CHEM 103
R&R 17
24 June 2024
Adapted from a 23 June 2020 document

1. A particular balloon is designed by its manufacturer to be inflated to a volume of no more than 2.50 L. A balloon enthusiast fills the balloon with 2.00 L helium at sea level; she plans to have the balloon rise to an altitude at which atmospheric pressure is only 500. mm Hg. Will the balloon burst before reaching that altitude?

@ sea level: $P_1V_1 = P_2V_2$ @ altitude

$$(760.\ \text{mm Hg})(2.00\ \text{L}) = (500.\ \text{mm Hg})V_2$$

$V_2 = 3.04$ L $\Rightarrow$ balloon will burst ☹

2. A mixture of NH_3 (g) and N_2H_4 (g) is placed in a sealed container at 300 K. The total pressure is 0.50 atm. The container is heated to 1200 K, at which time both substances decompose completely according to the following unbalanced equations:

$$2\,NH_3\ (g) \rightarrow N_2\ (g) + 3\,H_2\ (g)$$
$$N_2H_4\ (g) \rightarrow N_2\ (g) + 2\,H_2\ (g)$$

After decomposition is complete, the total pressure at 1200 K is found to be 4.5 atm. Find the mole percent of N_2H_4 (g) in the original mixtures. Assume two significant figures for the temperature.

Let x = [# atm NH_3 @ 300 K], y = [# atm N_2H_4 @ 300 K]

$x + y = 0.50$. From Gay-Lussac's Law, pressures @ 1200 K are 4x pressures at 300 K.

However, we must account for the decomposition.

2 atm NH_3 yields 4 atm total N_2, H_2

1 atm N_2H_4 yields 3 atm total N_2, H_2.

$$4(2x + 3y) = 4.5 \Rightarrow 8x + 12y = 4.5 \Rightarrow 8(x+y) + 4y = 4.5$$

$$\Rightarrow 4 + 4y = 4.5 \Rightarrow y = \tfrac{1}{4}\,0.50;\ x = \tfrac{3}{4}\,0.50$$

N_2H_4 is 25% of mixture by moles

3. 5.00 g solid calcium carbonate reacts with 100.0 mL of 0.200 M hydrochloric acid, represented by the following unbalanced equation:

$$CaCO_3 + \overset{2}{}HCl \rightarrow CaCl_2 + H_2O + CO_2$$

What volume of carbon dioxide gas is produced at a pressure of 750.0 mm Hg and a temperature of 22.0 °C?

$$5.00\,g\ CaCO_3 \cdot \frac{mol}{100.09\,g} = 0.0500\ mol\ CaCO_3\,;\quad (100.0\,mL)(0.200\,M\,HCl) = \underbrace{0.0200\ mol\ HCl}_{\text{limiting reactant}}$$

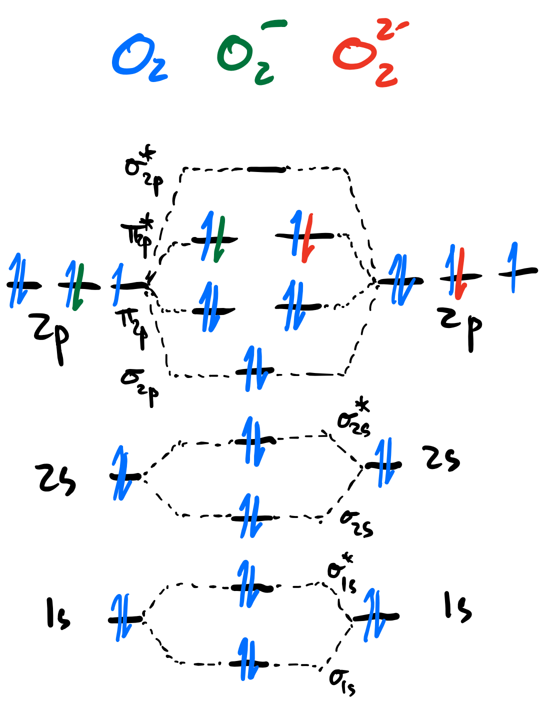
$$PV = nRT \Rightarrow V = \frac{1}{P}nRT$$

$$V = \frac{1}{750.0\,mm\,Hg} \cdot \frac{760.0\,mm\,Hg}{1\,atm} \cdot \left(0.0200\,mol\,HCl \cdot \frac{mol\ CO_2}{2\,mol\,HCl}\right) \cdot \frac{0.08206\,atm \cdot L}{mol \cdot K} \cdot 295.15\,K$$

$$= 0.245\ L$$

4. Using the molecular orbital model, describe the bonding, magnetism, and relative bond orders of the following species:

O_2, O_2^-, O_2^{2-}



The electrons present in O_2 are shown in blue. The additional electron for O_2^- is shown in green. The additional electron for O_2^{2-} is shown in red.

species	magnetism	bond order
O_2	para	$\frac{1}{2}(10-6) = 2$
O_2^-	para	$\frac{1}{2}(10-7) = 1.5$
O_2^{2-}	dia	$\frac{1}{2}(10-8) = 1$

5. A quantity of N_2 gas originally held at 5.25 atm in a 1.00-L container at 26 °C is transferred to a 12.5-L container at 20 °C. A quantity of O_2 gas originally at 5.25 atm and 26 °C in a 5.00-L container is transferred to this same container. What is the total pressure in the new container?

Considering N_2: $\frac{P_1 V_1}{T_1} = \frac{P_2 V_2}{T_2} \Rightarrow P_2 = P_1 \cdot \frac{V_1}{V_2} \cdot \frac{T_2}{T_1}$

$$P_2 = (5.25\text{ atm}) \cdot \frac{1.00\text{ L}}{12.5\text{ L}} \cdot \frac{293.15\text{ K}}{299.15\text{ K}} = 0.41\underline{1}5\text{ atm.}$$

We could plug-and-chug for O_2, but notice that the O_2 is held at the same conditions in a five-times-larger container. Therefore, there is 5 times as much O_2 as N_2.

$$P_{total} = 6(0.41\underline{1}5\text{ atm}) = 2.47\text{ atm}$$

6. A sample of 6.3 mg of a boron hydride is contained in a 385-mL flask at 25.0 °C and a pressure of 11 torr.

a. Determine the molar mass of the boron hydride. (1 atm = 760 torr)

$$n = \frac{PV}{RT} = (11\text{ torr})\left(\frac{1\text{ atm}}{760\text{ torr}}\right)(0.385\text{ L}) \cdot \frac{1}{298.15\text{ K}} \cdot \frac{\text{mol} \cdot \text{K}}{0.08206\text{ atm} \cdot \text{L}}$$

$$= 0.00022\underline{7}7\text{ mol}$$

$$\text{molar mass} = \frac{6.3 \times 10^{-3}\text{ g}}{0.00022\underline{7}7\text{ mol}} = 27.7\ \frac{\text{g}}{\text{mol}}$$

b. Which of the following boron hydrides is contained in the flask: BH_3, B_2H_6, or B_4H_{10}?

7. You may recall a discussion of gypsum, $CaSO_4 \cdot 2\ H_2O$, from R&R Worksheet 2. Back then, we calculated how much mass is lost as water vapor when gypsum is heated. We now have the tools to determine the volume or pressure of that water vapor!

Suppose I place 275 g of gypsum into a vacuum-sealed, highly reinforced 5.00-L container containing 1.00 atm of N_2 gas at 20.0 °C. I heat the gypsum until it is transformed into fully anhydrous calcium sulfate. I then heat my container to 727.0 °C.

The density of gypsum is 2.32 g cm^{-3}. The density of $CaSO_4$ is 2.97 g cm^{-3}.

a. After I place the gypsum into the container, but before I first heat the container, what is the pressure of the N_2 gas in the container?

The gypsum has a volume of $118.5\ cm^3 = 0.1185\ L$.

$$P_2 = P_1 \cdot \frac{V_1}{V_2} = (1.00\ atm) \cdot \frac{5.00L}{4.8815\ L} = 1.0\underline{2}4\ atm$$

b. How many moles of H_2O are given off by heating the gypsum?

$$275\ g\ gypsum \cdot \frac{mol\ gypsum}{172.19\ g\ gypsum} \cdot \frac{2\ mol\ H_2O}{mol\ gypsum} = 3.1\underline{9}4\ mol\ H_2O$$

c. What is the final pressure of gas within my container?

Final volume of container: $V_2 = 5.00L - (\text{volume } CaSO_4)$.

$$275g\ gypsum \cdot \frac{mol\ gypsum}{172.19\ g\ gypsum} \cdot \frac{mol\ CaSO_4}{mol\ gypsum} \cdot \frac{136.15\ g\ CaSO_4}{mol\ CaSO_4} \cdot \frac{cm^3}{2.97g\ CaSO_4} = 73.2\ cm^3$$

$$V_2 = 5.00L - 0.0732\ L = 4.9\underline{2}7\ L$$

Tracking the N_2: $P_2 = P_1 \cdot \frac{V_1}{V_2} \cdot \frac{T_2}{T_1} = (1.00\ atm) \cdot \frac{5.00L}{4.927\ L} \cdot \frac{1000.15\ K}{293.15\ K} = 3.4\underline{6}2\ atm$

Tracking the H_2O:

$$P = \frac{1}{V} nRT = \frac{1}{4.927\ L}(3.1\underline{9}4\ mol\ H_2O) \cdot \frac{0.08206\ atm \cdot L}{mol \cdot K} \cdot 1000.15K = 53.\underline{2}04\ atm$$

$$\boxed{P_{total} = 56.7\ atm}$$