Physics I

Ideal Gases

$R = 8.314\frac{\text{J}}{\text{Kmol}}$, $k_B = 1.38\times10^{-23} J/K$, $1\text{atm} = 1.013\times10^5\ pascals$

$T_{Kelvin} = T_{Celsius} + 273.15$ $PV=nRT$ or $PV=Nk_BT$

Problem 1.- How much mass of helium is contained in a 50.0 L cylinder at a pressure of 10.0 atm and a temperature of 35.0 °C?
[The atomic mass of helium is 4 amu]

Solution: The number of moles is: $n = \frac{PV}{RT} = \frac{(10\times1.013\times10^5)(0.05)}{8.314\times(273+35)} = 19.78$

The mass is $m = nM = 19.78\times0.004kg =$ **0.079 kg**

Problem 2.-A tank of compressed oxygen is at a temperature of 27 ºC and a pressure of 2,500 kPa. Calculate the mass of oxygen contained in the tank if its volume is $0.12m^3$.
[The molecular mass of O_2 is 32]

Solution: First, we calculate the number of moles:

$pV=nRT \rightarrow n = \frac{pV}{RT}$

$p=2,500\text{ kPa} = 2,500\text{x}10^3\text{ Pa}$

$T=27+273=300K$

$V=0.12m^3$

$R=8.314J/K$

$\rightarrow n = \frac{pV}{RT} = \frac{(2500\times10^3\text{Pa})(0.12m^3)}{8.314\text{J/K}(300\text{K})} = 120\text{ moles}$

Since each mole is 32 grams:

Mass of oxygen = 120×32g = **3.85kg**

Problem 3.- Calculate the molecular weight of a gas if 35.4 g of the gas stored in a 7.50 L tank exerts a pressure of 60.0 atm at a constant temperature of 45.5 °C

Solution:

$V = 7.5L = 7.5\times10^{-3}m^3$

$T = 45.5 + 273.15 = 318.65K$

$P = 60atm\left(\frac{1.013\times10^5\ pascals}{1atm}\right) = 60.8\times10^5\ pascals$

With these values: $n = \frac{PV}{RT} = \frac{(60.8\times10^5)(7.5\times10^{-3})}{8.314(318.65)} =$ **17.2 moles**

So, the molecular mass is $M = \frac{35.4}{17.2} =$ **2.05**

Problem 4.- How many moles of gas are contained in 890.0 mL at 21.0 °C and 750.0 mm Hg pressure?

Solution: The problem provides the following information:

$$V = 890mL = 890mL\left(\frac{1L}{1000mL}\right)\left(\frac{1m^3}{1000L}\right) = 890\times10^{-6}m^3$$

$$T = 21 + 273 = 294K$$

$$P = 750mmHg = 750mmHg\left(\frac{1atm}{760mmHg}\right)\left(\frac{1.013\times10^5\ pascals}{1atm}\right) = 0.999\times10^5\ pascals$$

With these values:

$$n = \frac{PV}{RT} = \frac{(0.999\times10^5)(890\times10^{-6})}{8.314(294)} = \mathbf{0.036\ moles}$$

Problem 5.-1.09 g of H_2 is contained in a 2.00 L container at 20.0 °C. What is the pressure in this container in mm Hg?

Solution: The number of moles is: $n = \frac{mass}{molecular\ mass\ in\ grams} = \frac{1.09g}{2g} = 0.545$

$$V = 2L = 2L\left(\frac{1m^3}{1000L}\right) = 2\times10^{-3}m^3$$

$$T = 20 + 273 = 293K$$

So, the pressure is: $P = \frac{nRT}{V} = \frac{(0.545)(8.314)(293)}{2\times10^{-3}} = 6.64\times10^5\ pascals$

In mmHg:

$$P = 6.64\times10^5\ pascal\left(\frac{1atm}{1.013\times10^5\ pascals}\right)\left(\frac{760mmHg}{1atm}\right) = \mathbf{5{,}000\ mmHg}$$

Problem 6.- Calculate the volume 3.00 moles of a gas will occupy at 24.0 °C and 762.4 mm Hg.

Solution: $n = 3$

$T = 24 + 273 = 297K$

The pressure is:

$$P = 762.4mmHg = 762.4mmHg\left(\frac{1atm}{760mmHg}\right)\left(\frac{1.013\times10^5\ pascals}{1atm}\right) = 1.016\times10^5\ pascals$$

And the volume is:

$$V = \frac{nRT}{P} = \frac{3(8.314)(297)}{1.016\times10^5} = \mathbf{0.073\ m^3}$$

Problem 7.- What volume will 20.0 g of Argon occupy at STP?

Solution: $n = \dfrac{mass}{molecular \quad mass \quad in \quad grams} = \dfrac{20g}{40g} = 0.5$

STP stands for:

$P = 1atm = 1.013 \times 10^5\, pascals$, $T = 0C = 273K$, so the volume is:

$$V = \frac{nRT}{P} = \frac{0.5(8.314)(273)}{1.013 \times 10^5} = \mathbf{0.011\ m^3}$$

Problem 8.- How many moles of gas would be present in a gas trapped within a 100.0 mL vessel at 25.0 °C at a pressure of 2.50 atmospheres?

Solution: The information given:

$$V = 100mL = 100mL\left(\frac{1L}{1000mL}\right)\left(\frac{1m^3}{1000L}\right) = 1 \times 10^{-4}\, m^3$$

$$T = 25 + 273 = 298K$$

$$P = 2.50atm = 2.5atm\left(\frac{1.013 \times 10^5\, pascals}{1atm}\right) = 2.53 \times 10^5\, pascals$$

With these values:

$$n = \frac{PV}{RT} = \frac{(2.53 \times 10^5)(1 \times 10^{-4})}{8.314(298)} = \mathbf{0.0102\ moles}$$

Problem 9.- How many moles of a gas would be present in a gas trapped within a 37.0-liter vessel at 80.00 °C at a pressure of 2.50 atm?

Solution: $V = 37L = 37L\left(\dfrac{1m^3}{1000L}\right) = 37 \times 10^{-3}\, m^3$

$$T = 80 + 273 = 353K$$

$$P = 2.50atm = 2.5atm\left(\frac{1.013 \times 10^5\, pascals}{1atm}\right) = 2.53 \times 10^5\, pascals$$

With these values:

$$n = \frac{PV}{RT} = \frac{(2.53 \times 10^5)(37 \times 10^{-3})}{8.314(353)} = \mathbf{3.2\ moles}$$

Problem 10.- If the number of moles of a gas is doubled at the same temperature and pressure, will the volume increase or decrease?

Solution: **It will double!**

Problem 11.- What volume will 1.27 moles of helium gas occupy at STP?

Solution: $n=1.27$
STP stands for:
$P=1atm=1.013\times10^{5}\ pascals$, $T=0C=273K$, so the volume is:

$$V=\frac{nRT}{P}=\frac{1.27(8.314)(273)}{1.013\times10^{5}}=\mathbf{0.028\ m^3}$$

Problem 12.- At what pressure would 1.50 mole of nitrogen gas at 23.0 °C occupy 8.90 L?

Solution: n=1.5

$$V=8.9L=8.9L\left(\frac{1m^{3}}{1000L}\right)=8.9\times10^{-3}m^{3}$$

$$T=23+273=296K$$

With these values:

$$P=\frac{nRT}{V}=\frac{1.5(8.314)(296)}{8.9\times10^{-3}}=\mathbf{414{,}000\ pascals}$$

Problem 13.- What volume would 32.0 g of NO_2 gas occupy at 3.12 atm and 18.0 °C?

Solution: The number of moles is: $n=\frac{mass}{molecular\quad mass\quad in\quad grams}=\frac{32g}{44g}=0.727$

$$T=18+273=291K$$

The pressure is: $P=3.12atm\left(\frac{1.013\times10^{5}\ pascals}{1atm}\right)=3.16\times10^{5}\ pascals$

So, the volume is: $V=\frac{nRT}{P}=\frac{0.727(8.314)(291)}{3.16\times10^{5}}=\mathbf{0.0055\ m^3}$

Problem 14.- Find the volume of 2.40 mol of gas whose temperature is 50.0 °C and whose pressure is 2.00 atm.

Solution: The number of moles is: $n=2.4$

$$T=50+273=323K$$

The pressure is: $P=2atm\left(\frac{1.013\times10^{5}\ pascals}{1atm}\right)=2.026\times10^{5}\ pascals$

Then, the volume is: $V=\frac{nRT}{P}=\frac{2.4(8.314)(353)}{2.026\times10^{5}}=\mathbf{0.0347m^3}$

Problem 15.- Calculate the molecular weight of a gas if 35.44 g of the gas stored in a 7.50 L tank exerts a pressure of 60.0 atm at a constant temperature of 35.5 °C

Solution: Let us find the number of moles:

$$V = 7.5L = 7.5L\left(\frac{1m^3}{1000L}\right) = 7.5\times10^{-3}m^3$$

$$T = 35.5 + 273 = 308.5K$$

$$P = 60atm = 60atm\left(\frac{1.013\times10^5\ pascals}{1atm}\right) = 60.78\times10^5\ pascals$$

With these values:

$$n = \frac{PV}{RT} = \frac{(60.78\times10^5)(7.5\times10^{-3})}{8.314(308.5)} = \mathbf{17.8\ moles}$$

And the molecular weight is 35.44 g/17.8 = **1.99**, so it could be hydrogen.

Problem 16.- How many moles of gas are contained in a 50.0 L cylinder at a pressure of 100.0 atm and a temperature of 35.0 °C?

Solution: $V = 50L = 50L\left(\frac{1m^3}{1000L}\right) = 50\times10^{-3}m^3$

$$T = 35 + 273 = 308K$$

$$P = 100atm = 100atm\left(\frac{1.013\times10^5\ pascals}{1atm}\right) = 101.3\times10^5\ pascals$$

With these values:

$$n = \frac{PV}{RT} = \frac{(101.3\times10^5)(50\times10^{-3})}{8.314(308)} = \mathbf{198\ \ moles}$$

Problem 17.- Determine the number of moles of Krypton contained in a 3.25-liter gas tank at 5.80 atm and 25.5 °C. If the gas is Oxygen instead of Krypton, will the answer be the same? Why or why not?

Solution: $n = \frac{PV}{RT} = \frac{(5.8\times1.013\times10^5\ pascals)(3.25\times10^{-3}m^3)}{8.314(298.65K)} = \mathbf{0.769\ moles}$

Oxygen at those conditions would give us the same value. Notice that the equation does not contain the mass.

Problem 18.- Determine the number of grams of carbon dioxide in a 450.6 mL tank at 1.80 atm and minus 50.5 °C. Determine the number of grams of oxygen that the same container will contain under the same temperature and pressure.

Solution: $n = \frac{PV}{RT} = \frac{(1.8\times1.013\times10^5\ pascals)(0.4506\times10^{-3}m^3)}{8.314(273.15-50.5)} =$ **0.0444 moles**

The mass is: 0.0444×44g=**1.95 g**

If it were oxygen, the mass would be 0.0444×32 = **1.42 g**

Problem 19.- Determine the volume of occupied by 2.34 grams of carbon dioxide gas at STP.

Solution: $V = \frac{nRT}{p} = \frac{\left(\frac{2.34}{44}\right)8.314(273.15)}{1.013\times10^5\ pascals} =$ **0.00119 m³**

Problem 20.- A sample of argon gas at STP occupies 56.2 liters. Determine the number of moles of argon and the mass in the sample.

Solution: $n = \frac{56.2}{22.4} =$ **2.509**

Mass=2.509×40 = **100.35g**

Problem 21.- At what temperature will 0.654 moles of neon gas occupy 12.30 liters at 1.95 atmospheres?

Solution: $T = \frac{pV}{nR} = \frac{(1.95\times1.013\times10^5\ pascals)(12.3\times10^{-3})}{0.654\times8.314} =$ **446.8 K**

Problem 22.- A 30.6 g sample of gas occupies 22.4 L at STP. What is the molecular weight of this gas?

Solution: It is **30.6**

Problem 23.- A 40.0 g gas sample occupies 11.2 L at STP. Find the molecular weight of this gas.

Solution: It is **80.0**

Problem 24.- A 12.0 g sample of gas occupies 19.2 L at STP. What is the molecular weight of this gas?

Solution: $n = \frac{19.2}{22.4} =$0.857, so M=12.0/0.857 =**14**

Problem 25.- 96.0 g. of a gas occupies 48.0 L at 700.0 mm Hg and 20.0 °C. What is its molecular weight?

Solution: $n = \frac{PV}{RT} = \frac{(700/760 \times 1.013 \times 10^5 \, pascals)(48 \times 10^{-3} m^3)}{8.314(293.15K)} =$ **1.83 moles**

M=96.0/1.83 = **48.98**

Problem 26.- 20.83 g. of a gas occupies 4.167 L at 79.97 kPa at 30.0 °C. What is its molecular weight?

Solution: $n = \frac{PV}{RT} = \frac{(79.97 \times 10^3 \, pascals)(4.167 \times 10^{-3} m^3)}{8.314(313.15K)} =$ **0.128 moles**

M=20.83/0.128 = **162.7**

Problem 27.- At STP 3.00 liters of an unknown gas has a mass of 9.50 grams. Calculate its molar mass.

Solution: $n = \frac{3}{22.4} =$ 0.1339, so M= 9.50/0.1339 = **70.9**

Problem 28.- At STP 0.250 liter of an unknown gas has a mass of 1.00 gram. Calculate its molar mass.

Solution: $n = \frac{0.25}{22.4} =$ 0.0111, so M= 1/0.0111= **89.6**

Problem 29.- At STP 150.0 mL of an unknown gas has a mass of 0.250 gram. Calculate its molar mass.

Solution: $n = \frac{0.150}{22.4} =$ 0.006696, so M= 0.25/0.006696 = **37.3**

Problem 30.-1.089 g of a gas occupies 4.50 L at 20.5 °C and 0.890 atm. What is its molar mass?

Solution: $n = \frac{PV}{RT} = \frac{(0.89 \times 1.013 \times 10^5 \, pascals)(4.5 \times 10^{-3} m^3)}{8.314(293.65K)} =$ 0.166 moles

So, M= 1.089/0.166=**6.55**

Problem 31.- 0.190 g of a gas occupies 250.0 mL at STP. What is its molar mass? What gas is it? Hint - calculate molar mass of the gas.

Solution: $n = \frac{0.25}{22.4} =$ 0.0111, so M= 0.19/0.0111=**17… could be ammonia**

Problem 32.- If 9.006 grams of a gas are enclosed in a 50.00-liter vessel at 273.15 K and 2.000 atmospheres of pressure, what is the molar mass of the gas? What gas is this?

Solution: $n = \frac{PV}{RT} = \frac{(2\times1.013\times10^5\ pascals)(50\times10^{-3}m^3)}{8.314(273.15K)}$ = **4.46 moles**

M=9.006/4.46=**2 It is hydrogen.**

Problem 33.- A 50.00-liter tank at minus 15.00 °C contains 14.00 grams of helium gas and 10.00 grams of nitrogen gas.
a. Determine the moles of helium gas in the tank.
b. Determine the moles of nitrogen gas in the tank.
c. Determine the mole fraction of helium gas in the tank.
d. Determine the partial pressure of helium gas in the tank.
e. Determine the partial pressure of nitrogen gas in the tank.
f. Determine the total pressure of the mixture in the tank.
g. Determine the volume that the mixture will occupy at STP.

Problem 34.- Determine the number of moles of Krypton contained in a 3.25-liter gas tank at 5.80 atm and 25.5 °C. If the gas is Oxygen instead of Krypton, will the answer be the same? Why or why not?
[1 atm=101,300 pascal]

Solution: The number of moles is $n = \frac{PV}{RT} = \frac{5.8\times1.013\times10^5\times0.00325}{8.314\times298.5}$ = **0.77 moles**

The same answer if it were oxygen instead of krypton because the law is universal for all ideal gasses.

Problem 35.- A compressed cylinder of O_2 contains 30 kg of oxygen at T=25ºC and 10^6 pascals. Calculate the volume of the cylinder.

Solution: We can use the ideal gas law: $pV=nRT \rightarrow V = \frac{nRT}{p}$

The number of moles is: $n = \frac{30{,}000g}{32g} = 937.5moles$

So the volume is:

$\rightarrow V = \frac{937.5(8.314J/K)(298K)}{10^6\,Pa}$ = **$2.32m^3$**

Problem 35a.- A compressed cylinder of O_2 contains 6.4 kg of oxygen at T=26.85ºC and P=6atm. Calculate the volume of the cylinder. [The molecular weight of oxygen is 32]

Solution: The number of moles is: $n = \frac{mass(in\ grams)}{Molecular\ mass} = \frac{6400}{32} = 200$ moles

The temperature is: $T = 26.85 + 273.15 = 300$ K

The pressure is: $P = 6atm\left(\frac{1.013\times10^5\ pascals}{atm}\right) = 6.78\times10^5$ pascals,

So the volume is: $V = \frac{nRT}{P} = \frac{200\times8.314\times300}{6.078\times10^5} =$ **0.82 m^3**

Problem 36.- A diver releases a 1cm-radius air bubble at a depth of 45m (so you can consider the absolute pressure to be 5.5 atm) at a temperature of 7ºC. Calculate the radius of the bubble just before it surfaces (where the pressure is 1.0 atm) if the temperature is 17ºC.

[Volume of a sphere= $\frac{4}{3}\pi R^3$, where R is the radius]

Solution: The number of moles stays the same in the process, so $\frac{P_1V_1}{T_1} = \frac{P_2V_2}{T_2}$, and according to the problem:

$P_1 = 5.5atm$

$T_1 = 7 + 273.15 = 280.15K$

$V_1 = \frac{4}{3}\pi R_1^3$

Notice that we are leaving the pressure in atm as those units will cancel each other.

Also:

$P_2 = 1atm$

$T_2 = 17 + 273.15 = 290.15K$

$V_2 = \frac{4}{3}\pi R_2^3$

So, $\frac{P_1V_1}{T_1} = \frac{P_2V_2}{T_2} \rightarrow \frac{5.5\times\frac{4}{3}\pi R_1^3}{280.15} = \frac{1\times\frac{4}{3}\pi R_2^3}{290.15} \rightarrow R_2 = R_1\sqrt{\frac{5.5\times290.15}{280.15}} =$ **1.79 cm**