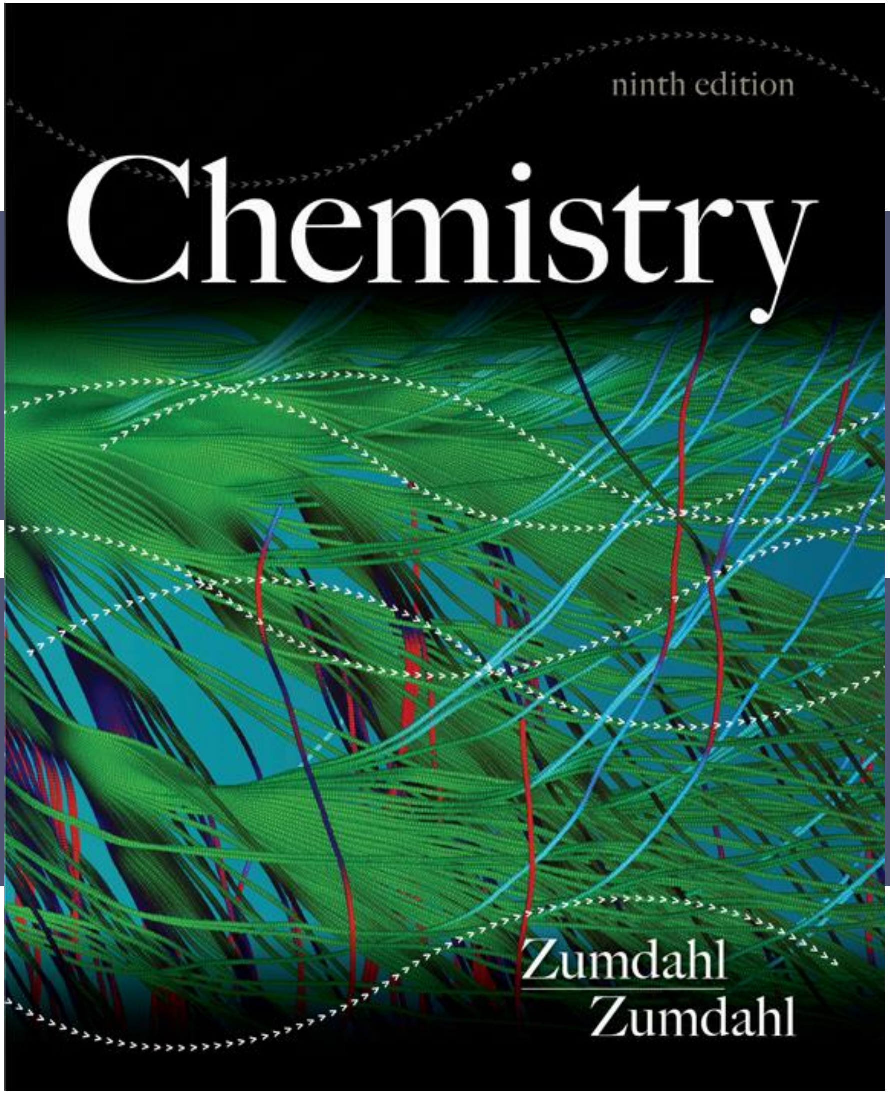


Chapter 5

Gases

Properties of gases

- Uniformly fill any container and take its shape.
- Easily compressed.
- Mixes completely with any other gas.
- Exerts pressure on its surroundings.

Measurement of Pressure:

- The atmospheric pressures is measured by barometer.
- The pressure of a gas confined in a container is measured by manometer. (car tire, home gas cylinder, …)

Pressure:

$$\text{Pressure} = \frac{\text{force}}{\text{area}}$$

- SI units = Newton/meter^2 = 1 Pascal (Pa)
- 1 standard atmosphere = 101.325 KPa ; (101,325 pa)
- 1 standard atmosphere = 1 atm

  = 1.01325 bar

  = 760 mm Hg = 760 torr

  = 14.7 Lb/in^2 ; (psi: pound per square inch)

<u>Example</u>: Pressure Conversions:

The pressure of a gas is measured as 2.5 atm. Represent this pressure in both torr and pascals.

$$(2.5\ \cancel{\text{atm}}) \times \left(\frac{760\ \text{torr}}{1\ \cancel{\text{atm}}}\right) = 1.9 \times 10^{3}\ \text{torr}$$

$$(2.5\ \cancel{\text{atm}}) \times \left(\frac{101{,}325\ \text{Pa}}{1\ \cancel{\text{atm}}}\right) = 2.5 \times 10^{5}\ \text{Pa}$$

Variables affecting the state of a gas:

- Temperature.
- Pressure
- Volume
- Number of moles

(T, P, V, n)

Ideal Gas Law

Pressure (P), temperature (T), and number of moles (n) are related to the volume as follows:

- Volume is inversely proportional to pressure, so, V = k/P
- Volume is directly proportional to temperature, so, V = bT
- Volume is directly proportional to number of moles, so, V = an

K, b, and a are proportionality constants. Consequently:

V = (kba)(nT/P)

The constants (kba) may be combined in one constant R, so:

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

OR: PV = nRT (Ideal Gas Law)

- R is called universal gas constant.

  R = 0.08206 L·atm/mol·K, (R has different values depending on the unit of the pressure.

  If certain amount of gas (n) is moved from certain initial state (i) to certain final state (f), then:

$$\frac{P_i V_i}{T_i} = \frac{P_f V_f}{T_f}$$

At constant pressure: $\frac{V_i}{T_i} = \frac{V_f}{T_f}$

At constant Temperature: $P_i V_i = P_f V_f$

Example:

A sample of helium gas occupies 12.4 L at 23 ^{o}C and 0.956 atm. What volume will it occupy at pressure of 1.20 atm at the same temperature?

$$V_f = Vi\left(\frac{P_i}{P_f}\right)$$

$V_f = (V_i)(P_i/P_f) = (12.4\ L)(0.956\ atm./1.20\ atm.) = 9.88\ L$

- <u>Example</u>: [Temperature in all calculations should be in K]

A balloon containing 1.30 L of air at 24.7 °C is placed into a beaker containing liquid nitrogen at –78.5°C. What will the <u>volume</u> of the balloon if the pressure stays constant?

K = °C + 273

T_1 = 24.7 + 273 = 297.7 K

T_2 = –78.5°C + 273 = 194.5 K

$$\frac{V_i}{T_i} = \frac{V_f}{T_f}$$

$V_f = (V_i)(T_f/T_i)$ = 0.849 L

Car tire at 23 ^{o}C with an internal volume of 25.0 L is filled with air to a total pressure of 3.18 atm. Determine the number of moles of air in the tire.

n = PV/RT

T = 23 + 273 = 296 K

n = (3.18atm)(25.0L)/(0.08206....)(296 K)

= 3.27 mol

Example:

What is the pressure in a 304.0 L tank that contains 5.670 kg of helium at 25 °C?   PV=nRT

T = 25 + 273 = 298K

n = mass/atomic mass = 5.670x1000/4 = 1417.5 mol

P = nRT/V   ;   R = 0.0821 L.atm./K.mol.

= . . . . = 114 atm

- Example:

At what temperature (in °C) does 121 mL of CO_2 at 27 °C and 1.05 atm. occupy a volume of 293 mL at a pressure of 1.40 atm.?

Solution:

$$\frac{P_i V_i}{T_i} = \frac{P_f V_f}{T_f}$$

$$T_f = T_i \frac{P_f V_f}{P_i V_i}$$

T_f= …….. = ……. = 696 °C

Standard Molar Volume of an Ideal Gas (SMV)

- SMV is the volume of <u>one</u> mole of a gas under STP
- For 1 mole of an ideal gas at 0 °C and 1 atm, the volume of the gas is 22.42 L.

$$V = \frac{nRT}{P} = \frac{(1.000 \text{ mol})(0.08206 \text{ L} \cdot \cancel{\text{atm}}/\text{K} \cdot \text{mol})(273.2 \cancel{\text{K}})}{1.000 \cancel{\text{atm}}} = 22.42 \text{ L}$$

- STP = Standard Temperature and Pressure
  - 0° C and 1 atm
  - Therefore, the molar volume is 22.42 L at STP.
  - (T,P,V,n)

Example:

A sample of oxygen gas has a volume of 2.50 L at STP. How many grams of O_2 are present?

$MM(O_2)$ = 32 g/mol

n = PV/RT

T = 273 K ; P = 1 atm. ; R = 0.0821 L.atm. ....

So, ... n = 0.112 mol,

mass = (MM)(n) = (32.....)(0.112...) = 3.57 g

OR STP: 1 mol = 22.42 L

Molar Mass (MM) and Density (d) of a gas

- PV = nRT
- n = mass/MM
- Density (d) = mass/V
- PV = (mass/MM)(RT)
- Rearrange for the MM, so:
- MM = (d)(RT/P)
- Rearrange for the density, So:
- d = (MM)(P/RT)
- (P, T, d, MM)   (P V T n)

What is the <u>density</u> of F_2 at STP (in g/L)?

d = (MM)(P/RT) , STP (1 atm. *and* 273 K)

MM(F_2) = 39 g/mol

d = 1.70 g/L

R = 0.0821 L.atm/mol.K

(i) What is the volume of a mixture of 5.00 g of H_2 gas and 5.00 g of He gas at STP?

V = ? PV = n_tRT

(ii) What is the mass of nitrogen gas (N_2) that occupies the same volume under the same conditions (STP)?

<u>*Solution*</u>: n = mass/MM

(i) n(H_2) = 5.00/2 = 2.50 mol.

n(He) = 5.00/4 = 1.25 mol.

n_t = ……. = 3.75 mol.

V = n_tRT/P = …..= (3.75)(0.0821…)(273 K)/ 1 atm. … = 84.05 L

(ii) n (N_2) = n_t = ……

mass (N_2) = (MM)(n_t) = …= (3.75 mol.)(28…)= 105 g

Gas Stoichiometry

Methane gas (CH_4), V = 2.80L, 25 °C, 1.65 atm. reacted with oxygen gas (O_2), 35.0L, 31 °C, 1.25 atm. To produce CO_2 and water. what is the <u>mass</u> of CO_2 produced? What is the <u>volume</u> of CO_2 produced under 2.5 atm. and 125 °C?

$$CH_{4\,(g)} + 2O_{2\,(g)} \rightarrow CO_{2(g)} + 2H_2O_{(g)}$$

n(mole): 0.189 1.75 ?

n = PV/RT

$n(CH_4)$ = (1.65 atm)(2.8L)/(0.0821Latm/mol.K)(298K) = 0.189 mol.

$n(O_2)$ = ……..= 1.75 mol.

∴ CH_4 is the limiting reactant.

NOW: All calculations are based on the L.R.

Moles(CO_2) = moles of CH_4 (L.R) = 0.189 mol.

Mass of CO_2 produced = moles x MM

= 0.189 mol. x 44 g/mol. = 8.3g

PV = nRT

V(CO_2) = nRT/P

= (0.189)(0.0821…)(398 K)/2.5 atm = 2.47 L

Exercise:

What is the volume of CO_2 at STP?

- For a <u>mixture of gases</u> 1, 2, 3, … in a container,

$$P_{Total} = P_1 + P_2 + P_3 + \ldots$$

3.0 L $PV = n_t RT$ O2

- Volume of gas mixture is V, and contains H_2, N_2, He = 10.0L
- P(mixture) = P(H_2) + P (N_2) + P (He)
- The total pressure exerted is the sum of the pressures that each gas would exert if it were alone under the same conditions of volume, temperature and number of moles.

<u>Example</u>:

A gas mixture of 10 g of each of H_2, N_2 and He under 25 °C has a volume of 15.0 L.

(i) What is the pressure of the gas mixture?

(ii) What is the partial pressure of (N_2) gas in the mixture?

$P = \frac{n_t RT}{V}$, T = 298 K, V = 15.0 L, R= 0.0821 L.atm./mol.K

- $n_t = n(H_2) + n(N_2) + n(He)$
- $n(H_2)$ = mass/MM = 10.0g/2 … = 5.0 mol.
- $n(N_2)$ =10.0g/28 … = 0.357 mol. ; n(He) = 10.0/4.0 = 2.5 mol.
- n_t = PV/RT = ….. = $n(H_2) + n(N_2) + n(He)$ = …. = 7.86 mol.

(i) P = n_tRT/V = (7.86 mole)(0.082 ….)(298 K)/15.0 L

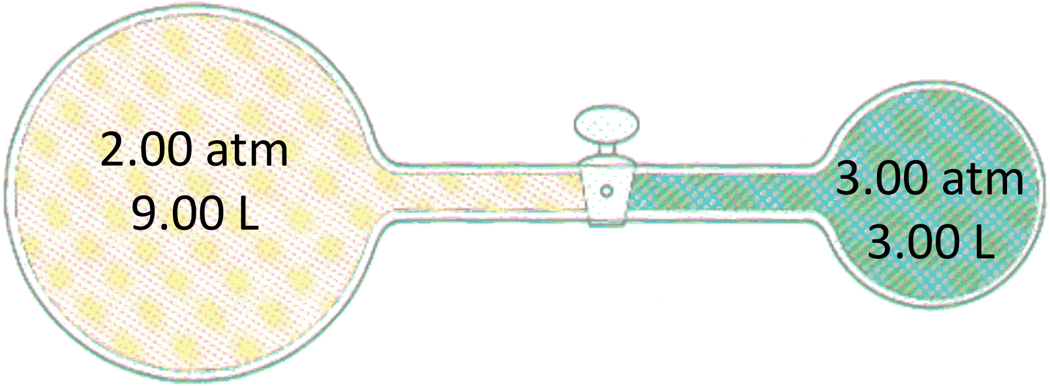
= 12.82 atm.

(ii) $P(N_2) = n(N_2)$RT/V = (0.357 mol.)(0.082 ….)(298 K)/15.0 L

= 0.582 atm.

Consider the following apparatus containing helium in both sides at 45 ^{o}C. Initially the valve is closed.

- After the valve is opened, what is the pressure of the helium gas, if there is no change in temperature?

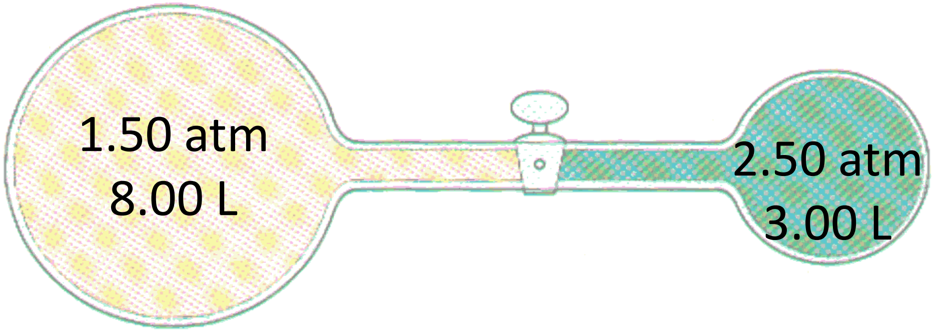


- n_{left} = PV/RT = (2)(9)/(0.0821…)(318K) = 0.689 mol.
- n_{right}= PV/RT = (3)(3)/(0.0821…)(318K) = 0.345 mol.
- n_{total} = 0.689 + 0.345 = 1.034 mol.
- New volume after mixing, V_{total}= 9 + 3 = 12 L
- P (after opening the valve) = $n_t RT/V_t$

  = (1.034mol)(0.0821 …)(318 K)/12 L

  = 2.25 atm.

Consider the apparatus below. The left-hand side contains O_2 and the right-hand side contains N_2. T = 300 K. Calculate the partial pressures and the pressure of the gas mixture after the valve is opened?



- n = PV/RT ; $P_i = n_i RT/V$
- $n(O_2)$, left = . . . = 0.487 mol. ; $n(N_2)$, right = . . . = 0.304 mol.
- After mixing: V = 3.0 + 8.0 = 11.0 L
- <u>After</u> opening the valve:
- $P(O_2)$ = . . . = 1.09 atm. ; $P(N_2)$ = . . . = 0.681 atm.
- P = 1.09 + 0.681 = 1.77 atm.

END OF CHAPTER 5