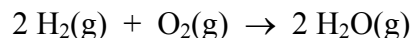# Gas Laws II
Gases in Reaction Stoichiometry

1. What volume of water vapor (measured at 755 mm Hg and 200.0°C) will be produced by the reaction of 32.0 g of oxygen gas with plenty of hydrogen gas?

$$2\ H_2(g)\ +\ O_2(g)\ \rightarrow\ 2\ H_2O(g)$$

$$n_{H_2O} = 32.0\ g\ O_2 \times \tfrac{1\ mol\ O_2}{32.00\ g\ O_2} \times \tfrac{2\ mol\ H_2O}{1\ mol\ O_2} = 2.00\ mol\ H_2O$$

$$P_{H_2O} = \frac{755\ mm\ Hg}{760\ \tfrac{mm\ Hg}{atm}} = 0.9934\ atm$$

$$T = 200.0°C + 273.2\ K = 473.2\ K$$

$$\frac{PV}{nT} = R \quad so.... \quad V = \frac{nRT}{P} = \frac{(2.00\ mol)(0.08206\ \tfrac{L \cdot atm}{mol \cdot K})(473.2\ K)}{0.9934\ atm} = 78.2\ L$$

2. What volume of oxygen gas, measured at 25.0°C and 1.00 atm would be formed by the complete decomposition of 2.00 g of $KClO_3$ (122.55 g/mol) at 250.0°C? (The products of the decomposition reaction are potassium chloride and oxygen gas.)

$$2\ KClO_3(s)\ \xrightarrow{\Delta}\ 2\ KCl(s)\ +\ 3\ O_2(g)$$
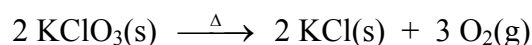
$$n_{KClO_3} = \frac{2.00\ g}{122.55\ \tfrac{g}{mol}} = 0.01632\ mol\ KClO_3$$

$$n_{O_2} = 0.01632\ mol\ KClO_3 \times \tfrac{3\ mol\ O_2}{2\ mol\ KClO_3} = 0.02448\ mol\ O_2$$

$$T = 25.0°C + 273.2\ K = 298.2\ K$$

$$V = \frac{nRT}{P} = \frac{(0.02448\ mol)(0.08206\ \tfrac{L \cdot atm}{mol \cdot K})(298.2\ K)}{1.00\ atm} = 0.599\ L$$

3. 3.0 L of nitrogen gas are reacted at 250.0°C and 1.5 atm with excess hydrogen gas to form ammonia. What will be the volume of ammonia present when collected and measured at STP assuming the reaction has a 100% yield?

$$N_2(g) + 3 H_2(g) \rightarrow 2 NH_3(g)$$
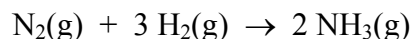
$V_{N_2} = 3.0 \text{ L}$ $\qquad\qquad\qquad\qquad$ $V_{NH_3} = ?$

$T_{N_2} = 250.0°C + 273.2 \text{ K} = 523.2 \text{ K}$ $\qquad$ $T_{NH_3} = 273.2 \text{ K}$

$P_{N_2} = 1.5 \text{ atm}$ $\qquad\qquad\qquad\qquad$ $P_{NH_3} = 1.00 \text{ atm}$

There are at least two ways to handle this problem:

1) $n_{N_2} \rightarrow n_{NH_3} \rightarrow V_{NH_3}$ or use the Avogadro's law:

2) $V_{N_2} \rightarrow V_{NH_3} \rightarrow V_{at STP}$ for this problem, we'll use Avogadro's Law

$$V_{NH_3} = 3.0 \text{ L N}_2 \times \frac{2 \text{ L NH}_3}{1 \text{ L N}_2} = 6.0 \text{ L NH}_3 \text{ (at 1.5 atm, 523.2 K)}$$

$$V_{STP} = \frac{P_1 V_1 T_{STP}}{P_{STP} T_1} = \frac{(1.5 \text{ atm})(6.0 \text{ L})(273.2 \text{ K})}{(1.00 \text{ atm})(523.2 \text{ K})} = 4.7 \text{ L}$$

4. Assume for the moment that when green plants inspire CO_2 gas during photosynthesis they produce only glucose for energy storage. Also assume that the photosynthetic reaction by the plant is

$$6 CO_2(g) + 6 H_2O(g) \rightarrow C_6H_{12}O_6(s) + 6 O_2(g)$$
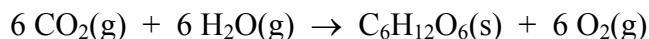
If over a period of time the glucose content of a plant increases by 425 g, what volume of CO_2 was removed from the air? All measurements were made at 22.0°C and 751.5 torr.

$$m_{glucose} = 425 \text{ g}$$

$$n_{glucose} = \frac{425 \text{ g}}{180.2 \frac{\text{g}}{\text{mol}}} = 2.359 \text{ mol C}_6\text{H}_{12}\text{O}_6$$

$$n_{CO_2} = 2.359 \text{ mol C}_6\text{H}_{12}\text{O}_6 \times \frac{6 \text{ mol CO}_2}{1 \text{ mol C}_6\text{H}_{12}\text{O}_6} = 14.15 \text{ mol CO}_2$$

$$T = 22.0°C + 273.2 \text{ K} = 295.2 \text{ K}$$

$$P = \frac{751.5 \text{ torr}}{760 \frac{\text{torr}}{\text{atm}}} = 0.9888 \text{ atm}$$

$$V = \frac{nRT}{P} = \frac{(14.15 \text{ atm})(0.08206 \frac{\text{L·atm}}{\text{mol·K}})(295.2 \text{ K})}{0.9888 \text{ atm}} = 347 \text{ L}$$

Gas Law II
Gases in Reaction Stoichiometry
Additional Problems

1. The amount of NO_2 on a very smoggy day in Houston, TX was measured to be 0.78 ppm (by mass). The barometric pressure was 1011 mbar. Calculate the partial pressure of the NO_2.

   (This problem is a little tougher since you have to calculate the molar mass of air (which also means you have to look up the composition of standard air.)

$$C_{NO_2} = \frac{0.78 \text{ g NO}_2}{10^6 \text{ g air}}$$

$$M_{air} = 0.7808 \tfrac{\text{mol N}_2}{\text{mol air}}\left(28.0134 \tfrac{\text{g}}{\text{mol}}\right) + 0.2095 \tfrac{\text{mol O}_2}{\text{mol air}}\left(32.00 \tfrac{\text{g}}{\text{mol}}\right) +$$

$$+ 0.00033 \tfrac{\text{mol CO}_2}{\text{mol air}}\left(44.01 \tfrac{\text{g}}{\text{mol}}\right) + 0.00934 \tfrac{\text{mol Ar}}{\text{mol air}}\left(39.948 \tfrac{\text{g}}{\text{mol}}\right)$$

$$= 28.965 \tfrac{\text{g}}{\text{mol}}$$

$$M_{NO_2} = 46.007 \tfrac{\text{g}}{\text{mol}}$$

$$X_{NO_2} = \frac{0.78 \text{ g NO}_2}{10^6 \text{ g air}} \times 28.965 \tfrac{\text{g air}}{\text{mol air}} \times \frac{1 \text{ mol NO}_2}{46.007 \text{ g NO}_2} = 4.91 \times 10^{-7} \tfrac{\text{mol NO}_2}{\text{mol air}}$$

$$P_{NO_2} = 4.91 \times 10^{-7} \tfrac{\text{mol NO}_2}{\text{mol air}} \times 1011 \text{ mbar} = 5.0 \times 10^{-4} \text{ mbar NO}_2$$

2. To minimize the possibility of loud and possibly dangerous "backfire", welders using large oxygen-acetylene cutting torches must be careful to prevent the ratio of acetylene (C_2H_2) to oxygen from becoming perfectly stoichiometric. What is the ratio of the pressures of acetylene and oxygen when they are stoichiometrically mixed?

$$2 \text{ C}_2\text{H}_2(g) + 5 \text{ O}_2(g) \rightarrow 4 \text{ CO}_2 + 2 \text{ H}_2\text{O}(g)$$
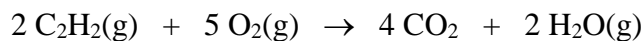
$$f = \frac{5 \text{ atm O}_2}{2 \text{ atm C}_2\text{H}_2}$$

3. Sodium metal reacts with molecular chlorine gas to produce sodium chloride (and a great deal of energy). A closed glass container, fitted with a pressure gauge, has a volume of 3000 mL (±10 mL) and contains chlorine gas at 24.0°C and 1255 torr. On the bottom of the reaction vessel is a 6.90 g lump of sodium metal. The sodium is heated briefly to start the reaction, which continues to completion with no further intervention by the experimenter. The reaction vessel rises in temperature to 47.0°C. Predict the final pressure of the chlorine gas?

$$2\ Na(l)\ +\ Cl_2(g)\ \rightarrow\ 2\ NaCl(s)$$
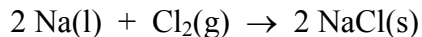
$$V = 3.00\ L$$

$$T_{initial} = 24.0°C + 273.2\ K = 297.2\ K$$

$$P_{Cl_2,\ initial} = {1255\ torr} \Big/ {760\ \frac{torr}{atm}} = 1.651\ atm$$

$$m_{Na} = 6.90\ g$$

$$n_{Na} = 6.90\ g \times \frac{1 mol\ Na}{22.99\ g\ Na} = 0.3001\ mol\ Na$$

$$T_{final} = 47.0°C + 273.2\ K = 320.2\ K$$

$$n_{Cl_2,\ initial} = \frac{PV}{RT} = \frac{(1.651\ atm)(3.00\ L)}{(0.08206\ \frac{L \cdot atm}{mol \cdot K})(297.2\ K)} = 0.2031\ mol\ Cl_2$$

$$n_{Cl_2,\ used} = 0.3001\ mol\ Na \times \frac{1\ mol\ Cl_2}{2\ mol\ Na} = 0.1501\ mol\ Cl_2$$

$$n_{Cl_2,\ remaining} = 0.2031\ mol - 0.1501\ mol = 0.0530\ mol\ Cl_2$$

$$P_{Cl_2} = \frac{nRT}{V} = \frac{(0.0530\ mol)(0.08206\ \frac{L \cdot atm}{mol \cdot K})(320.2\ K)}{3.00\ L} = 0.464\ atm$$

$$P_{Cl_2} = 0.464\ atm \times \frac{1013.25\ mbar}{1\ atm} = 470\ mbar$$