressure in terms of collisions between molecules and the walls of container, Understand that ideal gas have zero partial volume, State and use the ideal gas equation $PV = nRT$ in Calculations including determination of Mr. (Understanding)
- Describe simple properties of liquids e.g., diffusion, compression, expansion, motion of molecules, spaces between them, intermolecular forces and kinetic energy based on kinetic molecular theory. (Understanding)
- Describe types of intermolecular forces. (Understanding)
- Explain the strength and applications of dipole-dipole forces, hydrogen bonding and London forces. (Understanding)
- Describe physical properties of liquids such as evaporation, vapour pressure, boiling point, viscosity and surface tension. (Understanding)
- Apply the concept of hydrogen bonding to explain the properties of water (specifically high surface tension, high specific heat, low vapour pressure, high heat of vapourization, and high boiling point). (Application)
- Define molar heat of fusion and molar heat of vapourization. (Knowledge)
- Describe how heat of fusion and heat of vapourization affect the particles that make up matter. (Understanding)
- Outline the importance of heat of fusion in the study of glaciers and ice sheets (particularly while studying polar ice caps). (Understanding)
- Describe liquid crystals and give their uses in daily life. (Understanding)
- Differentiate liquid crystals from pure liquids and crystalline solids. (Understanding)
- Describe simple properties of solids e.g., compression, expansion, motion of molecules inter-particle space, intermolecular forces and kinetic energy based on kinetic molecular theory. (Understanding)
- Differentiate between amorphous and crystalline solids. (Knowledge)
- Describe properties of crystalline solids like geometrical shape, melting point, habit of a crystal, cleavage, and crystal growth. (Understanding)

➤ **Matter exists in four states:**

- (i) solid (ii) liquid (iii) gas (iv) plasma

- Gaseous State is the simplest form of matter.
- Most of matter around us is in the solid state. Liquids are less common than solids, gases and plasmas. The reason is that the liquid state of any substance can exist only within a relatively narrow range of temperature and pressure.

Let us study at the general properties of gases, liquids, and solids. Kinetic molecular theory of gases can help us to understand their properties.

PROPERTIES OF GASES

- Gases do not have a definite shape and volume. The volume of an ideal gas is the volume of the container.
- Ideal gases have zero particle volume.
- The molecules of gases are widely separated from one another and most of the volume of the gas is empty space (nearly 99.9%). That is why gases can be compressed easily. When sudden expansion of gases occurs cooling takes place. It is called Joule Thomson effect.
- Pressure of a gas is due to the collisions of gas molecules with the walls of the container.
- There are no intermolecular forces in ideal gases.



Rack Your Mind!

- Gases can be compressed more easily than solids or liquids because:
 - Gases have stronger intermolecular forces
 - Gas molecules are close together
 - Most of the volume of a gas is empty space
 - Gas molecules have fixed positions

IDEAL GAS EQUATION

It is a matter of common observation that when external conditions of temperature and pressure are changed, the volume of a given quantity of a gas is affected. The gas laws describe the relationships between volume of a given amount of gas and the prevailing conditions of temperature and pressure.

While describing Boyle's and Charles' laws, some of the variables are held constant during the changes produced in the gases.

According to Boyle's law

$$V \propto \frac{1}{P} \text{ (when 'n' and 'T' are held constant) } \quad (1)$$

According to Charles' law

$$V \propto T \text{ (when 'n' and 'P' are held constant) } \quad (2)$$

According to Avogadro's law volume of the given gas at constant temperature and pressure is directly proportional to the number of moles.

$$V \propto n \text{ (when P and T are held constant) } \quad (3)$$

If we think for a moment that none of the variables are to be kept constant, then all the above three relationships can be joined together as:

$$V \propto \frac{nT}{P}$$

$$V = \text{constant} \cdot \frac{nT}{P}$$

The constant suggested is 'R' which is called Ideal gas constant. Its value is $0.0821 \text{ atm dm}^3 \text{ K}^{-1} \text{ mol}^{-1}$. Hence,

$$V = R \frac{nT}{P}$$

$$PV = nRT \quad (4)$$

The equation (4) is called the ideal gas equation.



Rack Your Mind!

- Which equation represents the ideal gas law?
 - $V \propto 1/P$
 - $V \propto T$
 - $V \propto n$
 - $PV = nRT$

○ Calculation of Relative Molecular Mass (M_r) of a Gas

Equation (4) can be employed to calculate the relative molecular mass of a gas whose P, T, V and mass in grams are known. This is achieved by rearranging equation (4).

Putting $n = m/M$ in equation (4)

Where m = mass in g and M = molar mass of the gas:

$$PV = \frac{mRT}{M} \quad (5)$$

Now rearranging equation (5)

$$M = \frac{mRT}{PV} \quad (6)$$

At molecular level, the molar mass becomes relative molecular mass of a compound, therefore, we can write

$$M_r = \frac{mRT}{PV} \quad (7)$$

Sample Problem 5.1

The volume of 134 g of a gas at -73°C under 10 atm pressure is 5 dm^3 . Determine the relative molecular mass of the gas.

Solution: $P = 10 \text{ atm}$, $V = 5 \text{ dm}^3$, $T = -73^\circ\text{C} + 273 \text{ K} = 200 \text{ K}$

$m = 134 \text{ g}$, $R = 0.0821 \text{ dm}^3 \text{ atm mol}^{-1} \text{ K}^{-1}$

Molecular mass of gas = $M = ?$

The molecular mass of the gas can be calculated by using the formula:

$$M = \frac{mRT}{PV}$$

$$M = \frac{(134 \text{ g})(0.0821 \text{ atm dm}^3 \text{ mol}^{-1} \text{ K}^{-1})(200 \text{ K})}{(10 \text{ atm})(5 \text{ dm}^3)}$$

$$M = 44 \text{ g mol}^{-1}$$

QUICK CHECK 5.1

- Explain why gases can be compressed easily?

Ans. Gases can easily be compressed because the molecules in a gas are very widely separated. Moreover, there are weak intermolecular forces present in it. This large space between molecules allows them to be pushed together when pressure is applied and thus reduces the volume of gas significantly.
- What is Joule-Thomson effect?

Ans. Joule-Thomson Effect: When sudden expansion of gases occurs cooling takes place, it is called Joule Thomson effect.
- The volume of 84g a gas is 8 dm^3 at -90°C under 7 atm pressure. Calculate the relative molecular mass of the gas.

Ans. $T = -90^\circ\text{C} + 273 \text{ K} = 183 \text{ K}$

$$M = \frac{mRT}{PV} = \frac{(84 \text{ g})(0.0821 \text{ atm dm}^3 \text{ mol}^{-1} \text{ K}^{-1})(183 \text{ K})}{(7 \text{ atm})(8 \text{ dm}^3)} = \frac{1262.04}{56} = 22.53 \text{ g/mol}$$

PROPERTIES OF LIQUIDS

- Liquids also diffuse like gases, however the rate of diffusion in liquids is much lower than that in gases.
- There are little spaces among liquid molecules because of relatively stronger intermolecular forces.
- Liquids are 10^2 times less compressible than gases, but about 10 times more compressible than solids.

- iv. The molecules of a liquid are in constant random motion, but their speed of movement is lower than gases. Diffusion among the miscible liquids is an evidence for the free motion of liquid molecules. Similarly, liquids can flow because of the free movement of their molecules.

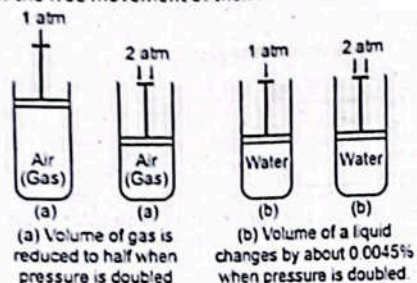


Figure: Effect of pressure on the volumes of gases and liquids.

- v. Liquids expand when their temperature is increased. However, this expansion is negligible compared to that in gases.
- vi. According to kinetic molecular theory, molecules of a liquid are in constant motion, therefore they possess a certain amount of kinetic energy at any temperature. The kinetic energies of the molecules may increase or decrease by the rise or fall in temperature respectively. For example, a liquid is converted into a solid by decreasing its kinetic energy (on cooling) and converted into vapour by increasing kinetic energy (on heating).

INTERMOLECULAR FORCES

(Exercise LO3)

- Q. What are London dispersion forces? Give examples, and discuss the factors affecting these forces. The intermolecular forces among the molecules of a liquid are reasonably stronger. Three types of such forces are mentioned here.

- Instantaneous dipole-induced dipole forces (id-id) (London dispersion forces)
- Permanent dipole-permanent dipole forces
- Hydrogen bonding

Instantaneous Dipole-Induced Dipole forces (id-id)

The momentary force of attraction between an instantaneous dipole and an induced dipole is called instantaneous dipole-induced dipole force.

These are only forces that exist among the molecules of non-polar compounds. The strength of these forces depend upon the following factors

i. Molecular Mass and Size:

When the molecular mass (M_r) of a compound is greater, the id-id forces are stronger and vice versa. This is because in a larger atom or molecule the dispersion of electronic cloud and polarization is relatively easier.

Examples:

This factor operates in the halogen and noble gas families.

Physical States of Halogens:

The physical state changes in the halogen family from top to bottom due to the increase in size and polarizability. The first two members in the halogen family (F_2 and Cl_2) are gases, but bromine is a liquid and iodine a solid (b.p. = 458K). The boiling points of noble gases in group 18 also increase from helium (He) to xenon (Xe) as in Table.

Table: Molar masses and boiling points of group 17 and 18 of periodic table.

17 (VII-A)	Molecular Mass	Boiling points (K)	18 VIII	Molecular mass	Boiling points (K)
F_2	38	85	He	4.003	4.22
Cl_2	71	239	Ne	20.18	27.1

Rack Your Mind!

3. Why does iodine have a higher boiling point than fluorine?

Br_2	159	333	Ar	39.95	87.3
I_2	253.8	458	Kr	83.8	120
			Xe	131.3	165

ii. Surface Area (shape of molecule)

A molecule with larger surface area has more number of contacts for a nearby molecule. Thus the forces among the molecules of a compound having larger surface area are stronger.

Saturated Hydrocarbons: Consider saturated hydrocarbons. These have chains of carbon atoms linked with hydrogen atoms.

Comparison of Ethane and Hexane:

Compare the length of the chains in C_2H_6 and C_6H_{14} . They have the boiling points $-88.6^\circ C$ and $68.7^\circ C$, respectively. It is evident that the molecules with larger chain length experiences stronger attractive forces. The reason is that longer molecules have more places along the length where they can be attracted to other molecules. Boiling points of some hydrocarbons are given in Table.

Table: Boiling points and physical states of some hydrocarbons

Name	B.Pt. $^\circ C$ (1 atm)	Physical state at S.T.P.	Name	B.Pt. $^\circ C$ (1 atm)	Physical state at S.T.P.
Methane (CH_4)	-164	Gas	Pentane (C_5H_{12})	36.1	Liquid
Ethane (C_2H_6)	-88.6	Gas	Hexane (C_6H_{14})	68.7	Liquid
Propane (C_3H_8)	-42.1	Gas	Decane ($C_{10}H_{22}$)	174.1	Liquid
Butane (C_4H_{10})	-0.5	Gas	Isodecane ($C_{20}H_{42}$)	327	Solid

Three isomers of pentane have the same relative molecular mass (M_r), however, they differ in their surface areas. Straight chain pentane has largest surface area and so is its boiling point among the three isomers of pentane. 2-Methylbutane (Isopentane) has smaller surface area than n-pentane but larger than 2, 2-Dimethylpropane (Neopentane). Therefore, the forces among 2-Methylbutane molecules are intermediate and the least strong forces occur in 2,2-Dimethylpropane. The isomers of pentane along with their boiling points are given in Figure.

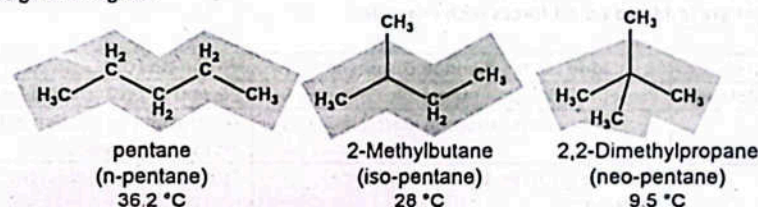


Figure: The three isomers of pentane have different structures, surface areas and intermolecular forces

Permanent Dipole-Permanent Dipole Forces (pd-pd)

The force of attraction between the positive end of a polar molecule and the negative end of a nearby polar molecule is called permanent dipole forces in HCl and chloroform dipole-permanent dipole force.

Example 1:

HCl Molecules: Whenever the HCl molecules are close to each other (as in liquid state), they tend to line up (as in Figure).

Example 2:

Chloroform Molecules: pd-pd forces are present among the molecules of chloroform ($CHCl_3$).

Rack Your Mind!

4. Permanent Dipole-Permanent Dipole Forces (pd-pd) are present among:
- Molecules of Iodine
 - Atoms of Neon in gaseous state
 - Chloroform molecules
 - CCl_4

The molecule of chloroform has a positive center at the H atom and the negative center on the end with Cl atoms.

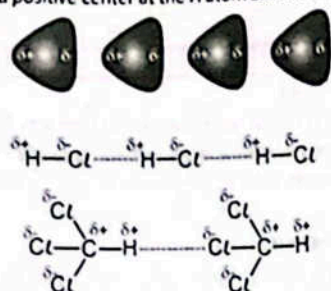


Figure: Permanent dipole-permanent dipole forces in HCl and chloroform

QUICK CHECK 5.2

a) To improve the quality of gasoline (petrol), straight chain hydrocarbons in the gasoline fraction of petroleum are converted to branched chain ones? What could be the possible reason?

Ans. The conversion of straight-chain hydrocarbons to branched-chain hydrocarbons in gasoline is done to improve its quality, particularly to improve its octane number.

Straight-chain alkanes (like n-heptane) have low octane numbers and tend to knock.

Branched alkanes (like iso-octane) have high octane numbers, meaning they burn more efficiently (smoothly) and are less prone to knocking in internal combustion engines than straight-chain hydrocarbons.

b) Which forces are present among the molecules of the following substances? CCl_4 , SiF_4

Ans. CCl_4 (Carbon Tetrachloride):

- Polarity: Non-polar (symmetrical shape cancels dipoles)
- Forces present: London dispersion forces (only)

SiF_4 (Silicon Tetrafluoride):

- Polarity: Non-polar (symmetric, dipoles cancel)

Although the Si-F bonds are polar, the molecule as a whole is non-polar despite having polar bonds because the dipole moments cancel out due to its symmetry.

- Forces present: London dispersion forces (only)

c) Differentiate id-id and pd-pd forces with examples.

Ans.

Feature	id-id Forces (London Dispersion)	pd-pd Forces (Dipole-Dipole)
Molecular Polarity	Present in non-polar molecules	Present in polar molecules
Cause	Temporary fluctuations in electron clouds	Electrostatic attraction between permanent dipoles
Strength	Weak (but can be significant in large molecules)	Stronger than id-id forces
Universality	Found in all molecules, even polar ones	Found only in polar molecules
Effect of Molecular Size	Increases with molecular size and surface area	Mostly influenced by dipole strength
Examples	CCl_4 , CH_4 , I_2	HCl , CH_2Cl_2 , SO_2

(Exercise 10)

Q. Hydrogen bonding is present in H_2O , NH_3 , HF , $(\text{CH}_3)_2\text{CO}$ and CHCl_3 molecules. Sketch structures and discuss briefly.

Hydrogen Bonding

- Hydrogen bond is a special type of dipole-dipole force.
- It is the strongest force among intermolecular forces, but is weaker than all the major types of bond, i.e. ionic, metallic, and covalent bonds.

- **Formation of Hydrogen Bond:** A hydrogen bond is formed when the following conditions are fulfilled:
 - The hydrogen atom is connected to a highly electronegative atom, such as F, O, or N.
 - The electronegative atom must have a lone pair of electrons on it.
 The covalent bond between a highly electronegative atom and hydrogen is highly polarized. It means the hydrogen atom carries a sufficient δ^+ charge and the electronegative atom δ^- charge. The presence of lone pair on the electronegative allows the partial positively charged hydrogen atom to make a bond with F, O, or N called a hydrogen bond. This bond is represented by a dotted line (...) and its strength is one tenth of an ordinary covalent bond. The number of hydrogen bonds a molecule can form on average depends on:
- The number hydrogen atoms bonded to the electronegative atom.
- The number of lone pairs present on F, O, or N.

SQ Why HF is a weaker acid than HCl, HBr and HI?

Examples:

(i) Water

- A water molecule contains two hydrogen atoms and two lone pairs on oxygen atom.
- Water can form two hydrogen bonds per molecule on average.
- This is why water molecules are extensively hydrogen bonded with one another.
- This unique feature of water is responsible for its characteristic properties, e.g., high boiling point of water (100°C). The water molecules in liquid form are arranged three dimensionally (as shown in Fig.).
- This bonding acts as a bridge between two electronegative oxygen atoms.

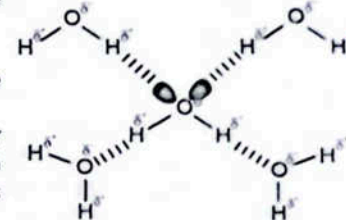


Figure: Hydrogen bonding in water

(ii) Ammonia

- Ammonia can form only one hydrogen bond per molecule although it has three hydrogen atoms.
- Reason: This is due to the availability of only one lone pair on the N atom as shown in Figure. The hydrogen bonding in liquid ammonia is much weaker than water. This is why its boiling point is much lower (-33°C).

(iii) HF

- HF is even more distinct than water and ammonia.
- It has three lone pairs on the F atom which allows it to form three H-bonds.
- However, it has only one H atom and due to this reason, it is restricted to form only one bond again.
- In HF, hydrogen bond is strong enough compared to NH_3 , which owes to its high electronegativity.
- Thus, its B.Pt. (19.9°C) is much higher than ammonia (-33.5°C).
- The molecules of HF join with one other in a zig-zag manner in liquid state due to the presence of the hydrogen bonds.

Lowest Acidic strength of HF among hydrogen halides:

The exceptional low acidic strength of HF molecule as compared to HCl, HBr and HI is attributed to this strong hydrogen bonding, because the partial positively charged hydrogen is entrapped between two highly electronegative atoms (Figure).

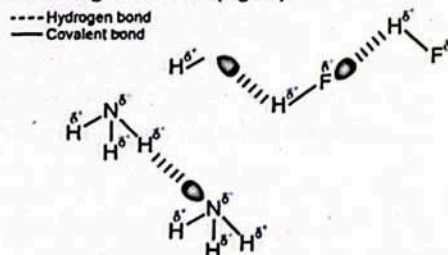
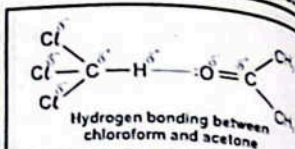


Figure: Hydrogen bonding in NH_3 and HF

LQ What is hydrogen bonding? Discuss the structure and low density of ice.

(iv) Acetone and Chloroform:

- Chloroform has three chlorine atoms are responsible for H-bonding with other molecules.
- These atoms deprive the carbon atom of its electrons and the partial positively charged hydrogen can form a strong hydrogen bond with oxygen atom of acetone (propanone).



(Exercise 1.1)

Q. Discuss the structural changes when water turns into ice. Justify the empty spaces in its crystals compared to H_2O at 4°C and lower density of ice.

○ Influence of Hydrogen Bonding on the Properties of Water

i. Structure and Low Density of Ice

- The molecules of water have tetrahedral structure.
- Two lone pairs of electrons on oxygen atom occupy two corners of the tetrahedron.
- When the temperature of water is decreased and ice is formed, the molecules become more regular and this regularity extends throughout the whole structure.
- Empty spaces are created in the extensively hydrogen bonded structure as shown in the following diagram (Figure). This is why, when water freezes, it (ice) occupies 9% more space and its density decreases. For this reason, ice floats on water. Due to this so called anomalous behaviour of ice, the fish and other living creatures survive under the frozen lakes and oceans. The ice blanket covers the water surface due to its low density and the water beneath is insulated from the environment.

Rack Your Mind!
5. Discuss anomalous behaviour of water saves aquatic life.

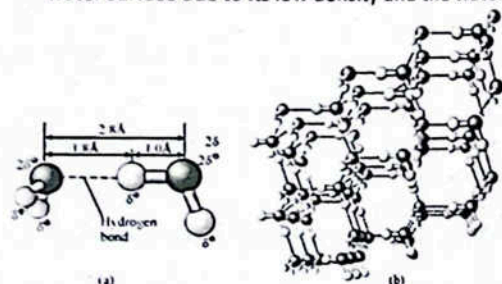


Figure: Extensive hydrogen bonding in ice and spaces among molecules



This part of a glacier is floating on the surface due to low density of ice

ii. High Heat Capacity

Water has a high specific heat capacity. This is due to its unique molecular structure which allows strong hydrogen bonds.

iii. Anomalous Heat of Vaporization and Boiling Point

The general trend of enthalpy change of vaporization of group 16 hydrides is a regular increase from H_2S to H_2Po (Figure). This is because the molecules of these compounds are bound by weak London dispersion forces.

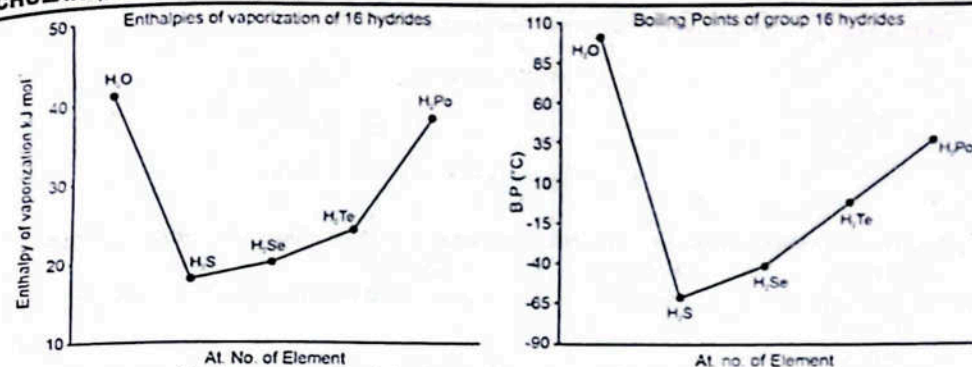


Figure: A graphical expression of variation in enthalpy of vaporization and B.P.s of group 16 hydrides. With the increasing atomic size down the group, from S to Po, the van der Waals forces also become stronger. If water had followed this trend, the heat of vaporization of water would be the lowest among the group members.

S/Q. Water has highest boiling point and highest enthalpy change of vaporization. Explain

Ans. Water has the highest enthalpy change of vaporization (41 kJ mol^{-1}) in the group. This is because water is exceptionally hydrogen bonded, which makes it difficult to break forces among water molecules and vaporize it. The boiling point of water is also remarkably higher than the rest of group 16 hydrides. Simply, the energy required to break the water molecules apart is very high due to extensive hydrogen bonding in it. It needs high temperatures to provide so much energy as to boil water into its vapour.

iv. Surface Tension and Viscosity

The surface tension and viscosity of water are also very high. Surface tension is a downward pull of water molecules at the surface, making the water surface stretched and strained. This downward pull is due to the attraction of inner molecules through hydrogen bonds.

- Viscosity is the resistance by a liquid to its flow. Water has higher viscosity than many of liquids including lower hydrocarbons and alcohols (e.g., hexane and ethanol). The high viscosity of water is also due to strong hydrogen bonds among the molecules. Alcohols can make hydrogen bonds, but the strength and extent of hydrogen bonding is far less than that in water. Hydrocarbons lack the ability to make the hydrogen bond.

- Order of Viscosity in Water, Hydrocarbons and Alcohols:

Water > Alcohols > Lower Hydrocarbons

QUICK CHECK 5.3

a) Can the CHF_3 molecule make a hydrogen bond? Explain why or why not?

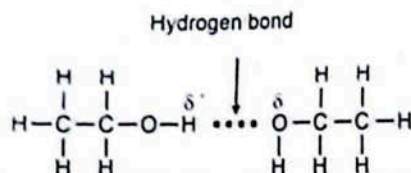
Ans. No, CHF_3 (trifluoromethane) cannot form hydrogen bonds with itself.

Explanation:

- Hydrogen bonding typically occurs when a hydrogen atom is covalently bonded to a highly electronegative atom (like F, O, or N) and this hydrogen has a partial positive charge that can interact with a lone pair on another electronegative atom.
- In CHF_3 :
 - The hydrogen is bonded to carbon, not to fluorine.
 - While fluorine is very electronegative, the H atom is not directly bonded to it, so the necessary strong dipole (H-F) does not exist.
- Therefore, CHF_3 does not meet the criteria for hydrogen bonding, although it does have dipole-dipole interactions and London dispersion forces.
- In short, CHF_3 cannot hydrogen bond because the hydrogen is not bonded directly to fluorine, oxygen, or nitrogen.

b) Show a hydrogen bond between two molecules of ethanol ($\text{CH}_3\text{CH}_2\text{OH}$).

Ans.

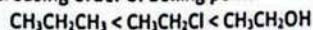


c) Describe which forces are present in the following and arrange them in increasing order of boiling point.

- i. $\text{CH}_3\text{CH}_2\text{CH}_3$ ii. $\text{CH}_3\text{CH}_2\text{OH}$ iii. $\text{CH}_3\text{CH}_2\text{Cl}$

Ans. The intermolecular forces present in each compound and then arrange them in increasing order of boiling point:

- i. $\text{CH}_3\text{CH}_2\text{CH}_3$ (Propane)
- Forces present: Only London dispersion forces (induced dipole-induced dipole)
 - Polarity: Nonpolar
 - Boiling point: Lowest among the three due to weak intermolecular forces.
- ii. $\text{CH}_3\text{CH}_2\text{OH}$ (Ethanol)
- Forces present:
 - Hydrogen bonding (due to $-\text{OH}$ group)
 - Dipole-dipole forces
 - London dispersion forces
 - Polarity: Polar
 - Boiling point: Highest due to strong hydrogen bonding.
- iii. $\text{CH}_3\text{CH}_2\text{Cl}$ (Chloroethane)
- Forces present:
 - Dipole-dipole forces (due to $\text{C}-\text{Cl}$ bond)
 - London dispersion forces
 - Polarity: Polar
 - Boiling point: Intermediate
 - Arrangement on the basis of increasing order of boiling point.



d) The boiling point difference in each of the following pairs is given

- i. CH_3CH_3 (-89°C) and CH_3OH (65°C), difference = 154°C
 ii. $\text{CH}_3\text{CH}_2\text{CH}_2\text{CH}_3$ (0°C) and $\text{CH}_3\text{CH}_2\text{CH}_2\text{OH}$ (97°C), difference = 97°C

Explain why the difference decreases as the size of the molecules increases.

Ans.

(i) The large boiling point difference (154°C) between ethane (CH_3-CH_3 , -89°C) and methanol (CH_3-OH , 65°C) is primarily due to hydrogen bonding in methanol, while ethane only has weak London dispersion forces.

A. Intermolecular Forces in Ethane (CH_3-CH_3):

- Only London dispersion forces (van der Waals) are present.
- Weak, temporary dipoles due to electron motion.
- Low molecular weight (30 g/mol) and very weak attractions result in lower boiling point = -89°C .

B. Intermolecular Forces in Methanol (CH_3OH):

- Hydrogen bonding (strong dipole-dipole interaction) is present in methanol molecules.
- Hydrogen bonding drastically increases the energy needed to separate molecules.

(ii) Let us compare the boiling points of two substances, butane ($\text{CH}_3\text{CH}_2\text{CH}_2\text{CH}_3$) and 1-Propanol ($\text{CH}_3\text{CH}_2\text{CH}_2\text{OH}$).

- n-Butane ($\text{CH}_3\text{CH}_2\text{CH}_2\text{CH}_3$) has a boiling point of 0°C .
- 1-Propanol ($\text{CH}_3\text{CH}_2\text{CH}_2\text{OH}$) has a boiling point of 97°C .

The difference in their boiling points is:

$$97^\circ\text{C} - 0^\circ\text{C} = 97^\circ\text{C}$$

This difference is due to the different types of intermolecular forces. 1-Propanol, which has hydrogen bonding due to its $-\text{OH}$ group, has a much higher boiling point than n-butane, which only has van der Waals forces between molecules.

Explain why the difference decreases as the size of the molecules increases.

As the size of molecules increases, the boiling point differences between polar (hydrogen-bonding) and nonpolar molecules tend to decrease. Here's why:

Reasons:

- i. **Increasing London Dispersion Forces:** Larger nonpolar molecules exhibit stronger London dispersion forces, which narrows the boiling point gap with polar molecules.
- ii. **Hydrogen Bonding Remains Strong:** Polar molecules continue to exhibit strong hydrogen bonding, but the relative impact on boiling point decreases as London dispersion forces become more significant.

Effect:

Convergence of Boiling Points: As molecular size increases, boiling points of polar and nonpolar molecules converge, reducing the difference.

This trend is observed when comparing smaller molecules (like methanol and ethane) to larger ones (like longer-chain alcohols and alkanes).

e) Molecules of ethanoic acid (acetic acid) exist in the form of dimers in pure form but not in aqueous solution. How hydrogen bond can explain this?

Ans. Hydrogen Bonding in Acetic Acid:

Dimer Formation: In pure acetic acid, molecules form dimers through hydrogen bonding between the carbonyl oxygen and hydroxyl hydrogen. This stabilizes the dimer structure.

In Aqueous Solution:

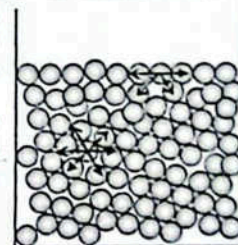
- i. **Competition with Water:** Water molecules form hydrogen bonds with acetic acid molecules, disrupting the dimer structure.
- ii. **Solvent Effect:** The polar aqueous environment favours solvation of individual acetic acid molecules over dimer formation.

Conclusion:

Hydrogen bonding with water molecules in aqueous solution competes with and disrupts the intermolecular hydrogen bonds between acetic acid molecules, preventing dimer formation.

SURFACE TENSION OF LIQUIDS

- Surface tension is a property of liquids that describes the force acting along the surface of a liquid, causing it to behave like an elastic sheet. This force arises due to the intermolecular forces between the molecules at the surface.
- Molecules at the surface experience a net force inward due to intermolecular forces, leading to a "skin" on the surface. Liquids tend to minimize their surface area due to surface tension, which explains why droplets form spheres.
- Surface tension influences various phenomena, such as:
 - capillary action
 - wetting of surfaces
 - formation of droplets and bubbles



Did You Know?

Q. Which of the following best explains why a small insect can walk on the surface of water?

- (A) Water has high density
- (B) Water has strong cohesive forces due to surface tension
- (C) The insect repels water molecules
- (D) Water has high viscosity

Factors Affecting Surface Tension

- i) **Temperature:** Surface tension typically decreases with increasing temperature.

$$\text{Surface tension} \propto \frac{1}{\text{Temperature}}$$

- ii) Intermolecular forces: Stronger intermolecular forces lead to higher surface tension.
Surface tension \propto Intermolecular forces



Mosquitos can float on surface on water due to high surface tension

Table: Surface tension of some liquids at 20°C in Nm^{-1}

Sr. No.	Liquid	$\gamma(10^{-3}\text{Nm}^{-1})$	Sr. No.	Liquid	$\gamma(10^{-3}\text{Nm}^{-1})$
1	Water H_2O	72.75	4	Acetone $(\text{CH}_3)_2\text{CO}$	23.70
2	Ethyl alcohol $\text{CH}_3\text{CH}_2\text{OH}$	22.75	5	Benzene C_6H_6	28.85
3	Methyl alcohol CH_3OH	22.61	6	Carbon tetrachloride CCl_4	26.95

' γ ' are values multiple of $10^{-3} = 1/1000$. It means ' γ ' value of the water (H_2O) at 20°C = $72.75 \times 10^{-3}\text{Nm}^{-1}$ or 72.75 dynes cm^{-1} .

VISCOSITY OF LIQUIDS

- Definition: "The resistance to the flow of a liquid is termed as viscosity".
- Units: In international system (SI), unit of viscosity is in $\text{kgm}^{-1}\text{s}^{-1}$.
- In CGS system, the unit of viscosity is poise (P).

Explanation

Example:

Take water in a beaker. It is stirred with a glass rod, and left undisturbed for some time. Its swirling motion subsides after a while.

It is observed that the liquid layer adjacent to the walls of the beaker comes to rest first and layer near the centre stops last. It can be inferred that stationary layer of walls of beaker slows down the motion of layer touching it immediately. This slowed layer in touch with container also slows the next inner layer, but to less extent. This means that a slow moving layer of a liquid tends to slow down the fast moving layer adjacent to it. This is a frictional force operating between adjacent layers.

Factors Affecting Viscosity

The factors affecting viscosity are as follows:

- Temperature:** An increase of temperature increases the average kinetic energy of molecules. This allows the molecules to overcome the attractive forces. This lowers the viscosity.
- Intermolecular Forces:** The stronger the intermolecular forces, the greater the viscosity of liquids because liquid molecules cannot move around each other freely, so the resistance to flow increases.

QUICK CHECK 5.4

- a) Arrange the following liquids in increasing order of surface tension, give reason: Acetone (CH_3COCH_3), ethanol ($\text{C}_2\text{H}_5\text{OH}$), methoxy methane (dimethyl ether, CH_3OCH_3)

Ans.

1. Ethanol ($\text{C}_2\text{H}_5\text{OH}$):

- **Hydrogen bonding:** Ethanol has a hydroxyl ($-\text{OH}$) group, which can form hydrogen bonds with other ethanol molecules. This results in a relatively high surface tension because hydrogen bonds are strong forces that resist the disruption of the surface.
- **Surface tension:** High compared to acetone and methoxy methane.

Rack Your Mind!

6. Which property allows insects to walk on water?
- A) Viscosity B) Surface tension
C) Capillarity D) Adhesion

2. Methoxy methane (dimethyl ether, CH_3OCH_3):

- **Dipole-dipole Interactions:** Methoxy methane has an ether group ($-\text{O}-$), which has some polarity, but it cannot form hydrogen bonds like ethanol. This results in weaker intermolecular forces compared to ethanol.
- **Surface tension:** Lower than ethanol, but higher than acetone, due to dipole-dipole interactions.

3. Acetone (CH_3COCH_3):

- **Dipole-dipole Interactions:** Acetone has a carbonyl group ($\text{C}=\text{O}$), which is polar, but it does not have hydrogen bonding capability because it lacks $-\text{OH}$ or $-\text{NH}$ groups. Therefore, it only experiences dipole-dipole interactions and weaker van der Waals forces compared to ethanol and methoxy methane.
- **Surface tension:** Lowest of the three due to weaker intermolecular forces.
- **Increasing order of surface tension:**

Acetone < Methoxy methane < Ethanol

- b) Why do you think tetrachloromethane (carbon tetrachloride, CCl_4) has higher viscosity than chloroform (CHCl_3) but less than ethanol ($\text{C}_2\text{H}_5\text{OH}$)?

Ans. CCl_4 has higher viscosity than CHCl_3 because it is a larger, more symmetrical molecule with stronger London dispersion forces, increasing resistance to flow.

However, ethanol ($\text{C}_2\text{H}_5\text{OH}$) has even stronger hydrogen bonding, which greatly increases intermolecular attraction, making its viscosity higher than CCl_4 .

Viscosity trend: $\text{CHCl}_3 < \text{CCl}_4 < \text{C}_2\text{H}_5\text{OH}$

Increasing strength of intermolecular forces i.e. London dispersion forces < dipole-dipole forces < hydrogen bonding.

- c) The viscosity of honey is higher than water, explain why.

Ans. Honey has higher viscosity than water because it contains large amounts of sugars (like macromolecules of glucose and fructose), which form extensive hydrogen bonds with water and each other. This creates a dense, structured network that resists flow, unlike water's smaller, more mobile molecules of water. Higher viscosity slows down molecular motion as compared to water.

- d) Which of the following is more viscous: glycerine ($\text{CH}_2\text{OHCH}_2\text{OHCH}_2\text{OH}$) or hexane (C_6H_{14})? Why?

Ans. Glycerine ($\text{CH}_2\text{OHCH}_2\text{OHCH}_2\text{OH}$) is more viscous than hexane (C_6H_{14}) because:

- Glycerine has three $-\text{OH}$ (hydroxyl) groups, enabling extensive hydrogen bonding, which strongly resists flow.
- Hexane is a nonpolar hydrocarbon with only weak van der Waals forces, offering minimal resistance to flow.

EVAPORATION

Definition:

"Evaporation is the spontaneous conversion of a liquid into vapour at any temperature".

- When high energy molecules leave the liquid and low energy molecules are left behind, the temperature of the liquid falls.
- The heat moves from the surrounding to the liquid and then the temperature of the surrounding also falls. This phenomenon helps to understand that evaporation causes cooling.

A person after bath feels a sense of cooling due to evaporation of water from his body when exposed to air. The molecules of H_2O take away the energy of body. Earthenware vessels keep water cooler under the same phenomenon. Earthenware vessels are porous.

Rack Your Mind!

7. Water in earthenware pots stay cool due to:
- A) boiling B) condensation
C) evaporation D) insulation

The water molecules having sufficient K.E to overcome inter molecular forces come out of these pores and evaporate. This process of evaporation keeps on taking place and energy required for this process comes from the liquid. Thus, the average K.E of remaining water molecules decreases which results in decrease in temperature of the liquid. Hence, earthenware vessels keep water cool.

Rack Your Mind!
8. Earthenware vessels keep water cool. Explain with reason.

Q. Evaporation causes cooling. Explain.

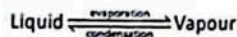
Ans. The molecules of a liquid are not motionless. The energy of molecules is not equally distributed. Evaporation causes cooling, because when high energy molecules leave the liquid and low energy molecules are left behind, the temperature of liquid falls and heat moves from the surrounding to the liquid and then the temperature of the surrounding also falls. That is why, evaporation causes a cooling effect.

VAPOUR PRESSURE

The molecules of a liquid which leave the open surface are mixed up with air above the liquid. If the vessel is open these molecules go on leaving the surface of liquid. But if we close the system the molecules of liquid start gathering above the surface. These molecules collide with the walls of the container, and also with the surface of the liquid as well. There are chances that these molecules are recaptured by the surface of liquid. This process is called condensation. The two processes, i.e., evaporation and condensation continue till a stage reaches when the rate of evaporation becomes equal to the rate of condensation Fig.

Definition:

"The pressure exerted by the liquid vapour in equilibrium with its liquid at a given temperature is called vapour pressure".



The magnitude of vapour pressure does not depend upon the amount of liquid in the container or the volume of container.

Surface Area of a liquid:

- Reason: The larger surface area presents a larger target for returning the molecules, so the rate of condensation also increases.

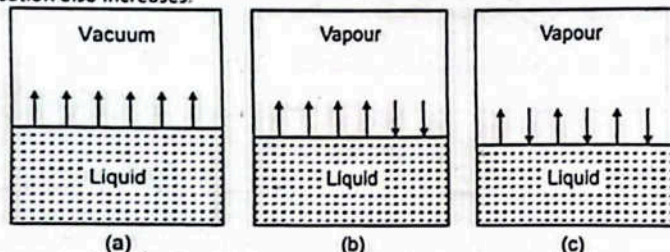


Figure: Attainment of equilibrium when the evaporation of liquid is carried out in an evacuated closed vessel. (a) Initial state, with evacuated space above the liquid, (b) intermediate state, and (c) equilibrium state, when the rate of evaporation is equal to the rate of condensation.

QUICK CHECK 5.5

- a) Which of the liquids in each of the following pairs has a higher vapour pressure?
i) Alcohol, glycerine ii) Petrol, kerosene, iii) Mercury, water?

Ans.

(i) Alcohol, Glycerine: Alcohol has a higher vapour pressure than glycerine. Glycerine, with three -OH groups, forms strong hydrogen bonds, making it less volatile and giving it a lower vapour pressure.

(ii) **Petrol, Kerosene:** Petrol has a higher vapour pressure than kerosene. Petrol consists of smaller, more volatile hydrocarbons with weaker intermolecular forces, allowing more molecules to escape into the vapour phase. Kerosene has larger, heavier molecules with stronger intermolecular forces, resulting in lower vapour pressure.

(iii) **Mercury, Water:** Water has a higher vapour pressure than mercury. Water has weaker intermolecular forces (hydrogen bonding) compared to mercury, which has strong metallic bonding. As a result, water molecules escape into the vapour phase more easily, leading to a higher vapour pressure.

b) Which one in each of the following pairs is more viscous: Glycerine or kerosene?

Ans. Glycerine is more viscous than kerosene.

Glycerine has 3-OH groups, allowing strong hydrogen bonding between molecules, which greatly increases resistance to flow. Kerosene, a mixture of hydrocarbons, has weak van der Waals forces and lacks hydrogen bonding, so it flows more easily.

In short, Viscosity of glycerine is greater than Kerosene due to stronger intermolecular (hydrogen) bonding present in glycerine.

c) Separate portions of acetone and water at the same temperature are poured on your hands. The acetone feels colder. Account for this in terms of attractive forces.

Ans. Acetone feels colder than water because it evaporates more quickly, absorbing more heat from your skin.

Reason: Acetone has weaker intermolecular forces (dipole-dipole) compared to water's strong hydrogen bonds. Weaker forces mean acetone molecules escape into the air more easily, causing faster evaporation and greater cooling (evaporative cooling).

d) Why evaporation gets faster at higher temperatures?

Ans. Evaporation gets faster at higher temperatures because more molecules gain enough kinetic energy to overcome intermolecular forces and escape into the vapour phase.

In short, Higher the temperature, higher kinetic energy, faster evaporation.

e) Why do we feel cool near the bank of a river?

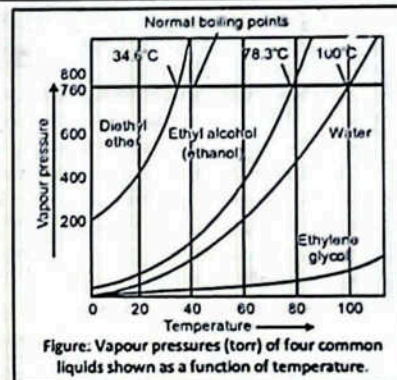
Ans. We feel cool near the bank of a river because the water evaporates, and evaporation is a cooling process. Also, water has a high specific heat capacity, so it absorbs heat from the surroundings, keeping the area cooler.

BOILING POINT

- When a liquid is heated, its vapour pressure goes on increasing. A stage reaches when the vapour pressure of the liquid becomes equal to the atmospheric or external pressure.

- At this temperature the liquid starts boiling. The reason for this is that the bubbles of vapour which are formed in the interior of the liquid have greater internal pressure than atmospheric pressure on the surface of liquid. This makes the bubbles to come out of the liquid and burst at the surface. A constant stream of bubbles comes out at the boiling point of the liquid.

- Temperature and B.Pt: When a liquid is heated, the kinetic energy of its molecules increases. This causes the increase of the temperature. At the boiling point, the kinetic energy of the molecules becomes maximum. Any further heating at this stage will not increase the temperature. This further heating is utilized to break the intermolecular forces and convert the liquid into its vapour. The boiling points of some commonly available liquids at 1 atmospheric pressure are shown in the Table.



- Graphical Evidence: The Figure shows the variation of vapour pressure of water, ethyl alcohol, ethylene glycol and diethyl ether with temperature. The graphs show that the liquids reach upto their boiling points when their vapour pressures are equal to 760 torr at sea level.

Factors Affecting Boiling Points of Liquids

The boiling point of a liquid is affected by the factors given below.

1) Strength of Intermolecular Forces \propto B.Pt

Stronger the intermolecular forces, lower will be the vapour pressure and higher will be the boiling point. Higher boiling point of H_2O indicates stronger intermolecular forces than that of ethanol and methanol, Table.

Table: Boiling points of some common liquids at 760 torr (1 atm)

Liquids	Formula	B.P. °C	Liquids	Formula	B.P. °C
Acetic acid	CH_3COOH	118.50	Carbon tetrachloride	CCl_4	76.50
Acetone	CH_3COCH_3	56.00	Ethanol	C_2H_5OH	78.30
Benzene	C_6H_6	80.15	Naphthalene	$C_{10}H_8$	218.00
Carbon disulphide	CS_2	46.30	Water	H_2O	100.00

2) External Pressure \propto B.Pt

When vapour pressure of a liquid becomes equal to the external pressure then the liquid boils. It means that when external pressure is changed, its boiling point will also change. When the external pressure is high the liquid requires greater amount of heat to equalize its vapour pressure to external pressure. In this way boiling point is raised. Similarly, at a lower external pressure a liquid absorbs less amount of heat and it boils at a lower temperature.

e.g., Application of B.Pt. Vacuum Distillation etc.

Pressure Cooker:

- We can increase the external pressure artificially on the surface of boiling water by using a pressure cooker. Pressure cooker is a closed container.
- The vapour of water formed is not allowed to escape.
- In this way, it exerts they develop more pressure on the water surface in the cooker and the boiling temperature increases.
- As more heat is absorbed in water, so food is cooked quickly under increased pressure.

Temperature – Vapour Pressure Graph	
External pressure (torr)	Boiling point (°C)
1489 torr	120°C
760 torr (at sea level)	100°C
700 torr (at Murree Hills)	98°C
323 torr (at Mount Everest)	69°C
23.7 torr	25°C

Boiling points of water at various external pressure

QUICK CHECK 5.6

a) Why food cooking is difficult in the areas with high altitudes?

Ans. At high altitudes, atmospheric pressure is lower, so water boils at a lower temperature, producing less heat for cooking. This makes food take longer to cook.

b) The food cooks faster in the pressure cooker, explain.

Ans. Food cooks faster in a pressure cooker because it traps steam, increasing the pressure inside. This raises the boiling point of water (above 100 °C), allowing food to cook at a higher temperature. The higher heat speeds up chemical reactions, reducing cooking time.

- Normally, water boils at 100°C (212°F) at 1 atm (sea level pressure).
- In a pressure cooker, pressure rises to ~1.5–2 atm, raising the boiling point to 110–120°C (230–250°F).

Factor	Open Pot (1 atm)	Pressure Cooker (~2 atm)
Boiling Point	100°C (212°F)	120°C (248°F)
Cooking Speed	Slow	3–10 × faster
Energy Use	More (longer time)	Less (shorter time)

In short, Higher the pressure, higher boiling point, faster cooking.

c) Why the boiling point of water (100°C) is higher than that of ethanol (78°C), although both have hydrogen bonds?

Ans. The boiling point of water (100°C) is higher than that of ethanol (78°C) because water forms stronger and more extensive hydrogen bonds due to its molecular structure, whereas ethanol's hydrogen bonding is partially hindered by its nonpolar ethyl group.

Property	Water (H_2O)	Ethanol (CH_3CH_2OH)
H-bond donors	2 (two H atoms)	1 (only -OH H)
H-bond acceptors	2 (two lone pairs on O)	1 (one lone pair on O)
Effect on boiling point	Stronger, more extensive network, higher energy needed to break bonds	Weaker, limited network, easier to vaporize

In short, While both substances have hydrogen bonds, water's smaller size, higher polarity, and ability to form twice as many H-bonds per molecule make its intermolecular forces significantly stronger, leading to a higher boiling point than ethanol.

ENERGETIC OF PHASE CHANGES

Whenever, matter undergoes a physical change, it is always accompanied by an energy change. This change in energy is the quantitative measurement of the difference in the strength of intermolecular forces.

Molar Heat of Fusion (ΔH_f)

The amount of heat absorbed by one mole of a solid to melt it into the liquid at its melting point at 1 atmospheric pressure is called molar heat of fusion.

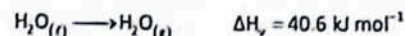
Example:



Molar Heat of Vaporization (ΔH_v)

The amount of heat absorbed by one mole of a liquid to convert it into one mole of vapour at its boiling point at 1 atmospheric pressure is called molar heat of vapourization.

The molar heats of vaportization depends upon the strength of intermolecular forces. When one mole H_2O is converted to vapour at 100°C, then heat absorbed is 40.6 kJ mol⁻¹.



NH_3 and HCl only need 21.7 and 15.6 kJ mol⁻¹ respectively to become vapour at their boiling points. This difference is due to the stronger intermolecular forces in water.

Effect of Molar Heat of Vapourization and Fusion on Matter Particles

The molar heat of fusion and vapourization affect the particles that make up matter by providing them with enough energy. Due to this, the particles move away from one another and change the state of the substances from solids to liquids and liquids to gases respectively. Particles gain more freedom to move and rotate in the liquid and gas phase.

SOLIDS

Solids are those substances which are rigid, hard, have definite shape and definite volume. The atoms, ions and molecules that make up a solid are closely packed. They are held together by strong cohesive forces. The constituent atoms, ions or molecules of solids cannot move at random.

General Properties of Solids

1) Compression of Solids

The atoms, molecules or ions of a solid substance are closely packed. The particles of solids cannot move closer to each other unlike gases. It is true for metallic solids that their atoms are spherically symmetrical. So, when such particles are arranged, they can give birth to hexagonal and cubic close-packed structures. Here outer boundaries of constituent particles touch each other but due to their spherical shapes, they cannot occupy more than 74% space. It means the compression of solids is not possible.

ii) Expansion of Solids

The expansion is the property in which spaces between constituent particles are increased. In case of solids the forces of attractions are so strong that increase of temperature hardly affects their relative positions. The particles in a solid have vibrational motions about their mean positions. Increase in temperature of solids hardly increases their volume. No doubt, there are parameters like coefficient of linear and cubic expansions of various solids, but these are negligible as compared to liquids and gases.

iii) Motion of Particles in Solids

The constituent particles of a solid do not undergo translatory motion, and neither rotational ones. They only vibrate about their mean positions. These vibrations become more intense at higher temperature.

iv) Inter-particle Space in Solids

The interparticle spaces in solids are far less than liquids. This is due to the stronger forces among their particles. Due to closely packed atoms, molecules, and ions, solids are mostly hard, have high melting points and high stability.

v) Inter-particle Forces in Solids

In solids, the particles (atoms, ions, molecules) are held together by ionic, covalent, metallic or van der Waals forces. These forces are strong enough to fix the particles at their places thus allowing these particles to just vibrate about their mean positions.

vi) Kinetic Energy Based on KMT

Kinetic energy is due to the motion of constituent particles of a solid. Solid particles have only vibratory motion and they do not have translational or rotational motion. Therefore, the only kinetic energy that solids possess is vibrational kinetic energy.

TYPES OF SOLIDS

There are two types of solids on the basis of the way their particles are arranged;

- i. Crystalline solids
- ii. amorphous solids

Crystalline Solids

Crystal Lattice

The regular arrangement of ions, atoms, or molecules in three dimensional space is called the crystal lattice. The solids which have definite regular and three dimensional geometric shapes are called crystalline solids. For example, diamond, sodium chloride, ice, etc.

[Exercise L.Q.7]

Q. Describe the following properties of crystalline solids.

- i) Geometrical shape
- ii) Melting point
- iii) Cleavage plane
- iv) Habit of a crystal

Properties of Crystalline Solids

i. Geometrical Shape

- All the crystalline solids have a definite, distinctive geometrical shape due to definite and orderly arrangement of atoms, ions or molecules in three-dimensional space.
- For a given crystal, the interfacial angles, at which the surfaces intersect, are always the same no matter in which shape they are grown.
- The faces and angles remain characteristic even when the material is ground to a fine powder.

ii. Melting Points

- Crystalline solids have sharp melting points.
- They can be identified from their definite melting points. e.g., Melting point of NaCl = 801°C

iii. Cleavage Planes

- Whenever the crystalline solids are broken they do so along definite planes.



Rack Your Mind!

9. Why the ionic crystalline solids have high melting points?



Rack Your Mind!

10. Cleavage of the crystals is itself anisotropic behaviour.

- These planes are called the cleavage planes and they are inclined to one another at a particular angle for a given crystalline solid.
- The value of this angle varies from one solid to another solid.

iv. Growing of a Crystal

- When we have a saturated or super saturated solution of a crystalline material in a suitable solvent, it can give us same types of crystals by arranging atoms, ions or molecules.
- This happens through the process called growth of crystals.
- This can be done by slow evaporation of the solvent or by Seeding process from saturated solution.

Seeding Process:

Seeding involves introducing a small "seed crystal" into a supersaturated solution or melt to initiate and guide the growth of larger, well-formed

- Example: The solubility of sodium thiosulphate $\text{Na}_2\text{S}_2\text{O}_3$ in water at 100°C is 231 g/100 cm³. At room temperature, solubility is 50 g/100 cm³. If we have saturated solution of $\text{Na}_2\text{S}_2\text{O}_3$ at 100°C, on cooling slowly no growth of crystal happens. It means that super saturated solution is not in equilibrium with solid substance. Now, if small crystal of $\text{Na}_2\text{S}_2\text{O}_3$ is added to super saturated solution, the crystallization happens rapidly.

v. Habit of a Crystal

- The shape of a crystal in which it usually grows is called habit of a crystal.
- If the conditions for growing a crystal are maintained, then the shape of the crystal always remains the same.
- If the conditions are changed the shape of the crystal may change.
- For example, a cubic crystal of NaCl becomes needle like when 10% urea is present in its solution as an impurity.

Amorphous Solids: (Prefix 'A' = without, morph: Shape ⇒ Shapeless)

Definition:

"Amorphous substances are those whose constituent atoms, ions or molecules do not possess a regular orderly arrangement".

Amorphous solids, contrary to the crystalline solids, do not possess regular three dimensional geometrical shapes.


Examples of Amorphous Solids: Glass, wood, amorphous sulphur (plastic sulphur), charcoal, coal, coke, etc.

Properties of Amorphous Solids:

- i. The amorphous solids can have small regions where orderly arrangement of particles is found, but they do not have long range of regularity. The regions where orderly arrangement of particles is present are known as crystallites.
- ii. Amorphous solids like glass melts over a wide temperature range.
- iii. They can be molded and blown to form different shapes.
- iv. Amorphous solids do not have definite value of heat of fusion.

Table: Comparison of crystalline and amorphous solids.

Property	Crystalline solids	Amorphous solids
1. Geometry of solid	Crystalline solids show characteristic geometrical shapes.	Amorphous solids generally appear in lump or in a fine powder form.
2. Melting of solid	Crystalline solids melt sharply at their melting points.	Amorphous solids do not have sharp melting points and they melt over a range of temperature.
3. Directional character of the properties	Crystalline solids are anisotropic in nature. It means that their properties depend upon the direction along which the measurements are made.	Amorphous solids are isotropic. Their properties do not depend upon the direction of measurement.
4. Order of particles in solid	Crystalline solids have long-range order.	In amorphous solids, long-range order is absent.
5. Examples:	NaCl, Diamond etc.	Glass, Glue etc.

 **QUICK CHECK 5.7**

a) Why solids have very low compressibility and expansion?

Ans. Solids have very low compressibility (resistance to volume reduction under pressure) and low thermal expansion due to their rigid, closely packed atomic/molecular structure. The main reasons are:

i. **Low Compressibility:**

- **Strong Intermolecular Forces:** Particles (atoms/ions/molecules) in solids are held tightly by strong bonds (e.g., covalent, ionic, or metallic) or van der Waals forces (in molecular solids).
- **Minimal Empty Space:** Particles are densely packed, leaving almost no gaps to compress further.
- **Electron Repulsion:** When forced closer, electrons in adjacent atoms repel strongly, resisting compression.

ii. **Low Thermal Expansion:**

- **Vibrational Motion Only:** When heated, particles vibrate more but cannot move freely (unlike liquids/gases). This limits expansion.

b) What is meant by habit of a crystal?

Ans. See (Properties of Crystalline solids) Above Point v. Habit of a crystal.

c) Why solids do not undergo translatory motion?

Ans. Solids do not undergo translatory motion (free movement of molecules from one position to another) because of their rigid, fixed molecular structure and strong intermolecular forces.

Reasons:

i. **Strong Intermolecular Forces:**

- Solids have strong bonds (ionic, covalent, metallic) or dense van der Waals forces that hold particles in fixed positions.
- **Example:** In a salt crystal (NaCl), ions are locked in place by electrostatic forces.

ii. **Fixed Lattice Structure:**

- Particles in solids are arranged in a rigid, ordered lattice (crystalline) or a tightly packed disordered structure (amorphous).
- Unlike liquids/gases, they cannot flow because their molecules lack freedom to move past one another.

iii. **Only Vibrational Motion:**

- When heated, particles vibrate (oscillate) around fixed positions but do not show translatory motion.
- **Example:** Atoms in a diamond vibrate but stay locked in a covalent network.

LIQUID CRYSTALS

(Exercise LQ8)

Q. How liquid crystals resemble liquids and solids? Give their uses in daily life.

Introduction


The distinction between liquids and solids is clear-cut and the phase transition between them is always sharply defined. However, at certain temperature, many substances exist in a phase that is neither fully liquid nor fully solid. The molecules in these substances can move around, as in viscous liquids, but have a restricted range of motion, as in solids. These substances are called liquid crystals.

Crystalline solid \longrightarrow Cloudy liquid (liquid crystal) \longrightarrow Clear liquid

In most liquid crystals, the molecules have a rigid, rod-like shape with a length four to eight times greater than their diameter. When packed together, the molecules tend to orient with their long axes roughly parallel, like logs in a stack of firewood. Individual molecules can migrate through the fluid. They can spin around their long axis, but they can't rotate end over end.

"The turbid liquid phase of a solid that exists in between the melting and clearing temperature is called liquid crystal."

Crystal \rightleftharpoons Liquid Crystal \rightleftharpoons Liquid

 **Rack Your Mind!**

9. Which of the following best describes liquid crystals?
- A) Solid substances
 - B) Amorphous solids
 - C) Substances with properties between liquids and solids
 - D) Completely gaseous substances

General Properties of Liquid Crystals

Liquid Crystals

The general properties of liquid crystals are as follows:

- i. They have parallel ordered arrangement.
- ii. They are elongated, rod-like and linear.
- iii. They flow like liquids.
- iv. They show viscosity like liquids.
- v. They show optical properties like crystals.
- vi. They are somewhat rigid.
- vii. They are always anisotropic.

Uses of Liquid Crystals in Daily Life

The main application area of liquid crystals is in electro-optic devices. These are electrically controlled devices that modulate light in a desired way. Liquid crystals have many uses in daily life.

i) **In Diagnostics**

- Special liquid crystal devices can be used to diagnose the tumors and infections in the human body.
- This is because often physical problems, such as tumors, have a different temperature than the surrounding tissue.
- When cholesteric liquid crystals are applied to the breast, a tumor is located because of being warmer than the other parts. This technique is successfully applied to diagnose breast cancer in the early stage.

ii) **Characteristic Higher Temperature Determination**

- Liquid crystal temperature sensors can also be used to find faulty connections on a circuit board by detecting the characteristic higher temperature.
- As temperature sensors, they are used in thermometers.

iii) **Liquid Crystal Displays (LCDs)**

- The most common application of liquid crystal technology is liquid crystal displays (LCDs).
- Examples of liquid crystal screens are oscillograph and TV, laptops, cell phone displays. Liquid crystals are used in TV displays, computer screens, calculators and watches, etc.
- **Note:** As new properties and types of liquid crystals are investigated and researched, these materials are sure to gain increasing importance in industrial and scientific applications.

 **QUICK CHECK 5.8**

a) Name the properties of liquid crystals in which they resemble solids.

Ans. Liquid crystals (LCs) share several key properties with solids, despite their fluid-like behaviour. Here are the solid-like characteristics they exhibit:

i. **Long-Range Orientational Order**

- Like solids, LCs have molecules aligned in a preferred direction (e.g., nematic phase) or in layers (smectic phase).
- **Solid-like Example:** Crystals have fixed atomic positions; LCs maintain directional order while allowing some mobility.

ii. **Optical Anisotropy**

- LCs split light into two polarized rays, just as crystalline solids do, due to their ordered structure.
- **Application:** LCD screens exploit this property to control pixels.

iii. **Elastic Response to Deformation**

- LCs resist distortions (e.g., bending, twisting) and recover their alignment when disturbed, similar to elastic solids.

b) Mention the properties of liquid crystals in which they resemble liquids.

Ans. Liquid crystals (LCs) exhibit several liquid-like properties while maintaining some degree of molecular order. Here are the key ways they resemble liquids:

i. **Fluid-like Flow and Viscosity**

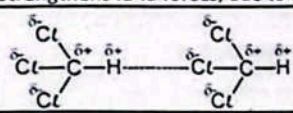
- LCs can flow and take the shape of their container, just like ordinary liquids (e.g., isotropic liquids).
- **Example:** Nematic LCs pour like oils but retain directional order.

Discovery of Liquid Crystals

- First of all, in 1888, Frederick Reinitzer, an Austrian botanist discovered the liquid crystals.
- He was studying an organic compound Cholesteryl benzoate.
- This compound turns milky liquid at 145°C and becomes a clear liquid at 179°C.
- When the substance is cooled, the reverse process occurs.
- This turbid liquid phase was called liquid crystal.

- ii. **No Fixed Positional Order (Short-Range Mobility)**
- Unlike solids, LC molecules do not occupy fixed lattice positions—they can slide past one another while maintaining alignment.
 - Exception: Smectic LCs have layered order but still allow in-plane flow.
- iii. **Surface Wetting Behavior**
- LCs spread and wet surfaces like liquids, forming droplets or films.
 - Used in coatings and responsive sensors.
- iv. **Diffusion and Mixing**
- LC molecules exhibit Brownian motion (random movement) and can diffuse, though slower than in isotropic liquids due to partial order.
- c) Which property of liquid crystals make it possible to use them in temperature sensing devices?
- Ans. The temperature-dependent optical properties of liquid crystals (especially cholesteric/chiral nematic phases) enable their use in temperature sensors.
- Their pitch (molecular twist length) changes with temperature, altering reflected/transmitted light wavelengths (visible as color shifts).
 - Example: Thermochromic strips (e.g., forehead thermometers) use this to display temperature via color.
 - The reversible, precise response to thermal energy makes LCs ideal for non-contact, visual temperature sensing.

Solution File Rack Your Brain!

Sr. #	Option	Explanation
1.	C	Gases have large distances between molecules, making them more compressible compared to solids and liquids, which have molecules that are closely packed.
2.	D	The equation, known as the ideal gas law, relates the pressure (P), volume (V), and temperature (T) of a gas, with n being the number of moles and R the gas constant. It combines Boyle's Charles's and Avogadro's laws.
3.	S.Q	Iodine has a larger molecular mass and more electrons, which increases polarizability and strengthens id-id forces, due to that reason its boiling point increases.
4.	C	
5.	S.Q	Anomalous Behaviour of Water Saves Aquatic Life: The lower density of ice allows it to float and form an insulating layer on water, maintaining liquid water below and protecting aquatic organisms during winter.
6.	B	Surface tension decreases with increase in temperature because molecular motion weakens cohesive forces.
7.	C	Water seeps through the earthenware and evaporates from the surface, taking heat away from the remaining water, thus cooling it down.
8.	S.Q	Earthenware vessels are porous. Water rises through these pores by capillary action and evaporates at the surface of the vessel. Remaining over water has low energy molecules so its temperature drops. Further, these earthenware vessels are insulators and do not allow the heat to move in them and hence, water remains cool in earthenware vessels.
9.	S.Q	The oppositely charged ions i.e. cations and anions in ionic crystals, are closely held together by strong attractive forces i.e. electrostatic force of attraction or ionic bond. That is why a very high energy or heat is required to separate cations and anions from each other and convert them into liquid. So, ionic crystalline solids have high melting points. e.g., melting point of NaCl = 801°C
10.	S.Q	In crystals, the particles are arranged in a regular repeating three dimensional pattern. This arrangement of particles is different in different planes. It is due to the reason that cleavage of crystals occur differently in different directions. Hence, cleavage of crystals is itself anisotropic behaviour. Difference in physical properties with direction.

Exercise

MULTIPLE CHOICE QUESTIONS (MCQs)

- Q.1 Four choices are given for each question. Select the correct choice.
- London dispersion forces are the only forces present among:
 - molecules of water in liquid state
 - atoms of helium in gaseous state at high temperature
 - molecules of solid iodine
 - molecules of hydrogen chloride gas
 - When the vapour pressure of a liquid equals the external pressure, what phenomenon occurs?
 - Sublimation
 - Condensation
 - Boiling
 - Freezing
 - When water freezes at 0°C, its density decreases due to:
 - cubic structure of ice
 - empty spaces present in the structure of ice
 - decrease in volume
 - decrease in viscosity
 - Which of the following is the correct sequence of decreasing ΔH_v values of substances mentioned?
 - $H_2O > NH_3 > F_2$
 - $F_2 > NH_3 > H_2O$
 - $NH_3 > H_2O > F_2$
 - $H_2O > F_2 > NH_3$
 - Surface tension of a liquid is due to:
 - inward pull of surface molecules
 - upward pull from the surface
 - collision of molecules
 - repulsive forces
 - Which change of state involves overcoming only London dispersion forces?
 - Melting of ice ($H_2O_{(s)} \rightarrow H_2O_{(l)}$)
 - Boiling of ethanol ($CH_3CH_2OH_{(l)} \rightarrow CH_3CH_2OH_{(g)}$)
 - Sublimation of iodine ($I_{(s)} \rightarrow I_{(g)}$)
 - Dissolving sodium chloride in water
 - In which of the following substances are London dispersion forces the only significant intermolecular forces present?
 - Ammonia (NH_3)
 - Water (H_2O)
 - Methane (CH_4)
 - Hydrogen fluoride (HF)
 - Which of the following is a characteristic property of crystalline solids?
 - They have a range of melting points.
 - They are isotropic.
 - They have a definite and sharp melting point.
 - They lack a regular arrangement of particles.
 - Which of the following liquids would you expect to have the highest viscosity at a given temperature?
 - Water (H_2O)
 - Ethanol (CH_3CH_2OH)
 - Diethyl ether ($CH_3CH_2OCH_2CH_3$)
 - Glycerol ($CH_2(OH)CH(OH)CH_2(OH)$)
 - Which type of intermolecular force is present in all types of molecule regardless of their polarity?
 - Dipole-dipole forces
 - Hydrogen bonds
 - London dispersion forces
 - Ion-dipole forces
 - Liquid crystals exhibit properties:
 - Only like solids.
 - Only like liquids.
 - Between solids and liquids.
 - Unlike solids or liquids.

Answer Key with Explanations

Sr.No.	Option	Answer	Explanation
I.	b	atoms of helium in gaseous state at high temperature	Helium atoms are monoatomic and non-polar. They only exhibit temporary London dispersion forces. Water and HCl have hydrogen bonding or dipole-dipole forces; iodine has London forces, but also in a solid lattice.
II.	c	Boiling	Boiling starts when the vapour pressure inside the liquid equals the atmospheric pressure, allowing vapor bubbles to form inside the liquid.

III.	b	empty spaces present in the structure of ice	<ul style="list-style-type: none"> Ice forms a hexagonal open structure with gaps due to hydrogen bonding, making it less dense than liquid water.
IV.	a	$H_2O > NH_3 > F_2$	<p>ΔH_v depends on intermolecular forces:</p> <ul style="list-style-type: none"> H_2O has strongest H-bonding \rightarrow highest ΔH_v NH_3 has weaker H-bonding \rightarrow moderate ΔH_v F_2 has only London forces \rightarrow lowest ΔH_v Thus, the decreasing order (which matches option a) is: $H_2O > NH_3 > F_2$
V.	a	inward pull of surface molecules	<ul style="list-style-type: none"> Surface molecules are pulled inward due to cohesive forces, causing the liquid to minimize surface area — this is surface tension.
VI.	c	Sublimation of iodine $I_{2(s)} \rightarrow I_{2(g)}$	<ul style="list-style-type: none"> Iodine is non-polar; its molecules are held together only by weak London dispersion forces, which are overcome during sublimation.
VII.	c	Methane (CH_4)	<ul style="list-style-type: none"> CH_4 is non-polar, and hence only exhibits London dispersion forces. The others have dipole or hydrogen bonding.
VIII.	c	They have a definite and sharp melting point	<ul style="list-style-type: none"> Crystalline solids have an orderly arrangement, causing them to melt sharply at a specific temperature
IX.	d	Glycerol ($CH_2(OH)CH(OH)CH_2(OH)$)	<ul style="list-style-type: none"> Glycerol has three $-OH$ groups, forming many hydrogen bonds, increasing resistance to flow (viscosity).
X.	c	London dispersion forces	<ul style="list-style-type: none"> London dispersion forces are present in all atoms and molecules due to temporary electron fluctuations.
XI.	c	Between solids and liquids	<ul style="list-style-type: none"> Liquid crystals have properties intermediate between solids and liquids. They flow like liquids but have some molecular order like solids, making them unique and useful in display technologies (e.g., LCD screens).

SHORT ANSWER QUESTIONS

Q.2 Attempt the following short-answer questions:

a. Explain, at a molecular level, why evaporation leads to a cooling effect.

Ans. Evaporation causes a cooling effect because of the loss of high-energy molecules from a liquid's surface.

1. Molecules in a Liquid Have Varying Energies

- In any liquid, molecules are in constant motion and have different kinetic energies.
- Some have high energy, others less — this distribution is random.

2. Only the Fastest Molecules Escape

- The highest energy molecules (with enough kinetic energy to overcome intermolecular forces) escape from the liquid surface and become gas (vapour).
- This process is evaporation.

3. Loss of High-Energy Molecules Lowers Average Energy

- When these high-energy molecules leave, the average kinetic energy of the remaining molecules decreases.
- Since temperature is a measure of average kinetic energy, the temperature of the liquid drops.

b. Explain why liquids with stronger intermolecular forces tend to have lower rates of evaporation at a given temperature compared to liquids with weaker intermolecular forces.

Ans. Liquids with stronger intermolecular forces (like hydrogen bonds or dipole-dipole forces) require more energy for molecules to escape the surface and become vapour.

At a given temperature, fewer molecules have enough energy to overcome these forces, so the rate of evaporation is lower compared to liquids with weaker intermolecular forces, where molecules escape more easily.

c. One feels sense of cooling under the fan after bath. Explain.

Ans. Evaporation is a cooling process and speed of air increases the rate of evaporation. After bath, a thin layer of water is formed on body. When one sits under the fan, the water gets energy from body and evaporates. Increase in the rate of evaporation is facilitated by speed of air. As a result, one feels sense of cooling due to decrease in body temperature.

d. How a dynamic equilibrium is established during evaporation of a liquid in a closed vessel at constant temperature.

Ans. When a liquid is placed in a closed container at constant temperature:

- Evaporation starts: Molecules at the surface escape into the vapour phase.
- Condensation also begins: Vapour molecules collide with the liquid surface and re-enter the liquid.

e. The boiling point of water is different at Lahore and Murree hills.

Ans. The boiling point of a liquid can be decreased by decreasing the external pressure.

Boiling Point of Water at Lahore:

At Lahore, the atmospheric pressure is 750.1 torr and boiling point of water is 99.1 °C (approx.) at this pressure.

Boiling Point of Water at Murree Hills:

At Murree Hills the pressure is 700 torr and boiling point of water is 98°C at this pressure.

f. Discuss two significant consequences of the lower density of ice compared to liquid water in natural environments.?

Ans. Two key consequences of ice being less dense than liquid water:

- Ice Floats on Water:** This insulates lakes and ponds in winter, allowing aquatic life to survive beneath the frozen surface.
- Prevention of Complete Freezing:** Since ice forms at the surface and floats, it prevents water bodies from freezing solid from the bottom up, preserving ecosystems.

g. Why boiling point (B.P) of a liquid increases when the external pressure rises?

Ans. The boiling point of a liquid increases with external pressure because:

Boiling occurs when the vapour pressure of the liquid equals the external pressure.

When the external pressure rises, the liquid must reach a higher temperature to produce enough vapour pressure to match it, thus raising the boiling point.

h. Mention four items in which liquid crystals are used.

Ans. Four common items that use liquid crystals:

- Digital watches and clocks
- Laptop and TV screens (LCDs)
- Thermometers (liquid crystal thermometers)
- Mobile phone displays

i. How do you differentiate between crystalline solids and amorphous solids?

Ans. Differences between Crystalline and Amorphous Solids

Property	Crystalline solids	Amorphous solids
Definition	Those solids in which atoms, ions or molecules are arranged in a definite three-dimensional pattern are called crystalline solids. This recurring regular geometrical pattern of structure extends three dimensionally.	Amorphous substances are those whose constituent atoms, ions or molecules do not possess a regular orderly arrangement.
Shape	They have definite characteristic geometrical shape.	They have irregular shape (Word Amorphous means shapeless).
Melting point	They melt at a sharp and characteristic temperature.	They gradually soften over a range of temperature.
Cleavage plane	When cut with a sharp edged tool, they into two pieces and the newly generated surfaces are plain and smooth.	When cut with a sharp edged tool, they cut into two pieces with irregular surfaces.
Heat of fusion	They have a definite and characteristic heat of fusion.	They do not have definite heat of fusion.
Anisotropy	These are anisotropic in nature	These are isotropic in nature.
Nature	They are true solids	They are pseudo solids or super cooled liquids or highly viscous liquids.
Examples	NaCl, Sugar, Ice, Diamond etc.	Rubber, Plastic, Glue, Glass, Paper etc.

j. Propanone (CH_3COCH_3), propanol ($\text{CH}_3\text{CH}_2\text{CH}_2\text{OH}$) and butane ($\text{CH}_3\text{CH}_2\text{CH}_2\text{CH}_3$) have very similar relative molecular masses. List them in the expected order of increasing boiling points. Explain your answer.

Ans. Boiling Point:

"The temperature at which the vapour pressure of a liquid becomes equal to external pressure is called boiling point of that liquid."

Order of boiling points is:



- Butane is non-polar and it has London dispersion forces.
- Propanone has dipole-dipole forces.
- Propanol has hydrogen bonding.

The strongest intermolecular forces are hydrogen bonding and weakest are London forces, so order of boiling points is same as given above.

k. Discuss how hydrogen bonding is responsible for the relatively high surface tension of water.

Ans. Hydrogen bonding is responsible for the relatively high surface tension of water due to the strong intermolecular attractions between water molecules. Each water molecule can form up to four hydrogen bonds with neighboring water molecules. At the surface, water molecules have fewer neighbouring molecules, so they form stronger bonds with the ones beside and below them. This creates an inward cohesive force, pulling surface molecules more tightly together. As a result, water's surface resists external force, leading to high surface tension.

In Short, Hydrogen bonding causes strong cohesive forces among water molecules, especially at the surface, resulting in high surface tension.

l. What type of intermolecular forces will dominate in the following liquids?

- (i) NH_3 (ii) Ar (iii) CH_3COCH_3 (iv) CH_3OH

Ans. (i) NH_3 (Ammonia): Hydrogen bonding is present in ammonia molecules.

(ii) Ar (Argon): London dispersion forces are present in argon (which is a noble gas).

(iii) CH_3COCH_3 (Acetone): Hydrogen bonding is present in acetone molecules.

(iv) CH_3OH (Methanol): Hydrogen bonding is present in methanol molecules.

m. The boiling points and molar masses of hydrides of some first-row elements are tabulated below:

Substance	Boiling Point (K)	Molar Mass (g mol^{-1})
CH_4	112	16
NH_3	240	17
H_2O	373	18

Suggest reasons for the difference in their boiling points in terms of the type of molecules involved and the nature of the forces present between them.

- Ans. • CH_4 : Methane is a symmetrical and non-polar molecule. It has London dispersion forces. Which are very weak so it has low boiling point.
- NH_3 : Ammonia is a polar molecule. It has hydrogen bonding between its molecules. These intermolecular forces are stronger than London forces. Due to these forces, ammonia has high boiling point and heat of vapourization than methane.
- H_2O : Water is a polar molecule. In water molecule strong hydrogen bonding is present. Water forms two H-bonds per molecule as a result the effect of hydrogen bonding in water is more than in ammonia. Due to this, boiling point and heat of vapourization of water is very high as compared to methane and ammonia.

DESCRIPTIVE QUESTIONS

Q.3 What are London dispersion forces? Give examples, and discuss the factors affecting these forces.

Ans. See Page No. (142)

Q.4 Hydrogen bonding is present in H_2O , NH_3 , HF , $(\text{CH}_3)_2\text{CO}$ and CHCl_3 molecules. Sketch structures and discuss briefly.

Ans. See Page No. (144)

Q.5 Discuss the structural changes when water turns into ice. Justify the empty spaces in its crystals as compared to H_2O at 4°C and lower density of ice.

Ans. See Page No. (146)

Q.6 How liquid crystals resemble liquids and solids? Give their uses in daily life.

Ans. See Page No. (158)

Q.7 Describe the following properties of crystalline solids.

- i) Geometrical shape ii) Melting point iii) Cleavage plane iv) Habit of a crystal

Ans. See Page No. (156)

NUMERICAL PROBLEMS

Q.8 A sample of an unknown gas has a mass of 0.560 g. It occupies a volume of $2.87 \times 10^{-4} \text{ m}^3$ at a temperature of 300 K and a pressure of $1.01 \times 10^5 \text{ Pa}$. Calculate the molar mass of the gas. (Gas constant, $R = 8.31 \text{ J K}^{-1} \text{ mol}^{-1}$)

Ans. Given data:

$$\begin{aligned} \text{Mass (m)} &= 0.560 \text{ g} \\ \text{Volume (V)} &= 2.87 \times 10^{-4} \text{ m}^3 \\ \text{Temperature (T)} &= 300 \text{ K} \\ \text{Pressure (P)} &= 1.01 \times 10^5 \text{ Pa} \\ \text{Gas constant (R)} &= 8.31 \text{ J K}^{-1} \text{ mol}^{-1} \end{aligned}$$

To find:

Molar Mass of Unknown Gas = ?

Solution:

Step 1: Use the Ideal gas law to find moles (n)

$$\begin{aligned} PV &= nRT \\ n &= PV/RT \\ n &= \frac{(1.01 \times 10^5 \text{ Pa})(2.87 \times 10^{-4} \text{ m}^3)}{(8.31 \text{ J K}^{-1} \text{ mol}^{-1})(300 \text{ K})} \\ n &= \frac{28.98}{2493} = 0.0116 \text{ mol} \end{aligned}$$

Step 2: Calculate molar mass (M)

$$\begin{aligned} M &= \text{mass / moles} = 0.560 \text{ g} / 0.0116 \text{ mol} \\ M &= 48.3 \text{ g mol}^{-1} \end{aligned}$$

Q.9 In a laboratory experiment, 150 cm^3 of a volatile liquid was completely vaporized at 98°C and a pressure of $1.01 \times 10^5 \text{ Pa}$. The mass of the vapour was found to be 0.495 g. Determine the molecular mass of the liquid ($R = 8.314 \text{ J K}^{-1} \text{ mol}^{-1}$).

Ans. Given data:

$$\begin{aligned} \text{Volume (V)} &= 150 \text{ cm}^3 = 1.50 \times 10^{-4} \text{ m}^3 \\ \text{Temperature (T)} &= 98^\circ\text{C} = 371 \text{ K} \\ \text{Pressure (P)} &= 1.01 \times 10^5 \text{ Pa} \\ \text{Mass (m)} &= 0.495 \text{ g} \\ \text{Gas constant (R)} &= 8.314 \text{ J K}^{-1} \text{ mol}^{-1} \end{aligned}$$

To find:

Molar Mass of Unknown Gas = ?

Solution:

Step 1: Use the Ideal gas law to find moles (n)

$$\begin{aligned} PV &= nRT \\ n &= \frac{(1.01 \times 10^5 \text{ Pa})(1.50 \times 10^{-4} \text{ m}^3)}{(8.314 \text{ J K}^{-1} \text{ mol}^{-1})(371 \text{ K})} \\ n &= \frac{15.15}{3083.6} \\ n &= 0.00491 \text{ mol} \end{aligned}$$

Step 2: Calculate molar mass (M)

$$\begin{aligned} M &= \text{mass / moles} \\ M &= 0.495 \text{ g} / 0.00491 \text{ mol} \\ M &= 100.8 \text{ g mol}^{-1} \end{aligned}$$

ADDITIONAL SLOs BASED MCQs

- The temperature at which two or more than two types of crystals exist in equilibrium is called.
 - Melting Point
 - Transition temperature
 - Eutectic temperature
 - Boiling point
- The solids in which atoms, ions or molecules have random non-repetitive three dimensional arrangements are termed as:
 - Crystals
 - Glasses
 - Alloys
 - Amalgams
- The nature of bond in diamond is:
 - Ionic
 - Covalent
 - Molecular
 - Metallic
- Crystal lattice is an arrangement of particles in:
 - One dimension
 - Two dimensions
 - Three dimensions
 - Four dimensions
- Lattice energy is also called:
 - Crystal energy
 - Ionization energy
 - Energy of affinity
 - Bond Energy
- When gaseous ions are allowed to form a crystal, energy,
 - is evolved
 - is absorbed
 - is sometimes absorbed and sometimes released
 - has no effect
- NaF and MgO have both atomic ratio 1:1 in their crystals such property is:
 - Polymorphism
 - Isomorphism
 - Isotropy
 - Allotropy
- Electric current can pass through graphite in one direction but not through other direction of crystal such a property is called:
 - Allotropy
 - Anisotropy
 - Isomorphism
 - Polymorphism
- Iron acts as an electrical conductor due to:
 - Electron cloud
 - Free protons
 - Free neutrons
 - Free ions
- A crystal of the purple compound, Potassium Permanganate, placed at the bottom of a beaker of water and the beaker left until there is no further change. What will be observed?
 - A uniformly purple solution.
 - A colourless liquid with the purple crystal unchanged.
 - A purple layer below a colourless layer.
 - A colourless layer below a purple layer.
- Which of the following method is most suitable for obtaining a pure, dry sample of NaCl from a mixture of NaCl and sand?
 - Shake the mixture with water. Filter and dry the substances on the filter paper.
 - Shake the mixture with water. Filter and evaporate the filtrate.
 - Shake the mixture with water and distill off the sand.
 - Heat the mixture gently and collect the substances which boil off.
- What method could be used to obtain copper from mixture of powdered copper and sodium chloride?
 - Heating the mixture
 - Fractional distillation of the mixture
 - Passing an electric current through the mixture
 - Adding excess water to the mixture and filtering
- A bottle of copper oxide has been contaminated with some sodium chloride. How can the NaCl be removed from the copper oxide?
 - Place the mixture in a separating funnel
 - Heat the mixture and allow it to cool
 - Add water to the mixture and filter
 - Add aqueous AgNO_3 to the mixture
- Lead and zinc can be separated by distillation because they have different.
 - Boiling point
 - Densities
 - Mass numbers
 - Reactivities

15. An insoluble solid was dropped into a measuring cylinder containing 50 cm³ of water. What will be the effect on volume of water?
 A. 15 cm³ B. 17 cm³ C. 50 cm³ D. 65 cm³

Answer Key with Explanations

Q. No	Option	Explanation
1.	B	At transition temperature, one crystalline form of a substance changes to another. Above and below this temperature, only one form exists. The transition temperature of allotropic forms of an element is always less than its melting point.
2.	B	An amorphous solid is a substance in which atoms, molecules or ions assume a random and non-repetitive three dimensional arrangements e.g. Glass.
3.	B	Diamond is an allotrope of carbon. In diamond carbon atoms are covalently bonded with each other.
4.	C	An array of points representing the arrangement of particles (atoms, ions or molecules) in three dimensional spaces is called crystal lattice.
5.	A	The energy released when one mole of an ionic crystal is formed from the gaseous opposite ions is called lattice energy. e.g. $\text{Na}_{(g)}^{+1} + \text{Cl}_{(g)}^{-1} \rightarrow \text{NaCl}_{(s)} \quad \Delta H_{\text{latt}} = -787 \text{ kJ mol}^{-1}$
6.	A	The energy released when one mole of the ionic crystal is formed from the gaseous ions is called lattice energy. e.g. $\text{Na}_{(g)}^{+1} + \text{Cl}_{(g)}^{-1} \rightarrow \text{NaCl}_{(s)} \Delta H_{\text{latt}} = -787 \text{ kJ mol}^{-1}$
7.	B	The phenomenon in which two different substances exist in the same crystalline form is called isomorphism. e.g. NaF and MgO are isomorphs and having cubic shape.
8.	B	It is because crystal has different arrangements in different directions e.g. graphite exist in the form of layers, so it is conductor in one direction, parallel to layers but insulator across the layers.
9.	A	Iron is a metal. The electrical conductivity of metals is due to the presence of free or mobile electrons. These electrons form electron cloud in the metal lattice.
10.	A	Diffusion is a spontaneous movement of gas or liquid molecules from a region of a higher concentration to a region of lower concentration, until they are equally dispersed. <ul style="list-style-type: none"> • A deep purple layer below a pale purple layer is formed after about 15 minutes. • A uniform purple solution is formed after about 30 minutes.
11.	B	A mixture of NaCl and sand is mixed with water. NaCl is soluble while sand is insoluble in water. Filter the mixture. The filtrate is NaCl solution. It is evaporated. Water evaporates leaving behind solid NaCl.
12.	D	NaCl is soluble in water while copper is insoluble.
13.	C	When excess water is added in the mixture, NaCl dissolves in water while copper oxide remains insoluble. The solution is filtered. The copper oxide is obtained as residue on filter paper.
14.	A	Distillation is the technique to separate liquids from a mixture on the basis of boiling points. Zinc distilled first as it has low boiling point than lead.
15.	D	Addition of insoluble solid increase the volume of water.

ADDITIONAL SHORT ANSWER QUESTIONS

Q.1 Write any four properties of gases.

Ans. Properties of Gases:

- Indefinite Volume:** Gases have an indefinite volume and occupy all the available space. The volume of a gas is the volume of the container.
- Indefinite Shape:** They don't have a definite shape and take the shape of the container just like liquids.
- Low Densities:** Due to low densities of gases, as compared to those of liquids and solids but gases bubble through liquids and tend to rise up.
- Diffusion and Effusion:** Gases can diffuse and effuse. This property is negligible in solids but operates (works) in liquids as well.

Q.2 Write any four properties of liquids.

Ans. Properties of Liquids:

- Volume:** Liquids have a fixed volume. The intermolecular forces in liquids are strong enough to maintain a fixed volume.
- Shape:** Liquids do not have a fixed shape. They always take the shape of the container in which they are placed. The intermolecular forces are present in liquids but they are not so strong that a liquid can have a fixed shape.
- Evaporation:** Due to constant movement and collisions between the liquid molecules, the high energy molecules leave the surface of liquid and the liquid is changed into its vapours. This process is called evaporation. Liquids evaporate at all temperatures.
- Diffusion:** A liquid can diffuse into another liquid with which it is miscible. However, the rate of diffusion in liquids is slower than in gases. This is due to less empty spaces between the liquid molecules.

Q.3 Give two statements of Boyle's law.

Ans. Boyle's Law:

Statement: "The volume of a given mass of a gas at constant temperature is inversely proportional to the pressure applied to the gas."

Mathematically: $V \propto \frac{1}{P}$ (at constant temperature and number of moles)

$$V = \frac{k}{P} \text{ Here 'k' is proportionality constant}$$

$$PV = k \text{ (when 'T' and 'n' are constant)}$$

The value of k is different for the different amounts of the same gas.

Another Statement: "The product of pressure and volume of a fixed amount of a gas at constant temperature is a constant quantity."

So, $P_1V_1 = k$ and $P_2V_2 = k$

Hence, $P_1V_1 = P_2V_2$

P_1V_1 are the initial values of pressure and volume while P_2V_2 are the final values of pressure and volume.

Q.4 State Charles's Law and write its mathematical form.

Ans. Charles's Law: "The volume of the given mass of a gas is directly proportional to the absolute temperature at constant pressure."

Mathematically:

$$V \propto T \text{ (at constant pressure and number of moles)}$$

$$\text{or } V = KT$$

$$\text{or } \frac{V}{T} = k$$

If temperature is changed from T_1 to T_2 , and volume changes from V_1 to V_2 , then

$$\frac{V_1}{T_1} = k \text{ and } \frac{V_2}{T_2} = k$$

$$\frac{V_1}{T_1} = \frac{V_2}{T_2}$$

Another Statement:

"The ratio of volume to temperature remains constant for same amount of gas at same pressure."

Q.5 What is Avogadro's law (of gases)? Give an example.

Ans. Avogadro's Law:

"Equal volumes of all the ideal gases at the same temperature and pressure contain equal number of molecules."

At STP, one mole of all gases has volume 22.414 dm³ and $N_A = 6.022 \times 10^{23}$ molecules.

Examples:

At STP,

$$H_2 = 2g = 1 \text{ mole} = 22.414 \text{ dm}^3 = 6.02 \times 10^{23} \text{ molecules}$$

$$O_2 = 32g = 1 \text{ mole} = 22.414 \text{ dm}^3 = 6.02 \times 10^{23} \text{ molecules}$$

Q.6 Derive molecular mass of a gas by general gas equation.

Ans. We can determine the molecular mass as follows:

Derivation:

$$PV = nRT \quad (\text{general gas equation})$$

Where

$$n = \frac{\text{mass of gas}}{\text{molecular mass}} = \frac{m}{M}$$

So

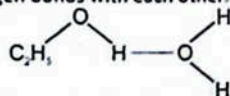
$$PV = \frac{m}{M}RT$$

$$M = \frac{m}{V \times P}RT$$

So by knowing m , V , P , T for a gas, one can determine its molecular mass.

Q.7 Show hydrogen bonding in alcohol and water.

Ans. Lower alcohols like Ethyl alcohol (C_2H_5OH) has the tendency to form hydrogen bonds so they are soluble in water because both can form hydrogen bonds with each other.



Q.8 What do you mean by liquid crystal? Write down any two uses of it.

Ans. Liquid Crystal:

"The turbid liquid phase of a solid that exists in between the melting and clearing temperature is called liquid crystal."



Example: Cholesteryl benzoate.

- It is discovered by Frederick Reinitzer in 1888.

Uses of Liquid Crystals:

- Like solid crystals, liquid crystals can diffract light. When one of the wavelengths of white light is reflected from a liquid crystal, it appears coloured. As the temperature changes, the distances between the layers of the molecules of liquid crystals change. Therefore, the reflected light changes accordingly. Thus liquid crystals can be used as temperature sensors.
- Liquid crystals are used to find the point of potential failure in electrical circuits. Room thermometers also contain liquid crystals with a suitable temperature range. As the temperature changes, figures show up in different colours.

Q.9 Why ice occupies more volume than liquid water?

Ans. Ice Floats Over the Surface of Water:

When temperature of water is decreased and ice is formed then the molecules become more regular and this regularity extends throughout the whole structure. Empty spaces are created in the structure. That is why, when ice freezes it occupies 9% more space and its density decreases. The result is that ice floats on water.

Q.10 Evaporation takes place at all temperatures. Justify.

Ans. Evaporation:

"The spontaneous change of a liquid into its vapours at all temperatures is called evaporation."

Evaporation Takes Place at All Temperatures:

- Rate of evaporation is directly proportional to temperature. At high temperature, the kinetic energy of the molecules increases, so evaporation also increases.
- At low temperature, the kinetic energy of molecules is less, so rate of evaporation slows down. Thus evaporation continues at all temperatures whether low or high.

Q.11 Why are the vapour pressure of solids far less than those of liquids?

Ans. The magnitude of vapour pressure is inversely proportional to the strength of intermolecular attractive forces. These forces are stronger in solids as compared to the liquids. Hence, vapour pressure of solids is far less than liquids.

Q.12 Define Boiling point and molar heat of vapourization.

Ans. Boiling Point: "The temperature at which the vapour pressure of a liquid becomes equal to the atmospheric/external pressure is called boiling point"

Molar Heat of Vaporization: "The amount of heat absorbed when one mole of a liquid is changed into vapours at its boiling point, is called heat of vaporization." The pressure during the change is kept one atmosphere.

Example: Molar heat of vaporization of $H_2O = 40.7 \text{ kJ/mol}$.

Q.13 What are ionic solids? Give two examples.

Ans. Ionic Solids:

"The crystalline solids in which the particles forming the crystal are positively and negatively charged ions which are held together by strong electrostatic forces of attraction (ionic bond) are called ionic solids."

Examples: The crystals of NaCl, KBr etc.

Q.14 Differentiate between Intermolecular and Intramolecular forces.

Intramolecular Forces	Intermolecular Forces
<ul style="list-style-type: none"> Those forces which are present within the molecules between atoms are called intramolecular forces. 	<ul style="list-style-type: none"> Those forces which are present between two molecules are called intermolecular forces.
<ul style="list-style-type: none"> Nature of substance is determined by intramolecular forces. 	<ul style="list-style-type: none"> State of a substance (solid, liquid and gas) is determined by intermolecular forces.
<ul style="list-style-type: none"> Chemical properties of a substance are related to its intramolecular forces. 	<ul style="list-style-type: none"> The physical properties of a substance are related to its intermolecular forces.
<ul style="list-style-type: none"> These are comparatively strong forces. 	<ul style="list-style-type: none"> These are relatively weak forces.
Examples: i. Covalent bond ii. Ionic bond iii. Coordinate covalent bond	Examples: i. Dipole-dipole forces ii. Dipole-induced dipole forces iii. London dispersion forces iv. Hydrogen bonding

