# Some Ideal Gas Laws and Their Applications-Part 2

## Basic Concepts in Chemistry(BCC)-Lecture 2

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## Ideal Gas Equation(Equation of State)

$$V \propto \frac{1}{P}$$ B.L : T and mass - constants

$$V \propto T$$ C.L : P and mass - constants

$$V \propto n$$ A. L : P and T constants

Combining these three laws, we have

$$V \propto \left(\frac{1}{P}\right) \times T \times n \Rightarrow \boxed{PV = nRT}$$

R = Universal Gas constant (When, T, P, V and mass vary)

n = no. of moles.

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PV=nRT

$$R = \frac{PV}{nT} = \frac{1 \times 22.4}{1 \times 273.15} = 0.082\, L.atm.mol^{-1}K^{-1}$$

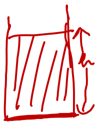
$$R = \frac{PV}{nT} = \frac{76 \times 13.6 \times 980 \times 22400}{1 \times 273.15} = 8.3 \times 10^{7}\, erg.mol^{-1}K^{-1} = 8.3 J.mol^{-1}K^{-1}$$

✓ $R = 0.082\ L.atm.mol^{-1}K^{-1}$

$= 8.314 \times 10^{7}\ Erg.mol^{-1}.K^{-1}$

$= 8.314 J.mol^{-1}.K^{-1}$

$\simeq 2\ Cals.mol^{-1}.K^{-1}$




ρ = density $\left(\frac{m}{V}\right)$

$P \times V = \frac{N}{m^2} \times m^3$ $\quad \frac{F}{A} = \frac{N}{m^2}$ $\quad \boxed{P = h\rho g}$ g = acc. due to gravity

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✓ $\frac{g}{cm \cdot s^2} = \frac{dynes}{cm^2} = \frac{g \times cm/s^2}{cm^2} = \frac{g}{s^2 \times cm}$

$F = dyne = m \times a = g \times cm/s^2$

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- Old STP: T = 0$^0$C = 273.15 K ≃ 273 K
- Pressure = 1 atmosphere = 760 mm of Hg = 76 cm of Hg
- GMV = 22.4 L at STP (Old)

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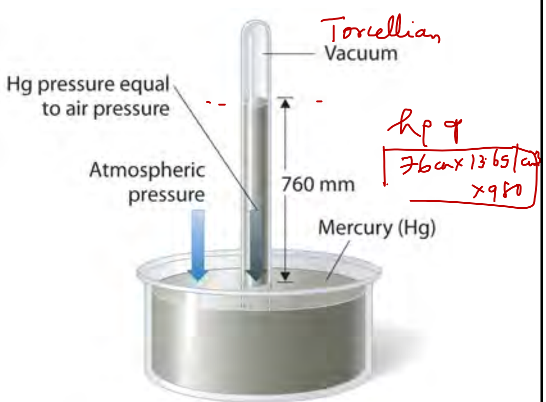
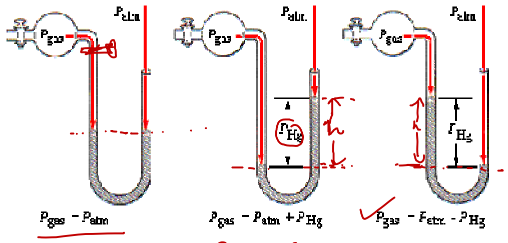
## Barometer to measure Atmospheric Pressure



MANOMETRE

(with one side open)



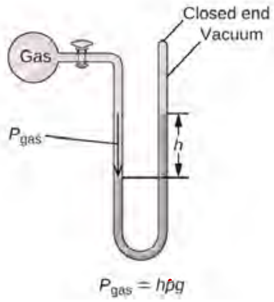

$P_{atm} + h = P_{gas}$

$\Rightarrow P_{gas} = P_{atm} + h$

$P_{atm} = P_{gas} + h$

$\Rightarrow P_{gas} = P_{atm} - h$

Closed Manometer




Pressure meter

## New STP

- Standard Pressure(Latest) = 1 bar
- 1 atmosphere = 1.01325 bar
- 1 bar = $10^5$ $N.m^{-2}$(Pa)
- 1 atm. = 1.01325 X $10^5$ Pa = 101.325 kPa
- Temperature = 273.15K ≃273K
- GMV (at Latest STP) = 22.7 L
- This value is often not used in most texts.
- Value of 'R' is same in both systems.

$$R = \frac{PV}{nT} = \frac{10^5 \times 22.7 \times 10^{-3}}{1 \times 273.15} = 8.3 J.mol^{-1}K^{-1}$$

## Density of Gas

- Density(d) ($\rho$) of gas (mass/volume) depends on both T and P.

$$PV = nRT = \left(\frac{m'}{M}\right)RT \Rightarrow d = \frac{m'}{V} = \frac{PM}{RT}$$

m' = mass of gas(g);
M = gm. Molecular Mass of gas
d = density of the gas at T and P

$$\boxed{d = \frac{PM}{RT}}$$

Alternative method to determine Density:

- Find the volume of one mole of the gas at the given conditions by using the combined gas equation with STP data.
- Mass of the gas remains the same(1 mole) at all different temperatures and pressures. Only volume changes if T and P change
- So density of the gas at given condition =

$$= \frac{\text{mass(1 mole)}}{\text{Volume at given conditions}}$$

- See Example later

- SAQ 3 : Calculate the molecular mass of a gas 1.0 g of which occupies 395 mL at 27$^0$C and 1520 mm of Hg pressure.

$m = 1g$ , $M$ = unknown.

$T = 273 + 27 = 300\,K$ , $V = 395\,mL = \frac{395}{1000}\,L$

$P = 1520\,mm = \frac{1520}{760}\,atm$ ,

$\boxed{PV = nRT}$ $\Rightarrow \frac{1520}{760}\,atm \times \left(\frac{395}{1000}\right)L$

$0.082\,L.atm.K^{-1}mol^{-1}$

$= \left(\frac{1.g}{M}\right) \times 0.082\,L.atm.K^{-1}mol^{-1} \times 300K$

$M = 31.94 \simeq 32$

- SAQ 4 : Find the density of CO gas at 27$^0$C and 1.5 atm. pressure. Find in both the methods.

1st method

$$d = \frac{PM}{RT} = \frac{1.5\ atm \times 28\ g\ mol^{-1}}{0.082\ L.atm.K^{-1}mol^{-1} \times 300\ K}$$

$$= 1.707\ g/L$$

$$= 0.001707\ g/mL$$

2nd Method

STP 22.4 L ← 1 mole = 28 gm

$$\frac{P_1V_1}{T_1} = \frac{P_2V_2}{T_2} \Rightarrow \frac{1\ atm \times 22.4}{273} = \frac{1.5 \times V_2}{300}$$

$$\Rightarrow V_2 = 16.41\ L \qquad d = \frac{28\ g}{16.41\ L} = 1.704\ g/L$$

- SAQ 5: Find the density of $H_2$ gas at STP.

(i)

$$d = \frac{PM}{RT} = \frac{1\ atm \times 2\ g\ mol^{-1}}{0.082\ L.atm.K^{-1}mol^{-1} \times 273\ K}$$

$$= 0.089\ g/L$$

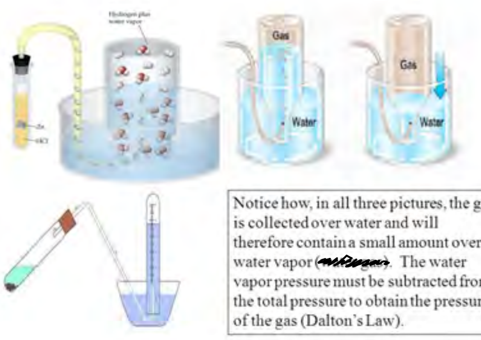
$$= 0.000089\ g/mL\ (g/cm^3)$$

## Some Ideal Gas Laws and Their Applications-Part 3

### Basic Concepts in Chemistry(BCC): Lecture-3

## Aqeuous Tension (Water Vapour Pressure)

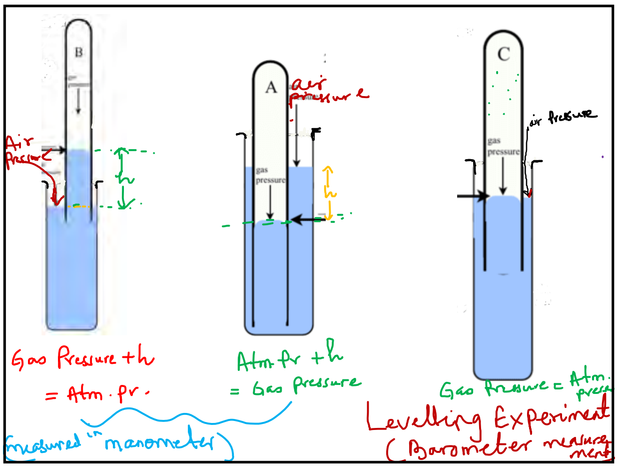
- When a gas is collected over water, it carries some water vapour in it.
- The pressure of water vapour is called Aqueous Tension, which has fixed value at a particular temperature for a given liquid, and increases with increase in T.
- For $H_2O$ : f = 23.8 mm of Hg (298K);
- To the find the pressure(P) of the dry gas, we have to substract Aqueous Tension(f) from the pressure of the moist gas.
- $P_{dry} = P_{moist} - f$ (aqueous tension)



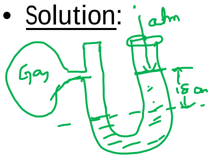

Notice how, in all three pictures, the gas is collected over water and will therefore contain a small amount over water vapor. The water vapor pressure must be subtracted from the total pressure to obtain the pressure of the gas (Dalton's Law).

## Measurement of Gas Pressure

- Manometer
- Barometer after levelling experiment




- SAQ 6: In a manometer, which is open in one end, the Hg level in the right column was 18 cm above that in the left column, which is connected to an enclosed gas vessel. The barometric pressure was 80 cm of Hg at that time. Calculate the pressure of the gas in terms of height of mercury column.
- Solution:




Gas Pr = atm. pr + 18 cm

= 80 + 18

= 98 cm

1 atm = 1.01325 bar, 0.0784 bar = $\frac{0.0784}{1.01325}$ = 0.07734 atm

- SAQ 7: A gas vessel is connected to a manometer closed at both ends. The liquid inside the manometer has a density of 8 g/cm$^3$. The differential height between the two sides was found to be 10 cm. Calculate the the gas pressure in Pa, bar and atm. units.


liquid (ρ) = 8 g/cm$^3$

h = 8 cm.

P = h × ρ × g

= $\left(\frac{8}{100}\right)$ m × 8000 kg/m$^3$ × 9.8 m/s$^2$

= 7840 Pa (N/m$^2$)

1 bar = $10^5$ Pa

⇒ 7840 Pa = $\frac{7840}{10^5}$ = 0.0784 bar

## Vapour Density(VD)/ Relative Density(RD)

$$\text{V.D} = \frac{\text{Density of a gas or vapour}}{\text{Density of hydrogen gas}}$$

(Measurements done at same T and P)

*N.B: The Relative Density(Specific Gravity) of Liquids and Solids are determined relative to water. But for gases, it is determined relative to hydrogen gas.*

$$\text{V.D} = \frac{\dfrac{\text{mass of the gas or vapour}}{\cancel{\text{volume of the gas or vapour}}}}{\dfrac{\text{mass of hydrogen gas}}{\cancel{\text{volume of hydrogen gas}}}}$$

If the volumes of both are same, then

$$\boxed{\text{V.D} = \frac{\text{Mass of certain volume of gas or vapour}}{\text{Mass of same volume of hydrogen}}}$$

(Measurements done under same T and P)

## Molecular Mass = 2 X V.D

$$\text{V.D} = \frac{\text{Mass of V cc of the gas or vapour}}{\text{Mass of V cc of hydrogen gas}}$$

(T & P Const).

$$= \frac{\text{Mass of 'N' molecules of the gas or vapour}}{\text{Mass of 'N' molecules of hydrogen gas}}$$

(Avogadro's law)

$$= \frac{\text{Mass of 1 molecule of the gas or vapour}}{\text{Mass of 1 molecule of hydrogen gas}}$$

$$= \frac{\text{Mass of 1 molecule of the gas or vapour}}{\text{2 X Mass of 1 atom of hydrogen gas}}$$

$$= \frac{\text{Molecular Mass}}{2}$$

[ M.M = 2×V.D ]

- V.D is independent of T and P, though absolute values of densities are.
- Since V.D is a ratio, changes in densities of both the gas and $H_2$ occur proportionately and always the ratio is constant.
- SAQ 8: What is the V.D of (a) $SO_2$ (b) $O_2$ (c) Ar

(a) $V.D = \frac{64}{2} = 32$

(b) $V.D = \frac{32}{2} = 16$

(c) $V.D = \frac{40}{2} = 20$

- SAQ 9: A certain unknown elementary gas has a density equals to 0.00125gm/cc at STP. What are its vapour density and molecular mass? Can you identify the gas?(density of hydrogen gas at STP=0.000089gm/cc)

$d = 0.00125\ g/cm^3$ (STP)

(VD) $D = \frac{d_x}{d_{H_2}} = \frac{0.00125}{0.000089} = 14.0449 \simeq 14$

$MM = 2 \times V.D = 2 \times 14 = 28$ ($N_2$)

- SAQ 10: The V.D of an unknown gas is 14, what would be its density at STP ? Can you guess what gas(or gases) this will represent ?

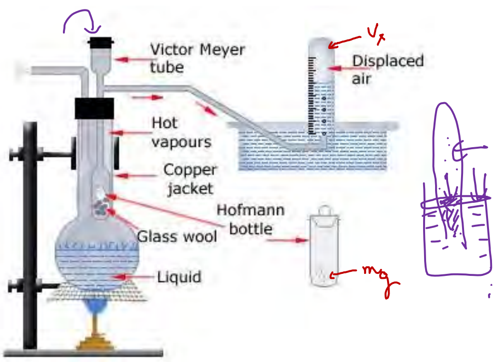
V.D (D) = 14

$V.D = \frac{d_{x(STP)}}{d_{H_2(STP)}} = 14 \Rightarrow d_x = 14 \times 0.000089 = 0.001246\ g/cc$

$MM = 2 \times 14 = 28$ → $N_2$, CO

## Measurement of V.D by Victor Meyer's Method

- The V.D of the vapours of the many volatile organic liquids such as acetone, ether etc. are determined by this method.
- The liquid is vaporized in Victor Meyer's tube which displaces equal volume of air and the displaced air is collected over water.
- The Pressure of dry air, Temperature and Volume of displaced air are determined. Then we get the volume at STP by using combined gas equation.
- Then the mass of same volume of $H_2$ is determined. Thus V.D is determined.




$$V.D = \frac{\text{Mass of certain volume of gas or vapour}}{\text{Mass of same volume of hydrogen}} \quad \frac{(m)_g}{(V \times 0.000089)_{STP}}$$

- Procedure : A known mass(m) of the liquid, taken in the Hoffmann bottle is introduced into the Victor Meyer's tube which is kept in equilibrium at 100$^0$C(water vapour).
- The liquid vaporizes and displaces equal volume of air which is collected by the downward displacement of water.
- Volume and Pressure of moist air are measured after levelling experiment. Temperature is also noted.
- Combined gas equation is then used to find the volume at STP ($V_{STP}$)
- Then:

$$V.D = \frac{\text{Mass of certain volume of gas or vapour}}{\text{Mass of same volume of hydrogen}}$$

$$= \frac{m}{0.000089 \times V_{STP}\,(mL)} \quad (d_{H_2} = 0.000089\ g/cc)$$

- **SAQ 11**: *2.0 gm of a certain unknown volatile liquid vaporized in Victor Meyer's expt. displaces 418 mL of air at 27$^0$C and 755mm Hg pressure. Find out the molecular mass of the liquid.(aqueous tension at 27$^0$C =15mm)*

$$V.D = \frac{\text{mass of certain volume of vapour}}{\text{mass of same volume of } H_2} \quad (T \,\&\, P)$$

$$P_{dry\ air} = (755 - 15)\ mm$$

$$\frac{P_1V_1}{T_1} = \frac{P_2V_2}{T_2}$$

$$\frac{(755-15) \times 418}{(273+27)} = \frac{760 \times V_2}{273} \Rightarrow V_2 = 370.37\ mL\ (STP)$$

$$V.D = \frac{2}{0.000089 \times 370.37} = 60.67$$

$$MM = 2 \times 60.67 = 121.34$$

Alternative (GMV)

STP = 370.37 mL (STP)

370.37 mL (STP) weighs 2g

22400 mL (STP) $\quad '' \quad \frac{2 \times 22400}{370.37}$

$= 120.96$

## GMV(STP) from Avogadro's Law

$$\text{Molecular Mass} = 2 \times V.D = 2 \times \frac{\text{Mass of 1 litre of gas or vapour at NTP}}{\text{Mass of 1 litre of hydrogen gas at NTP}}$$

$$= 2 \times \frac{\text{mass of 1 litre of gas or vapour at NTP}}{0.089}$$

(Since density of $H_2$ at STP = 0.089 g/cc)

= 22.4 X mass of 1 L of vapour at STP

= Mass of 22.4 L of vapour at STP

## Assignments

- 1: If 4L of $H_2$ gas at 1.43 atm. is at standard temperature, and the pressure were to increase by a factor of 2/3, what is the final volume of the $H_2$ gas? (Hint: Boyle's Law) (A: 2.4L)
- 2 : If 1.25L of gas exists at 35ºC with a constant pressure of 0.70 atm in a cylindrical block and the volume became 3/5 of the initial volume by raising temperature, while keeping pressure constant. What is the new temperature of the gas? (Hint: Charles's Law) (A : 184.8 K)

- 3 : A ballon with 4.00 g of Helium gas has a volume of 500mL. When the temperature and pressure remain constant. What will be the new volume of Helium in the ballon if another 4.00g of Helium is added into the ballon? (Hint: Avogadro's Law) (A: 1000 mL or 1L)
- 4: At 655 mm Hg(P)and 25.0ºC(T), a sample of Chlorine gas has volume of 750 mL. How many moles of Chlorine gas is at this condition? (Hint: Ideal Gas Equation) (A: 0.026).

- 5 : Find the volume of 7 g of nitrogen gas kept at 300K; exerting a pressure of 600 mm of Hg. (R=0.082 $L.atm.K^{-1}.mol^{-1}$) (A : 7.8 L)
- 6 : What mass of $CO_2$ gas at $27^0C$ and 1.75 atm. pressure will occupy a volume 1.2 L? (A : 3.756 g)
- 7 : The density of a certain unknown gas is 0.712 g/L at STP. Calculate the molecular mass of the gas. Can you guess what could be the gas, if it is made up of two elements. (15.938≃16 ; $CH_4$)
- 8 : 0.45 g of a volatile liquid in Victor Meyer's apparatus displaced 98.75 mL of moist air at $20^0C$ and 718 mm of Hg pressure. Calculate the Vapour Density of the vapour of the liquid. What will be its Molecular Mass ? (aqeous tension at $20^0C$ = 17.4 mm of Hg) (59.6; 119.2)

- 9 : In a Victor Meyer's experiment, 0.168 gm of a volatile liquid displaced 49.4 mL of air measured over water at $20^0C$ and 740mm of pressure. Calculate the vapour density and molecular mass of of the compound. (Aqueous tension at $20^0C$= 18mm) (A: 43.17, 86.34)
- 10: Find the volume, in mL, when 7.00 g of $O_2$ and 1.50 g of $Cl_2$ are mixed in a container with a pressure of 482 atm and at a temperature of $22^0$ C. Assume no reaction between the gases and the mixture behaves ideally. (12.03 mL)

- 11. The pressure of a gas was measured in a mercury manometer open at one end. It was observed that the Hg level in the right column is 270 mm below that in the left column, which is connected to the enclosed gas vessel. If the barometric pressure at that time is 670 mm of Hg, what is the pressure of the gas in terms of height mercury column ? (A: 400 mm of Hg)
- 12. In a manometer, closed at both ends, the enclosed gas connected to one end produced a differential height of 10 cm on the other side due to its pressure. If the liquid has a density of 6 $g/cm^3$, calculate the gas pressure in bar unit. (A: 0.0588 bar)