# Chemistry 120

Gases.

## Properties of Gases

- No definite Shape or Volume
  - Liquids: definite volume, indefinite shape
  - Solids: definite volume, definite shape
- Most easily measured Properties are Volume and Pressure
  - Both depend on temperature and amount
- Solubility in Solids and Liquids generally very poor
  - Except where there is a reaction

## Gas-Forming Reactions

- Gases relatively Insoluble in Water
  - Reactions producing gases rapidly saturate solution, excess escapes

$CO_3^{2-}$ (aq) + 2 $H^+$ (aq) $\longrightarrow$ "$H_2CO_3$ (aq)" $\longrightarrow$ $CO_2$ (g) + $H_2O$ (l)

$HCO_3^-$ (aq) + $H^+$ (aq) $\longrightarrow$ $CO_2$ (g) + $H_2O$ (l)

$S^{2-}$ (aq) + 2 $H^+$ (aq) $\longrightarrow$ $H_2S$ (g)

$SO_3^{2-}$ (aq) + 2 $H^+$ (aq) $\longrightarrow$ $SO_2$ (g) + $H_2O$ (l)

$NH_4^+$ (aq) + $OH^-$ (aq) $\longrightarrow$ $NH_3$ (g) + $H_2O$ (l)

## Gas-Forming Reactions

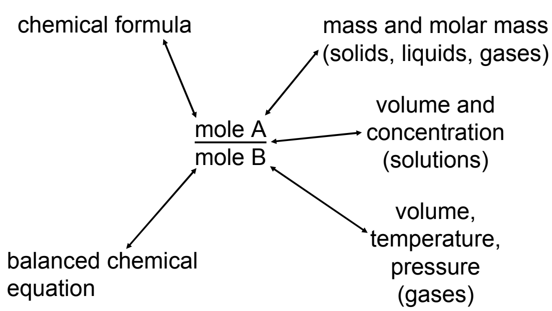
- These Reactions also work on Solids or Liquids
- Examples

$CaCO_3$ (s) + $H^+$ (aq) ⟶ $Ca^{2+}$ (aq) + $CO_2$ (g) + $H_2O$ (l)

ZnS (s) + $H^+$ (aq) ⟶ $Zn^{2+}$ (aq) + $H_2S$ (g)

2 Fe (s) + 6 $H^+$ (aq) ⟶ 3 $Fe^{3+}$ (aq) + 3 $H_2$ (g)

## Stoichiometry Overview




## Stoichiometry of Reactions involving Gases

- Need a Way to go from Laboratory-Scale to Moles
  - Concentration of limited use
- Focus on Physical Properties of Gases
  - Volume, pressure, temperature, amount
- *Ideal Gas Law*: p·V = n·R·T
  - Where R = 0.082057 $L\cdot atm\cdot K^{-1}\cdot mol^{-1}$
  - Initially this was an *empirical* equation

## Ideal Gas Law

- Combination of other empirical Gas Laws into One applicable under Conditions of
  - High temperature (relative to substance's boiling point)
  - Low pressure
- Units
  - Temperature, K (= °C + 273.15)
  - Volume, L
  - Amount of material, mole

## Ideal Gas Law

- Pressure Units
  - Torr (mm Hg)
  - Pascal (Pa = 1 N/$m^2$)
  - Atmosphere (1 atm = 101.325 kPa = 760 torr)
  - Bar (1 bar = 100000 Pa = 100.000 kPa)
- SI Unit is the Pascal, but Torr and Atm are more useful

## Standard Temperature and Pressure

- For Gases STP is
  - Temperature = 273.15 K
  - Pressure = 1 atm
- At STP 1 Mole of Ideal Gas occupies 22.414 L (*standard molar volume*)
  - Derivation

## Ideal Gas Calculations

- A 125.0 mL sample of a gas at 25.0 °C is heated to 100.0 °C at constant pressure, what is its new volume?

## Ideal Gas Calculations

- If 0.1439 g of a solid substance sublimes to give 73.29 mL of the substance in the gaseous state at STP, what is its molar mass?

## Gas Laws and Stoichiometry

- Zinc metal reacts with hydrochloric acid to give $H_2$ gas. If 10.0 g Zn are allowed to react 100.0 mL of 0.500 M HCl, how many mL of $H_2$ will be generated at 25.0 °C and 750.0 mm Hg ?

## Gas Laws and Stoichiometry

$Zn\ (s) + 2\ HCl\ (aq) \longrightarrow H_2\ (g) + ZnCl_2\ (aq)$

| | | | | |
|---|---|---|---|---|
| volume | ------ | 100.0 | ? | ------ |
| conc. | ------ | 0.500 | ------ | ------ |
| grams | 10.0 | ------ | ------ | ------ |
| molar mass | 65.39 | ------ | ------ | ------ |
| moles | | | | ------ |

## Gas Mixtures

- *Dalton's Law of Partial Pressure*
  - Treat each gas as being alone in vessel
  - Total pressure is sum of the pressures of each individual gas (*partial pressure*)

$$p_{total} = p_1 + p_2 + p_3 + \ldots$$

  - Assumes gases do not interact
  - Gas is insoluble in any liquids present
- Also written in terms of *Mole Fraction* ($\chi_i$)

$$\chi_i = \frac{n_i}{n_{total}} \qquad p_i = \chi_i \cdot p_{total}$$

## Partial Pressure Problem

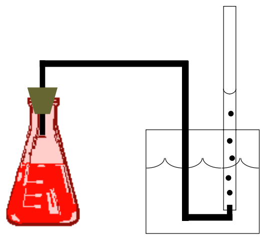
- A 1.56 g sample containing an unknown amount of $KClO_3$ is heated to decompose the $KClO_3$ to give $O_2$. When the reaction is over 327.0 ml $O_2$ is collected over water at 19.0 °C. The total pressure is 735.0 Torr, what is weight percent of $KClO_3$ in the sample? The vapor pressure of water is 16.5 Torr at 19.0 °C.

$$2\ KClO_3\ (s) \longrightarrow 2\ KCl\ (s) + 3\ O_2\ (g)$$

Adapted from Kotz and Treichel problem 12-59.

## Experimental Set-Up

- $O_2$ is collected by bubbling it through Water into a water-filled Gas Buret



Not only will there be $O_2$ gas present, but there will also be some water vapor!

## Kinetic-Molecular Theory

- Tenets of Kinetic-Molecular Theory
  - Particles are in constant, random, rapid motion
  - Average kinetic energy is proportional to temperature (in Kelvin)
  - Kinetic energy depends on particle mass
- Predicts Average Speed of Particles
  - Increases as temperature increases
  - Decreases as molar mass increases

## Application of Kinetic-Molecular Theory to Gases

- Ideal Gas Law can be derived
  - Assume particle collisions are elastic
  - Separation of gas particles is much larger than their size
- Fraction of Particles, $f(u)$ with a given Speed, $u$ is

$$f(u) = 4\pi \left(\frac{M}{2\pi RT}\right)^{3/2} u^2 e^{-Mu^2/2RT}$$

## Kinetic-Molecular Theory

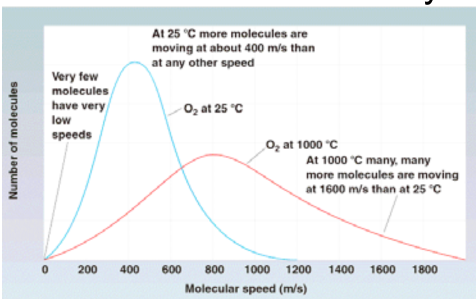



Figure 12.18 in Kotz and Treichel

## Kinetic-Molecular Theory

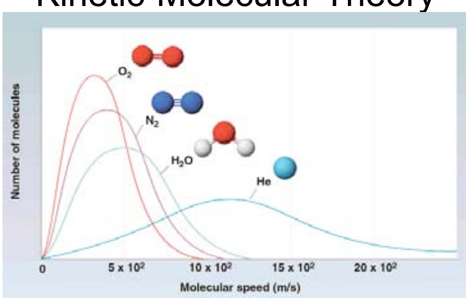



Figure 12.19 in Kotz and Treichel

## Diffusion and Effusion

- *Diffusion*: Mixing of two or more Gases due to random Motions of their Particles
- *Effusion*: Movement of Gas through a small Hole into an Area of Low Pressure
  - Graham's Law of Effusion

$$\frac{\text{Rate of effusion of gas 1}}{\text{Rate of effusion of gas 2}} = \sqrt{\frac{M_2}{M_1}}$$

  - Diffusion of two gases through air does <u>not</u> follow this law

## Non-Ideal Gases

- Real Gases
  - Interact with each other inelastically
  - Have a finite size
- Many Attempts have been made to correctly model these Effects
  - Van der Waals equation

$$\left(p + a\left(\frac{n}{V}\right)^2\right)(V - bn) = nRT$$

Corrects for interactions — Corrects for size