Chemistry 20

Lesson 33 – Gas Stoichiometry

Gas volume stoichiometry is similar to gravimetric and solution stoichiometry in that quantities are converted to moles, the mole ratio is used, and the unknown is calculated. However, if we are dealing with gas volumes only, an interesting thing happens. In the electrolysis of water, for example, an electric current through the water results in decomposition.

$$2\,H_2O_{(l)} \xrightarrow{\text{electric current}} 2\,H_{2\,(g)} + O_{2\,(g)}$$

The volume of hydrogen gas produced is **twice** the volume of oxygen gas – just as the balanced equation predicts. Why? For gravimetric and solution stoichiometry there was no mass ratio or concentration ratio in the balanced equation. Why do gas volumes apparently obey the Law of Mole Ratios?

I. Gay-Lussac's Law of Combining Volumes

In 1808, Joseph Gay-Lussac measured the relative volumes of gases involved in chemical reactions and observed a simple law – the **law of combining volumes** states: **when measured at the same temperature and pressure, volumes of gaseous reactants and products of chemical reactions are always in simple ratios of whole numbers**. In other words, gas volumes combine according to a mole ratio. Historically speaking, the law of combining volumes was discovered first which eventually led to the mole ratio idea.

The reason that gas volumes combine according to a mole ratio is due to Avagadro's theory that **gases at the same temperature and pressure contain equal numbers of molecules or equal numbers of moles** (see pages 294 to 299 in the text).

$N_{2\,(g)}$	+	$3\,H_{2\,(g)}$	→	$2\,NH_{3\,(g)}$		
1.00 L		3.00 L		2.00 L		
$C_3H_{8\,(g)}$	+	$5\,O_{2\,(g)}$	→	$3\,CO_{2\,(g)}$	+	$4\,H_2O_{\,(g)}$
1.00 L		5.00 L		3.00 L		4.00 L
$2\,H_{2\,(g)}$	+	$O_{2\,(g)}$	→	$2\,H_2O_{\,(g)}$		
2.00 L		1.00 L		2.00 L		

Example 1

25 L (at **STP**) of methane gas is burned. Under the same conditions, what volume of water vapour is produced?

$$CH_{4(g)} + 2O_{2(g)} \longrightarrow CO_{2(g)} + 2H_2O_{(g)}$$

$$v_{CH_4} = 25\,L \qquad v_{H_2O} = ?$$

$$\frac{v_{CH_4}}{1} = \frac{v_{H_2O}}{2}$$

$$\frac{25\,L}{1} = \frac{v_{H_2O}}{2}$$

$$v_{H_2O} = \mathbf{50\,L}$$

Since the volume of water vapour is at the same conditions as the methane gas, we can use a volume ratio just as we would use a mole ratio.

Example 2

What volume of oxygen gas is required to react with 10.0 g of octane ($C_8H_{18(l)}$) at **SATP**?

$$2C_8H_{18(g)} + 25O_{2(g)} \longrightarrow 16CO_{2(g)} + 18H_2O_{(g)}$$

$$m_{C_8H_{18}} = 10.0\,g \quad v_{O_2} = ?$$

$$v_{O_2} = \frac{10.0\,g\,C_8H_{18}}{} \times \frac{1\,mol\,C_8H_{18}}{114.26\,g\,C_8H_{18}} \times \frac{25\,mol\,O_2}{2\,mol\,C_8H_{18}} \times \frac{24.8\,L}{1\,mol\,O_2}$$

$$v_{O_2} = \mathbf{27.1\,L}$$

II. Assignment

1. What volume of oxygen at SATP is needed to completely burn 15 g of methanol in a fondue burner?

2. Most combustion reactions use oxygen from the air. Since air is 20% oxygen, 250 L of air contains 50 L of oxygen. What mass of propane from a tank can be burned using 250 L of air at SATP?

3. Hydrogen gas is burned in pollution-free vehicles in which pure hydrogen and oxygen gases react to produce water vapour. What volume of hydrogen at 40^{o}C and 150 kPa can be burned using 300 L of oxygen measured at the same conditions?

4. A Down's Cell is used in the industrial production of sodium from the decomposition of molten sodium chloride. What volume of chlorine gas is produced (measured at SATP), along with 100 kg of sodium metal, from the decomposition of sodium chloride?

5. A typical Canadian home heated with natural gas consumes 2.00 ML of natural gas during the month of December. What volume of oxygen at SATP is required to burn 2.00 ML of methane measured at 0^{o}C and 120 kPa?

6. A convenient source of oxygen in the laboratory is the decomposition of aqueous hydrogen peroxide to produce oxygen and water. What volume of 0.88 mol/L hydrogen peroxide is required to produce 500 mL of oxygen gas at SATP?

7. Hydrogen gas is produced industrially from the reaction of methane with steam in the presence of a catalyst to produce hydrogen and carbon dioxide gases. What volume of hydrogen gas, measured at 25^{o}C and 120 kPa, can be produced from 1.0 t of steam?

8. Calculate the volumes of hydrogen and oxygen at STP that can be obtained by the electrolysis of 50 g of water.

9. What volume of oxygen is required to burn 10.0 L of acetylene gas (C_2H_2) at SATP?

10. What mass of magnesium is required to react with hydrochloric acid to produce 300 mL of hydrogen gas at 25^{o}C and 105 kPa?

11. What volume of oxygen is required to burn 11 L of hydrogen? What volume of water vapour will be formed?

12. 14 g of methane is burned and the carbon dioxide gas is trapped in a balloon at 20^{o}C and 105 kPa. If 19.6 L of carbon dioxide gas is recovered, what is the percent error?

13. In the Haber-Bosch process, hydrogen and nitrogen combine to form ammonia. If 19.5 g of hydrogen produces 140 L of ammonia at STP, what is the percent error?