Chapter 5 – Gases

Section 3 - Stoichiometry, Speed of Gases and Real Gases

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Introduction – Gas Stoichiometry

Just like we study stoichiometry in reactions with solids and solutions, we can also study the amounts of gaseous reactants and products by using the ideal gas law.

- The ideal gas law to relate moles to T, P and V.
- Moles can be related to mass by the molar mass.
- The coefficients in the balanced equation to relate moles of reactants and products.

Solved Problem: Gas Stoichiometry

When a 2.00 L bottle of concentrated HCl was spilled, 1.20 kg of $CaCO_3$ was required to neutralize the spill. What volume of CO_2 was released by the neutralization at 735 mmHg and 20.0 °C?

Step 1 First, write the balanced chemical equation.

$$CaCO_{3(s)} + 2HCl_{(aq)} \rightarrow CaCl_{2\,(aq)} + H_2O_{(l)} + CO_{2\,(g)}$$

Step 2 Molar mass of $CaCO_3$ = 100.09 g/mol

Step 3 Use stoichiometry to find mols of CO_2.

$$1.2 \times 10^3 \text{g } CaCO_3 \frac{1 \text{ mol } CaCO_3}{100.09 \text{ g } CaCO_3} \frac{1 \text{ mol } CO_2}{1 \text{ mol } CaCO_3} = 11.99 \text{ mol}$$

Step 4 Use gas law to find the volume of the gas.

n = 11.99 mol

P = 735 mmHg/760 = 0.967 atm

T = 20°C + 273 = 293 K

$$V = \frac{nRT}{P}$$

$$V = \frac{(11.99 \text{ mol})\left(0.08206 \frac{\text{L} \bullet \text{atm}}{\text{mol} \bullet \text{K}}\right)(293 \text{ K})}{(0.967 \text{ atm})}$$

$$= 2.98 \times 10^2 \text{ L}$$

Solved Problem: Gas Stoichiometry

Calculate the mass of $KClO_3$ decomposed when 325 mL of oxygen was produced at 22.0 ºC and a pressure of 733 torr. Calculate the number of moles of O_2 and the mass of $KClO_3$ decomposed.

$$2\ KClO_{3(s)} \rightarrow 2\ KCl_{(s)} + 3\ O_{2(g)}$$

Step 1 Find mols of O_2 using ideal gas law

P_{O_2} = 733 torr convert to atm = (733/760) atm = 0.964 atm

V = 325 mL = 0.325 L

T = 22ºC + 273 = 295 K

$$n = \frac{PV}{RT}$$

$$n_{O_2} = \frac{(0.964\ \text{atm})(0.325\ \text{L})}{\left(0.08206\ \frac{\text{L}\cdot\text{atm}}{\text{mol}\cdot\text{K}}\right)(295\ \text{K})} = 1.29\times10^{-2}\ \text{mol } O_2$$

Step 2 Use stoichiometry to find grams of $KClO_3$.

Molar mass of $KClO_3$ = 122.6 g/mol

$$1.29\times10^{-2}\ \text{mol } O_2 \left(\frac{2\ \text{mol } KClO_3}{3\ \text{mol } O_2}\right)\left(\frac{122.6\ \text{g } KClO_3}{1\ \text{mol } KClO_3}\right) = 1.06\ \text{g } KClO_3$$

Solved Problem: Gas Stoichiometry with volumes

How many liters of CO_2 gas can be produced in the reaction of 5.24 L CO and 2.65 L O_2 gas if all gases are measured at the same temperature and pressure?

Step 1 | First, write the balanced chemical equation.

$$2CO(g) + O_2(g) \rightarrow 2CO_2(g)$$

Step 2 | Determine limiting reagent since both starting volumes are given.

$$n = \frac{PV}{RT}$$

T and P are constant, and R is the same in ideal gas law so, number of moles = volume of gas.

Now we can use mol ratio to determine limiting reagent.

$$5.24 \text{ L CO x } \frac{2 \text{ L } CO_2}{2 \text{ L CO}} = 5.24 \text{ L } CO_2$$

$$2.65 \text{ L O x } \frac{2 \text{ L } CO_2}{1 \text{ L } O_2} = 5.30 \text{ L } CO_2$$

Limiting reagent is CO, so volume of CO_2 gas is 5.24 L.

Solved Problem: Gas Stoichiometry

A 100 g sample of aqueous hydrogen peroxide solution decomposes over time, producing 3.31 L of O_2 at 21.0 °C and 715 mmHg. What was the mass percent of H_2O_2 in the solution?

$$2\ H_2O_{2(aq)} \rightarrow 2\ H_2O_{(l)} + O_{2\ (g)}$$

P = 715 mmHg/760 = 0.941 atm

T = 21°C + 273 = 294 K

V = 3.31 L O_2

Equation: $2\ H_2O_{2(aq)} \rightarrow 2\ H_2O_{(l)} + O_{2\ (g)}$

mass percent? 3.31 L

Strategy: Mol O_2 -> mol H_2O_2 -> g H_2O_2

Step 1 — Find mols of O_2 using ideal gas law

$$n = \frac{PV}{RT}$$

$$n_{O_2} = \frac{(0.941\ \text{atm})(3.31\ \text{L})}{\left(0.08206\ \frac{\text{L·atm}}{\text{mol·K}}\right)(294\ \text{K})} = 0.129\ \text{mol}\ O_2$$

Step 2 — Use stoichiometry to find grams of H_2O_2.

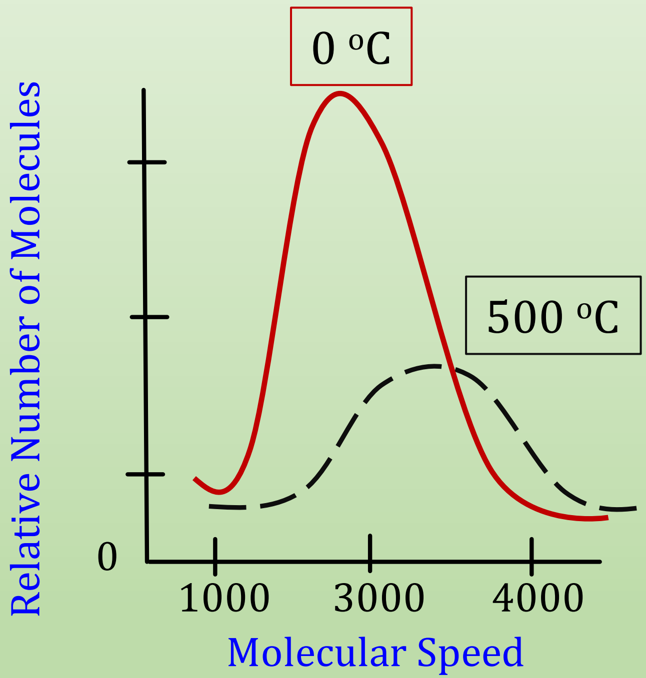
$$0.129\ \text{mol}\ O_2 \left(\frac{2\ \text{mol}\ H_2O_2}{1\ \text{mol}\ O_2}\right)\left(\frac{34.02\ \text{g}\ H_2O_2}{1\ \text{mol}\ H_2O_2}\right) = 8.78\ \text{g}\ H_2O_2$$

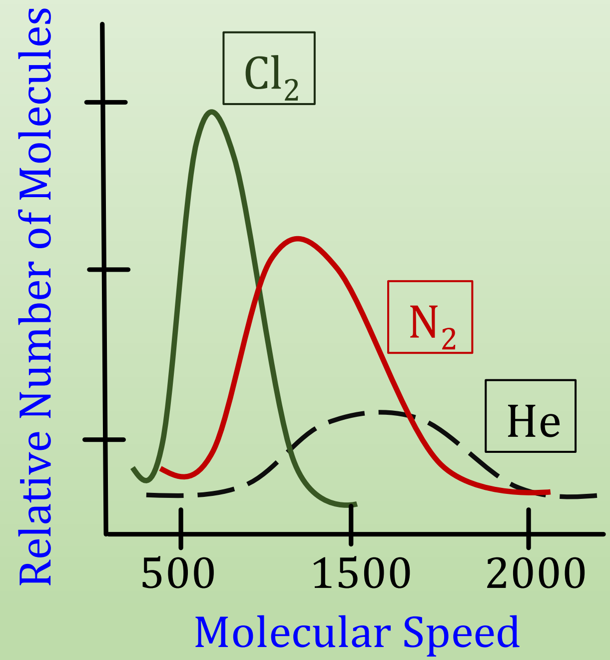
Step 2 — Find mass percent of H_2O_2.

$$\frac{8.78\ g}{100\ g}\ x\ 100\% = 8.78\ \%\ H_2O_2$$

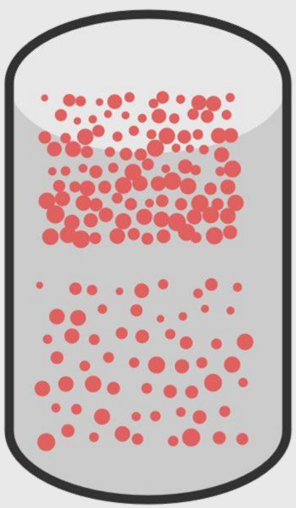
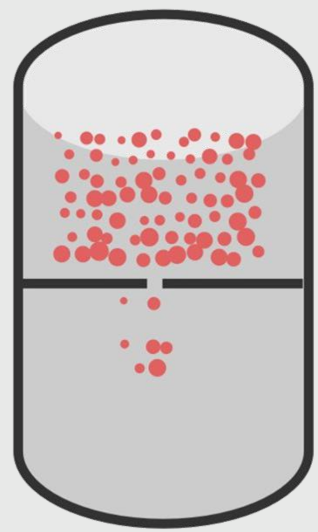
Speed of Gas

- Effect of Temperature on Molecular Speed (1st graph) – speed of gas is directly proportional to temperature.
- Effect of Molar Mass on Molecular Speed (2nd graph) – speed of gas is inversely proportional to molecular/atomic weight.





Diffusion and Effusion

Diffusion	Effusion
The process whereby a gas spreads out through another gas to occupy the space uniformly. Example would be gases from the atmosphere interacting with ocean. Below molecules diffuses through air.	The process by which a gas flows through a small hole in a container. An example would be a pinprick in a container.
	

Real Gases

At high pressure the relationship between pressure and volume does not follow Boyle's law.

At high pressure, some assumptions of the kinetic theory no longer hold true. At high pressure:

1. the volume of the gas molecule is **not** negligible.
2. the intermolecular forces are **not** negligible.

The term V becomes $(V - nb)$ to account for the space between molecules.

The term P becomes $(P + n^2a/V^2)$ to account for attraction/repulsion between molecules.

Values for a and b are different for different gases and can be found in data tables.

Van der Waal rewrote the he ideal gas equation to accommodate these deviations.

PV = nRT becomes $\left(P + \frac{an^2}{V^2}\right)(V - nb) = RT$

Key Points

- Gas stoichiometry
- Gas mixtures
    - Molecular speed
    - Diffusion and effusion
- Deviation from ideal behavior
    - Factors causing deviation