

# Weird Chemist

## DPP-5 : Vapour Density

Chapter: Some Basic Concepts of Chemistry

Complete Solution Sheet — Q.1 to Q.9

### Key Concepts: Vapour Density

**Definition:** Vapour Density (VD) = ratio of mass of a given volume of gas to the mass of the same volume of hydrogen, at same T and P.

$$M_r = 2 \times \text{VD} \quad \text{or} \quad \text{VD} = \frac{M_r}{2}$$

**From mass and volume at STP/NTP:**

$$M_r = \frac{\text{mass of gas (g)}}{\text{volume (L)}} \times 22.4 \quad \Rightarrow \quad \text{VD} = \frac{M_r}{2} = \frac{\text{mass} \times 22.4}{2 \times \text{volume}}$$

**From density at STP:**

$$M_r = \rho \text{ (g/L)} \times 22.4 \quad \text{or} \quad M_r = \rho \text{ (g/mL)} \times 22400$$

## TYPE : Vapour Density

**Q.1** At NTP, 5.6 L of a gas weighs 8 grams. The vapour density of gas is

### Explanation

**Step 1: Find molar mass.**

At NTP, 1 mol of gas occupies 22.4 L.

$$n = \frac{5.6}{22.4} = 0.25 \text{ mol}$$

$$M_r = \frac{8}{0.25} = 32 \text{ g/mol}$$

**Step 2: Vapour Density.**

$$\text{VD} = \frac{M_r}{2} = \frac{32}{2} = 16$$

### Approach / Analogy

Two-step: find  $M_r$  from mass and volume at STP, then halve it to get VD. Think of VD as “how many times heavier than  $\text{H}_2$ ” —  $\text{H}_2$  has  $M_r = 2$ , so  $\text{VD} = M_r/2$ . A molar mass of 32 (like  $\text{SO}_2$  or S) gives  $\text{VD} = 16$ .

### Common Mistake

Reporting  $M_r = 32$  as the vapour density.  $\text{VD} \neq M_r$ .  $\text{VD} = M_r/2 = 16$ . Always divide the molar mass by 2 to get VD. This is the single most common error in vapour density problems.

### Answer

(3) 16

**Q.2 The atomic mass of an element is 27. If valency is 3, the vapour density of the volatile chloride will be**

### Explanation

**Step 1: Write the formula of the volatile chloride.**

Valency 3  $\Rightarrow$  the chloride formula is  $MCl_3$  (element combines with 3 Cl atoms).

**Step 2: Molar mass of  $MCl_3$ .**

$$M_r(MCl_3) = 27 + 3 \times 35.5 = 27 + 106.5 = 133.5 \text{ g/mol}$$

**Step 3: Vapour Density.**

$$VD = \frac{M_r}{2} = \frac{133.5}{2} = \mathbf{66.75}$$

The element is Aluminium (Al, at. mass 27, valency 3) and its volatile chloride is  $AlCl_3$ .

### Approach / Analogy

Valency = number of Cl atoms in the chloride. Valency 3  $\rightarrow MCl_3$ . Molar mass = at. mass of M + 3  $\times$  35.5. Then  $VD = M_r/2$ . The at. mass 27 and valency 3 perfectly describe aluminium —  $AlCl_3$  is a well-known compound used in organic chemistry.

### Common Mistake

Writing the formula as  $MCl$  instead of  $MCl_3$  (ignoring the valency). Valency 3 means the element bonds with 3 chlorine atoms to satisfy the valency. Using  $MCl$  gives  $M_r = 27 + 35.5 = 62.5$  and  $VD = 31.25$  — completely wrong. Always use valency as the subscript on Cl.

### Answer

(1) 66.75

**Q.3 Vapour density of gas is 11.2. Volume occupied by 2.4 g of this gas at STP will be**

### Explanation

**Step 1: Molar mass from VD.**

$$M_r = 2 \times VD = 2 \times 11.2 = 22.4 \text{ g/mol}$$

**Step 2: Moles of gas.**

$$n = \frac{2.4}{22.4} = \frac{3}{28} \approx 0.1071 \text{ mol}$$

**Step 3: Volume at STP.**

$$V = n \times 22.4 = \frac{3}{28} \times 22.4 = \frac{3 \times 22.4}{28} = \frac{67.2}{28} = 2.4 \text{ L}$$

### Approach / Analogy

Notice the elegant pattern here:  $M_r = 22.4$  g/mol and volume = 2.4 L. The gas has  $M_r = 22.4$ , so 22.4 g occupies 22.4 L (1 mole). By proportion: 2.4 g occupies  $\frac{2.4}{22.4} \times 22.4 = 2.4$  L. The mass in grams numerically equals the volume in litres when  $M_r = 22.4$ !

### Common Mistake

Computing  $M_r = 11.2$  (forgetting to multiply VD by 2).  $VD = M_r/2$ , so  $M_r = 2 \times VD$ . If  $M_r = 11.2$  is used,  $n = 2.4/11.2 = 0.214$  mol and  $V = 4.8$  L — wrong. The factor of 2 between VD and  $M_r$  is crucial.

### Answer

(4) 2.4 L

**Q.4** If  $V$  mL of the vapours of substance at NTP weigh  $W$  g, then the molecular weight of substance is

### Explanation

At NTP, 1 mole occupies 22400 mL (= 22.4 L).

$V$  mL of gas weighs  $W$  g, so:

$$\begin{aligned} \text{Moles in } V \text{ mL} &= \frac{V}{22400} \\ M_r &= \frac{\text{mass}}{\text{moles}} = \frac{W}{V/22400} = \frac{W}{V} \times 22400 \end{aligned}$$

### Approach / Analogy

This is the formula version of “mass/moles = molar mass.” Converting volume to moles:  $V$  mL / 22400 mL per mol. Then  $M_r = W \div (V/22400) = W \times 22400/V$ . The key is using 22400 mL/mol (not 22.4 L/mol) since volume is given in mL.

### Common Mistake

Writing  $M_r = V/W \times 22400$  (flipping  $W$  and  $V$ ). The mass  $W$  is in the numerator and volume  $V$  in the denominator. Think: bigger mass per given volume  $\rightarrow$  higher molar mass, so  $W$  must be on top:  $M_r = (W/V) \times 22400$ .

### Answer

(1)  $(W/V) \times 22400$

**Q.5** A gas is found to have the formula  $(\text{CO})_x$ . Its VD is 70. The value of  $x$  must be

### Explanation

**Step 1: Molar mass from VD.**

$$M_r = 2 \times 70 = 140 \text{ g/mol}$$

**Step 2: Molar mass of (CO)<sub>x</sub>.**

$$M_r(\text{CO})_x = x \times M_r(\text{CO}) = x \times (12 + 16) = 28x$$

**Step 3: Solve for x.**

$$28x = 140 \implies x = \frac{140}{28} = 5$$

The gas is (CO)<sub>5</sub>, i.e., C<sub>5</sub>O<sub>5</sub> with  $M_r = 140$ .

### Approach / Analogy

(CO)<sub>x</sub> means  $x$  CO units in the formula. Each CO unit has molar mass = 28 g/mol (C=12, O=16). So  $M_r = 28x$ . From VD:  $M_r = 140$ . Solve:  $x = 140/28 = 5$ . Real-world note: Fe(CO)<sub>5</sub> (iron pentacarbonyl) is an actual compound that uses this framework!

### Common Mistake

Using  $M_r(\text{CO}) = 12 + 8 = 20$  (confusing oxygen's atomic mass as 8 instead of 16). Oxygen has atomic mass **16**. CO = 12 + 16 = 28, not 20. Using 20 gives  $x = 140/20 = 7$  — wrong.

### Answer

(3) 5

### Q.6 Weight of 1 L gas is 2 g. The molecular mass of the gas is

#### Explanation

1 mole of gas at STP occupies 22.4 L.

1 L weighs 2 g, so 22.4 L weighs:

$$M_r = 2 \times 22.4 = 44.8 \text{ g/mol}$$

#### Approach / Analogy

Direct proportion: if 1 L = 2 g, then 22.4 L =  $2 \times 22.4 = 44.8 \text{ g} = M_r$ . This is because 22.4 L = 1 mole at STP, and molar mass = mass of 1 mole. Think of it as scaling up: one mole occupies 22.4 L, so multiply the mass per litre by 22.4.

#### Common Mistake

Dividing 2 by 22.4:  $M_r = 2/22.4 = 0.089 \text{ g/mol}$ . That would be the moles in 1 L, not the molar mass. To get  $M_r$  from g/L density: **multiply** by 22.4 (not divide).  $M_r = \rho(\text{g/L}) \times 22.4 = 2 \times 22.4 = 44.8$ .

#### Answer

(1) 44.8

### Q.7 The vapour densities of two gases are in the ratio of 1 : 3. Their molecular masses are in the

## ratio of

### Explanation

Since  $M_r = 2 \times \text{VD}$ :

$$\frac{M_{r,1}}{M_{r,2}} = \frac{2 \times \text{VD}_1}{2 \times \text{VD}_2} = \frac{\text{VD}_1}{\text{VD}_2} = \frac{1}{3}$$

**Molecular masses are in the ratio 1 : 3.**

### Approach / Analogy

Since  $M_r = 2 \times \text{VD}$ , the factor of 2 appears in both numerator and denominator when taking the ratio — it cancels out. So VD ratio =  $M_r$  ratio. If VD ratio is 1:3, then  $M_r$  ratio is also 1:3. Ratios are preserved under multiplication by a constant.

### Common Mistake

Thinking the molecular mass ratio =  $2 \times \text{VD ratio} = 2:6 = 1:3$  (accidentally doubling each term). The *ratio* stays the same when both terms are multiplied by the same factor (2).  $M_{r,1} : M_{r,2} = 2 \times \text{VD}_1 : 2 \times \text{VD}_2 = \text{VD}_1 : \text{VD}_2 = 1 : 3$ .

### Answer

(1) 1 : 3

**Q.8 At NTP the density of a gas is 0.00445 g/mL. The molecular mass of the gas is**

### Explanation

Converting density to g/L:

$$\rho = 0.00445 \text{ g/mL} = 0.00445 \times 1000 \text{ g/L} = 4.45 \text{ g/L}$$

$$M_r = \rho(\text{g/L}) \times 22.4 = 4.45 \times 22.4 = \mathbf{99.68} \approx \mathbf{100} \text{ g/mol}$$

The gas is likely  $\text{CO}_2$  or similar ( $M_r \approx 44$ )... actually 100 corresponds to gases like  $\text{SF}_4$  or a mixture.

### Approach / Analogy

Density in g/mL must first be converted to g/L (multiply by 1000). Then  $M_r = \rho(\text{g/L}) \times 22.4$ . Common trap: mixing up g/mL and g/L.  $0.00445 \text{ g/mL} = 4.45 \text{ g/L}$  — this is the gas density at NTP. Multiplying by 22.4 L/mol gives  $M_r \approx 100 \text{ g/mol}$ .

### Common Mistake

Multiplying by 22400 (mL/mol) instead of 22.4 (L/mol) when density is already in g/mL:  $0.00445 \times 22400 = 99.68 \approx 100$ . Actually both approaches give the same answer here! But conceptually: if density is in g/mL, use  $\times 22400$  (molar volume in mL). If density is in g/L, use  $\times 22.4$  (molar volume in L). The key is matching units consistently.

### Answer

(1) 100

**Q.9** The vapour density of a mixture of  $\text{NO}_2$  and  $\text{N}_2\text{O}_4$  is 39 at  $25^\circ\text{C}$ . What is the mass of  $\text{NO}_2$  present in 100 g of the mixture?

### Explanation

**Step 1: Average molar mass of mixture.**

$$\bar{M} = 2 \times \text{VD} = 2 \times 39 = 78 \text{ g/mol}$$

**Step 2: Set up mole fraction equation.**

Let mole fraction of  $\text{NO}_2 = \chi_1$  and  $\text{N}_2\text{O}_4 = \chi_2 = 1 - \chi_1$ .

$M_r(\text{NO}_2) = 46 \text{ g/mol}$ ,  $M_r(\text{N}_2\text{O}_4) = 92 \text{ g/mol}$ .

Average molar mass:

$$\bar{M} = \chi_1 \times 46 + (1 - \chi_1) \times 92 = 78$$

$$46\chi_1 + 92 - 92\chi_1 = 78$$

$$-46\chi_1 = -14 \implies \chi_1 = \frac{14}{46} = \frac{7}{23}$$

**Step 3: Mass fraction of  $\text{NO}_2$ .**

In a mixture, mass fraction  $\neq$  mole fraction. We must convert.

Take a basis of 1 mole of mixture:

$$n(\text{NO}_2) = \frac{7}{23} \text{ mol}, \quad n(\text{N}_2\text{O}_4) = \frac{16}{23} \text{ mol}$$

$$\text{Mass of NO}_2 = \frac{7}{23} \times 46 = \frac{322}{23} = 14 \text{ g}$$

$$\text{Mass of N}_2\text{O}_4 = \frac{16}{23} \times 92 = \frac{1472}{23} = 64 \text{ g}$$

$$\text{Total mass} = 14 + 64 = 78 \text{ g} (= \bar{M}, \text{ consistent})$$

**Mass % of  $\text{NO}_2$ :**

$$\% \text{NO}_2 = \frac{14}{78} \times 100 = 17.95\%$$

**Mass of  $\text{NO}_2$  in 100 g mixture:**

$$= \frac{17.95}{100} \times 100 = \mathbf{17.9 \text{ g}}$$

### Approach / Analogy

Key insight:  $\text{N}_2\text{O}_4$  is exactly the dimer of  $\text{NO}_2$  ( $M_r = 92 = 2 \times 46$ ). The VD of 39 gives  $\bar{M} = 78$  — halfway between 46 and 92 suggests roughly equal mole fractions, but the exact answer requires the calculation above.

Step flow: VD  $\rightarrow$   $\bar{M}$   $\rightarrow$  mole fractions via weighted average  $\rightarrow$  convert to mass fractions  $\rightarrow$  mass in 100 g.

### Common Mistake

Directly using the mole fraction of  $\text{NO}_2$  ( $= 7/23 = 30.4\%$ ) as its mass fraction and multiplying by 100 g, giving 30.4 g. Mole fraction  $\neq$  mass fraction (unless all components have equal molar masses, which they don't here). Always convert mole fractions to mass fractions by computing actual masses in a sample of known total moles.

**Answer**

(1) 17.9 g

**— End of DPP-5 Complete Solution Sheet —**

Vapour Density · Q.1 to Q.9 · All Questions Complete

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