

Chapter 10 — Gas Laws

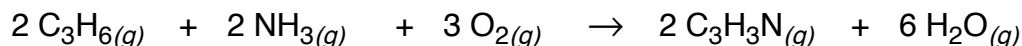
Lecture Examples Answer Key

- Ex 1** Some nitrogen gas is in a 2.00-L tank at a pressure of 3.00 atm. The tank is connected to a 5.00-L tank that is completely empty (evacuated), and a valve connects the two tanks. If the valve is opened, determine the total pressure in this two-tank system after the nitrogen stops flowing. No temperature change occurs in the process.

$$P_1V_1 = P_2V_2$$

$$P_2 = P_1V_1/V_2 = (3.00 \text{ atm})(2.00 \text{ L})/(7.00 \text{ L}) = 0.857 \text{ atm}$$

- Ex 2** A certain mass of C_3H_6 reacts completely with an excess of ammonia and oxygen to give 38.2 L of C_3H_3N at 75°C and $P = 1 \text{ atm}$. If the same mass of C_3H_6 reacts completely at 350°C and $P = 1 \text{ atm}$, what volume of C_3H_3N can be collected at the higher temperature?



$$V_1/T_1 = V_2/T_2$$

$$V_2 = V_1T_2/T_1 = (38.2 \text{ L})(623\text{K})/(348\text{K}) = 68.4 \text{ L}$$

- Ex 3** A gas is in a container with a movable piston under a pressure of 6.4 atm. The volume of the container is increased by a factor of 4.5 by moving the piston. The absolute temperature is simultaneously doubled. Calculate the pressure of the gas after these changes.

$$P_1 = 6.4 \text{ atm}$$

$$P_2 = ??$$

$$V_1$$

$$V_2 = 4.5 V_1$$

$$T_1$$

$$T_2 = 2 T_1$$

$$P_2 = P_1V_1T_2/V_2T_1 = (6.4 \text{ atm})V_1(2T_1)/(4.5V_1)T_1 = 2.8 \text{ atm}$$

- Ex 4** At what temperature (in K) does 29.8 g of O_2 gas have a pressure of 2.00 atm in a 10.0-liter tank?

$$n = (29.8 \text{ g})(1 \text{ mol} / 31.9988 \text{ g}) = 0.9313 \text{ mol}$$

$$T = PV/nR = (2.00 \text{ atm})(10.0 \text{ L}) / (0.9313 \text{ mol})(0.08206 \text{ L}\cdot\text{atm/mol}\cdot\text{K}) = 262\text{K}$$

- Ex 5** Calculate the density of gaseous SF_6 at a temperature of 27°C and a pressure of 0.873 atm.

$$PV=nRT$$

$$\text{density} = d = m/V$$

$$n/V = P/RT$$

$$m/V = P \mathcal{M} / RT = (0.873 \text{ atm})(146.0564 \text{ g/mol}) / (0.08206 \text{ L}\cdot\text{atm/mol}\cdot\text{K})(300\text{K}) = 5.18 \text{ g / L}$$

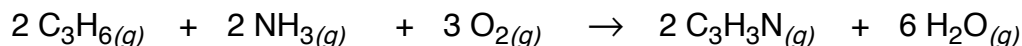
Ex 6 The empirical formula of a gaseous fluorocarbon is CF_2 . If 1.55 g of this compound occupies 0.174 L at STP determine the molecular formula of this compound.

$$\mathcal{M} = (m/V)RT/P = (1.55 \text{ g}/0.174 \text{ L})(0.08206 \text{ L}\cdot\text{atm/mol}\cdot\text{K})(273\text{K}) / (1 \text{ atm}) \\ = 199.56 \text{ g / mol}$$

$$\mathcal{M}_{\text{CF}_2} = 50.0078 \text{ g / mol} \\ 199.56 / 50.0078 = 4$$

$$\text{Molecular formula} = \text{C}_4\text{F}_8$$

Ex 7 An important process for the production of acrylonitrile ($\text{C}_3\text{H}_3\text{N}$) is given by the following reaction:



A 150.0-L reactor is charged to the following partial pressures at 25°C:

$$P_{\text{C}_3\text{H}_6} = 4.93 \text{ atm}, P_{\text{NH}_3} = 7.90 \text{ atm}, P_{\text{O}_2} = 14.8 \text{ atm}$$

What mass of acrylonitrile can be produced from this mixture?

$$n_{\text{C}_3\text{H}_6} = (4.93 \text{ atm})(150.0 \text{ L})/R(298\text{K}) = 30.24 \text{ mol C}_3\text{H}_6$$

$$n_{\text{acrylonitrile}} = (30.24 \text{ mol C}_3\text{H}_6)(2 \text{ mol acrylonitrile} / 2 \text{ mol C}_3\text{H}_6) = 30.24 \text{ mol}$$

$$n_{\text{NH}_3} = (7.90 \text{ atm})(150.0\text{L})/R(298\text{K}) = 48.46 \text{ mol NH}_3$$

$$n_{\text{acrylonitrile}} = (48.46 \text{ mol NH}_3)(2 \text{ mol acrylonitrile} / 2 \text{ mol NH}_3) = 48.46 \text{ mol}$$

$$n_{\text{O}_2} = (14.8 \text{ atm})(150.0 \text{ L})/R(298\text{K}) = 90.78 \text{ mol O}_2$$

$$n_{\text{acrylonitrile}} = (90.78 \text{ mol O}_2)(2 \text{ mol acrylonitrile} / 3 \text{ mol O}_2) = 60.52 \text{ mol}$$

C_3H_6 is the limiting reactant

$$\text{mass acrylonitrile} = (30.24 \text{ mol})(42.0804 \text{ g / 1 mol}) = 1.27 \text{ kg}$$

Ex 8 A 0.326-g sample of XH_2 reacts with water according to the equation



The hydrogen evolved is found to have a volume when dry of 375 cm³ at 21°C and 1.00 atm. What is the atomic mass of X?

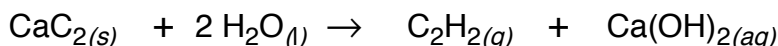
$$n_{\text{H}_2} = (1.00 \text{ atm})(0.375 \text{ L})/R(294\text{K}) = 0.01554 \text{ mol}$$

$$n_{\text{XH}_2} = (0.01554 \text{ mol H}_2)(1 \text{ mol XH}_2 / 2 \text{ mol H}_2) = 0.00777 \text{ mol XH}_2$$

$$\text{molar mass XH}_2 = 0.326 \text{ g} / 0.00777 \text{ mol} = 41.96 \text{ g / mol}$$

$$\text{molar mass of X} = 41.96 \text{ g / mol} - 2(1.0079 \text{ g / mol}) = 39.94 \text{ g / mol}$$

Ex 9 Acetylene (C₂H₂) can be made by allowing calcium carbide to react with water.



You place 2.65 g of CaC₂ in excess water and collect the acetylene over water.

(a) Calculate the theoretical yield of acetylene (in grams).

$$\text{mol CaC}_2 = (2.65 \text{ g})(1 \text{ mol} / 64.10 \text{ g}) = 0.04134 \text{ mol CaC}_2$$

$$\text{mol C}_2\text{H}_2 = (0.04134 \text{ mol})(1 \text{ mol C}_2\text{H}_2 / 1 \text{ mol CaC}_2) = 0.04134 \text{ mol C}_2\text{H}_2$$

$$\text{mass C}_2\text{H}_2 = (0.04134 \text{ mol})(26.0378 \text{ g} / 1 \text{ mol}) = 1.08 \text{ g} \quad \text{Theoretical yield}$$

(b) After reaction, the volume of the acetylene and water vapor is 795 mL at 25.0°C and a pressure of 0.967 atm. Calculate the percent yield of acetylene. The vapor pressure of water at 25.0°C is 0.0313 atm.

$$P_{\text{C}_2\text{H}_2} = 0.967 \text{ atm} - 0.0313 \text{ atm} = 0.9357 \text{ atm}$$

$$n_{\text{C}_2\text{H}_2} = PV/RT = (0.9357 \text{ atm})(0.795 \text{ L})/R(298\text{K}) = 0.03042 \text{ mol}$$

$$m = (0.03042 \text{ mol})(26.0378 \text{ g} / 1 \text{ mol}) = 0.792 \text{ g} \quad \text{Actual yield}$$

$$\% \text{ yield} = (0.792 \text{ g} / 1.08 \text{ g}) \times 100\% = 73.3\%$$

Ex 10 The partial pressure of O_{2(g)} in a mixture of O_{2(g)} and H_{2(g)} is 2.54 atm. The total pressure of the mixture is 3.92 atm. Determine the partial pressure of H_{2(g)}, and the mole fraction of each gas in the mixture.

$$P_{\text{H}_2} = 3.92 \text{ atm} - 2.54 \text{ atm} = 1.38 \text{ atm}$$

$$X_{\text{H}_2} = P_{\text{H}_2} / P_{\text{tot}} = 1.38 \text{ atm} / 3.92 \text{ atm} = 0.352$$

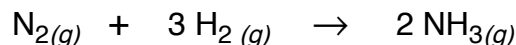
$$X_{\text{O}_2} = P_{\text{O}_2} / P_{\text{tot}} = 2.54 \text{ atm} / 3.92 \text{ atm} = 0.648$$

Ex 11 A gas mixture at room temperature contains 4.3 mol of H₂ and 8.2 mol of N₂.

(a) Compute the mole fraction of N₂ in the mixture.

$$X_{N_2} = n_{N_2} / n_{\text{tot}} = 8.2 \text{ mol} / (4.3 \text{ mol} + 8.2 \text{ mol}) = 0.66$$

(b) The mixture is then heated, and the N₂ starts to react with the H₂ to give NH₃:



The reaction is stopped when 2.8 mol of NH₃ is present. Determine the mole fraction of N₂ in this new mixture.

$$\text{mol } N_2 \text{ used} = (2.8 \text{ mol } NH_3)(1 \text{ mol } N_2 / 2 \text{ mol } NH_3) = 1.4 \text{ mol } N_2 \text{ used}$$

$$\text{mol } N_2 \text{ left over} = 8.2 \text{ mol} - 1.4 \text{ mol} = 6.8 \text{ mol } N_2 \text{ left}$$

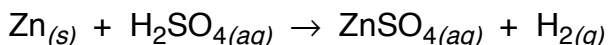
$$\text{mol } H_2 \text{ used} = (2.8 \text{ mol } NH_3)(3 \text{ mol } H_2 / 2 \text{ mol } NH_3) = 4.2 \text{ mol } H_2 \text{ used}$$

$$\text{mol } H_2 \text{ left over} = 4.3 \text{ mol} - 4.2 \text{ mol} = 0.1 \text{ mol } H_2 \text{ left}$$

$$\text{Total mol of gas} = 2.8 \text{ mol} + 6.8 \text{ mol} + 0.1 \text{ mol} = 9.7 \text{ mol}$$

$$X_{N_2} = n_{N_2} / n_{\text{tot}} = 6.8 \text{ mol} / 9.7 \text{ mol} = 0.70$$

Ex 12 Hydrogen gas is produced when zinc reacts with sulfuric acid:



If 159 mL of wet H₂ is collected over water at 24°C and a barometric pressure of 738 torr, how many grams of Zn have been consumed?

$$(P_{H_2O, 24^\circ C}) = 22.38 \text{ torr.}$$

$$P_{H_2} = 738 \text{ torr} - 22.38 \text{ torr} = 715.62 \text{ torr} = 0.942 \text{ atm}$$

$$n_{H_2} = PV/RT = (0.942 \text{ atm})(0.159 \text{ L})/R(297K) = 0.006146 \text{ mol } H_2$$

$$\text{mass Zn} = (0.006146 \text{ mol } H_2)(1 \text{ mol Zn} / 1 \text{ mol } H_2)(65.39 \text{ g} / 1 \text{ mol Zn}) = 0.402 \text{ g Zn}$$