**SCH 3U**

# THE IDEAL GAS LAW & the STOICHIOMETRY of GASES

**AVOGADRO'S PRINCIPLE:**

*"When measured at the same temperature and pressure, equal volumes of gases contain equal numbers of moles."*

A corollary to Avogadro's principle is that *the volume of a gas is directly proportional to its number of moles, n.* That is, $V \; \alpha \; n$ for any gas.

**VOLUME RATIOS = MOLE RATIOS** in a balanced equation

| | | | | | |
|---|---|---|---|---|---|
| Given | $N_{2(g)}$ | + | $3H_{2(g)}$ | $\rightleftharpoons$ | $2NH_{3(g)}$ |
| # moles | 1 mol | | 3 mol | | 2 mol |
| Volumes | 1 vol | | 3 vol | | 2 vol |

**STANDARD MOLAR VOLUME of a gas = 22.4 L = 1 mol at STP**

- Volume occupied by one mole of any gas must be identical for all gases under the same STP conditions: (temperature of 273 K and pressure of 101.3 kPa).

The combined gas equation tells us that $\frac{PV}{T} = \text{a constant}$, and that it is directly proportional to the fixed mass (or number of moles) of gas. This can be made into an equation by introducing a constant, R, known as the ***universal gas constant***. This leads to the Ideal Gas Equation.

## IDEAL GAS LAW – Relationship for an Ideal Gas

$$\frac{PV}{T} \; \alpha \; n \quad \Rightarrow \quad \boxed{PV = nRT}$$

**where P = pressure in kPa**
**V = volume in L**
**n = # moles**
**R = universal gas constant = $8.314 \frac{kPa \cdot L}{mol \cdot K}$**
**T = temperature in K**

- ***Unit conversions*** must be carried out before using the formula with indicated value of R.

Use of the ideal gas equation enables us to calculate how systems respond to change in pressure, volume, and temperature, and to calculate molar mass. Gas density can also be derived by applying the relationship, $density = \frac{mass}{volume}$.

The guidelines below, based on the use of SI units only, should help you avoid some of the common mistakes that arise.

| VARIABLE | DESIRED UNITS | IF GIVEN... | THEN... |
|---|---|---|---|
| Pressure, P | **kPa** | Pa | divide by $10^3$ |
| | | atm | multiply by 101.3 |
| | | torr | multiply by $\frac{101.3}{760}$ |
| Volume, V | **L** | $dm^3$ | = L |
| | | $cm^3$ (or mL) | divide by $10^3$ |
| Moles, n | **mol** | mass | $n = \frac{m}{M}$ |
| Temperature, T | **K** | °C | add 273 |

**EXAMPLES:**

① What volume (in millilitres) does a sample of nitrogen with a mass of 0.245 g occupy at 21°C and 750 torr?

② A student collected a sample of a gas in a 0.220 L gas bulb until its pressure reached 0.757 atm at a temperature of 25.0°C. The sample weighed 0.299 g. What is the molecular mass of the gas?

③ The label on a cylinder of an inert gas became illegible, so to identify the gas a student transferred some of the gas into a 300 mL gas bulb until the pressure was 685 torr. The sample weighed 1.45 g; its temperature was 27.0°C. What is the molecular mass of this gas? Which of the Group 0 gases (inert gas) was it?

④ A gaseous compound of phosphorous and fluorine was found to have a density of 3.50 g $L^{-1}$ at a temperature of 25.0°C and a pressure of 740 torr. It was also found to consist of 35.2% P and 64.8% F. What is its empirical formula, its molecular mass, and its molecular formula?

⑤ A gaseous compound of phosphorous and fluorine with an empirical formula of $PF_2$ was found to have a density of 5.60 g·$L^{-1}$ at 23.0°C and 750 torr. Calculate its molecular mass and its molecular formula.

⑥ Propylene, $C_3H_6$, reacts with hydrogen under pressure to give propane, $C_3H_8$. A sample of 18.0 g of propylene requires how many litres of hydrogen when measured at 740 torr and 24°C?

⑦ In one lab, sodium carbonate was mixed with excess hydrochloric acid. The gas collecting apparatus used a gas bulb with a volume of 250 $cm^3$. How many grams of sodium carbonate would be needed to prepare enough carbon dioxide gas to fill this bulb when the pressure is 738 torr and the temperature is 23°C?

⑧ In the first step for one industrial preparation of nitric acid, ammonia reacts with oxygen at 650°C and 1 atm. The reaction produces nitrogen monoxide and water. What volume of oxygen is needed to react with 36.0 L of ammonia at 400°C and 6.00 atm?

⑨ Ammonia is converted to ammonium sulfate, an important fertilizer, by the reaction with sulfuric acid. In one batch, 214 kg of ammonium sulfate is to be made.

a) What volume of ammonia is needed when the volume is measured at 24°C and 100kPa.
b) How many moles of sulfuric acid are needed?
c) If the sulfuric acid is an 8.0 $mol \cdot dm^{-3}$ solution, what volume of this solution is needed?

⑩ A sample of an unknown gas with a mass of 1.620 g occupied a volume of 941 mL at a pressure of 748 torr and a temperature of 20.00°C. When it is decomposed into its elements, 1.389 g of carbon and 0.2314 g of hydrogen were obtained.

a) What is the percentage composition of the compound?
b) What is the empirical formula?
c) What is the molecular formula?

⑪ A 0.010 mol sample of the barium nitrate formed was heated until it had completely decomposed according to the following equation.

$$2Ba(NO_3)_2\,(s) \rightarrow 2BaO(s) + 4NO_2\,(g) + O_2\,(g)$$

Use the ideal gas equation to calculate the total volume, in $cm^3$, of gaseous products obtained at 387 K and $1.12 \times 10^5$ Pa.

⑫ Calculate the density of hydrogen gas at 25°C at 1 atm.

**ANSWERS:**

1. 214
2. 44.0
3. 132, Xe
4. $PF_3$
5. 138, $P_2F_4$
6. 10.7
7. 1.06
8. 370
9. 80000, 1619, 202.4
10. 85.74, 14.28; $CH_2$, $C_3H_6$
11. 720
12. $8.28 \times 10^{-2}$