Avogadro's Hypothesis and Kinetic Molecular Theory

- At given temperature all molecules have the same kinetic energy. KE = ½ mv^2
- Pressure exerted by a gas is determined by the number of molecules in the gas and the speed that they travel
- Thus equal numbers must occupy equal volumes

Gas laws and Ideal Gas Laws

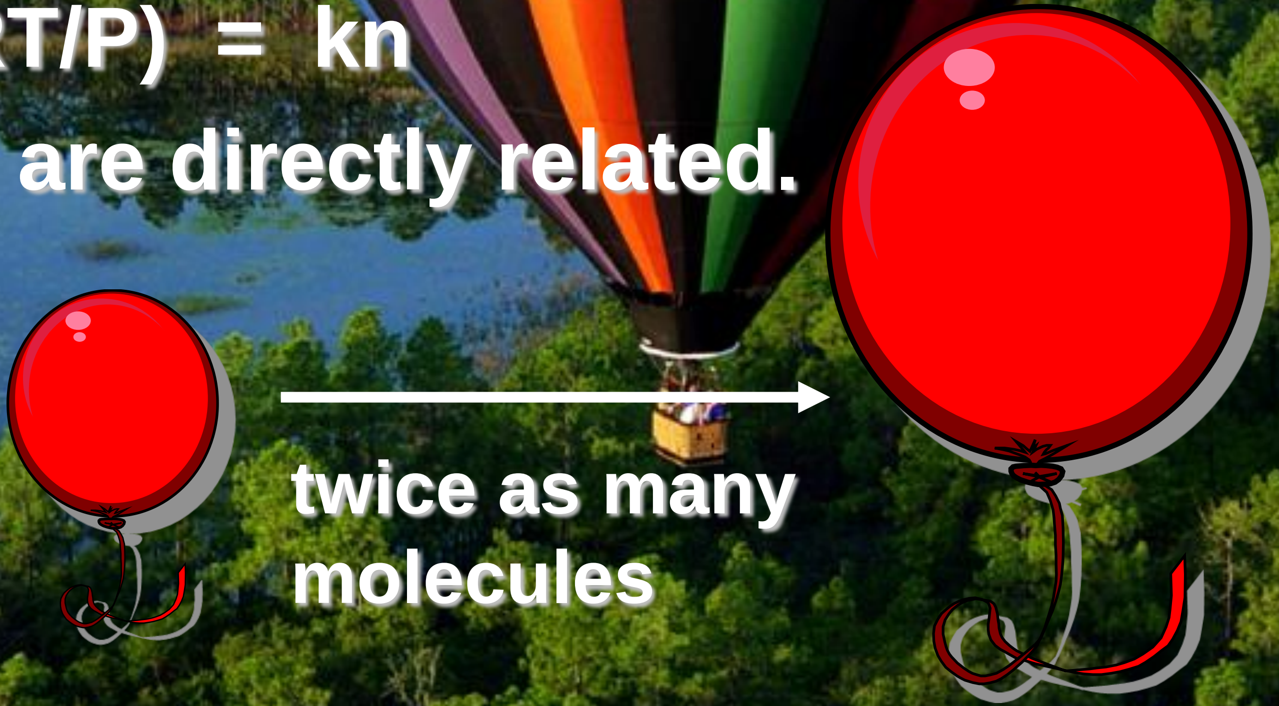
- **Boyles Law V=k/P or VP=k**
- **Charles Law**
  - **V=kT or V/T=K**

Avogadro's Hypothesis

Equal volumes of gases at the same T and P have the same number of molecules.

$V = n\ (RT/P) = kn$

V and n are directly related.



Molar Volume

- If the number of moles (n) are equal under similar Temperature and pressure then volume must be equal
- 1 mole of any gas will occupy 22.4 dm^3 STP
- Ideal gas equation combines Charles and Boyles with moles (n)
  - $V=k(T/P)$ or $PV = kT$
  - k depends on the number of molecules or particles present and number of particles present is your number of moles
    - » If one mole occupies 22.4 dm^3 @ STP then k has to include all of these (volume, pressure, temperature) and moles

IDEAL GAS LAW

$$P\,V = n\,R\,T$$

- Brings together gas properties.
- Can be derived from experiment and theory.
- BE SURE YOU KNOW THIS EQUATION!

Gas and the Mole

- **Since PV=kT and k must include moles and (temperature, pressure, volume)**
- **The (temperature, pressure, volume) of one mole is given the symbol R**
  a) So k = nR
  b) $$R = \frac{(101.325\ \text{kPa})\ (22.4\ \text{dm}^3)}{(1\text{mole})\ (273\ \text{K})}$$
  c) $R = 8.31\ \text{dm}^3 \cdot \text{kPa/mol} \cdot \text{K}$

Using PV = nRT

P = Pressure

V = Volume

T = Temperature

N = number of moles

R is a constant, called the **Ideal Gas Constant**

Instead of learning a different value for R for all the possible unit combinations, we can just **memorize one** value and **convert the units to match R.**

$$R = 8.31 \frac{dm^3 \cdot kPa}{Mol \cdot K}$$

Using PV = nRT

How much N_2 is required to fill a small room with a volume of 960 cubic feet (27,000 L) to 745 mm Hg at 25 ºC?

Solution

1. Get all data into proper units

   $V = 27{,}000\ L = 27000\ dm^3$

   $T = 25\ ^oC + 273 = 298\ K$

   $P = 745\ mm\ Hg\ (101.3\ kPa/760\ mm\ Hg)$
   $= 99.3\ kPa$

And we always know R, $8.31\ dm^3 \cdot kPa/\ mol\ K$

2. Now plug in those values and solve for the unknown.

$PV = nRT$

Molecular Mass Determination

- Moles = mass/molecular mass or n=m/M
- Then M=mRT/PV

Ideal Gas Law Questions

1. How many moles of CO_2(g) is in a 5.6 dm^3 sample of CO_2 measured at STP?
2. a) Calculate the volume of 4.50 mol of SO_2(g) measured at STP. b) What volume would this occupy at 25°C and 150 kPa? (solve this 2 ways)
3. How many grams of Cl_2(g) can be stored in a 10.0 dm^3 container at 1000 kPa and 30°C?
4. At 150°C and 100 kPa, 1.00 dm^3 of a compound has a mass of 2.506 g. Calculate its molar mass.
5. 98 cm^3 of an unknown gas weighs 0.087 g at STP. Calculate the molar mass of the gas. Can you determine the identity of this unknown gas?

Learning Check

Dinitrogen monoxide (N_2O), laughing gas, is used by dentists as an anesthetic. If 2.86 mol of gas occupies a 20.0 L tank at 23°C, what is the pressure (kPa) in the tank in the dentist office?

Learning Check

A 5.0 L cylinder contains oxygen gas at 20.0°C and 98 kPa. How many grams of oxygen are in the cylinder?

GAS DENSITY

22.4 L of ANY gas
AT STP = 1 mole

Low density

High density

Mass/Gas/Volume relationships

- It is easier to measure the volume of a gas than its mass
- Measure volume under existing conditions and convert to STP to find mass
  - Solving Mass Gas Volume equations
  - Example: What volume of hydrogen at STP can be produced from the reaction ooof 6.54 g Zn with HCl
    - » Write balanced equation: $2HCl + Zn \rightarrow H_2 + ZnCl_2$
    - » Find the number of moles of a given substance: 6.54 g Zn (1n Zn/64.5gZn)
    - » Find mole ratio of given to mole ratio of required
    - » Express moles of gas in terms of volume

$$6.54\text{g Zn} \cdot \frac{1\text{n Zn}}{65.4\text{ g Zn}} \cdot \frac{1\text{n } H_2}{1\text{n Zn}} \cdot \frac{22.4\text{ dm}^3}{1\text{n } H_2} = 2.24\text{ dm}^3$$

Gas Volume Mass Relationship

- Find the mass of a substance formed when the volume is known
- Example: How many grams of NaCl will result from the reaction of 112cm^3 of Cl_2 at STP with sodium
  - Determine the balanced equation: $2Na + Cl_2 \rightarrow 2NaCl$
  - Change volume of gas to moles
  - Determine mole ratio
  - Convert moles to grams
  - $0.112\ dm\,Cl_2 \cdot \frac{1n\ Cl_2}{22.4\ dm^3} \cdot \frac{2n\ NaCl}{1n\ Cl_2} \cdot \frac{58.5\ g\ NaCl}{1n\ NaCl} = 585\ g\ NaCl$

Volume Volume relationships

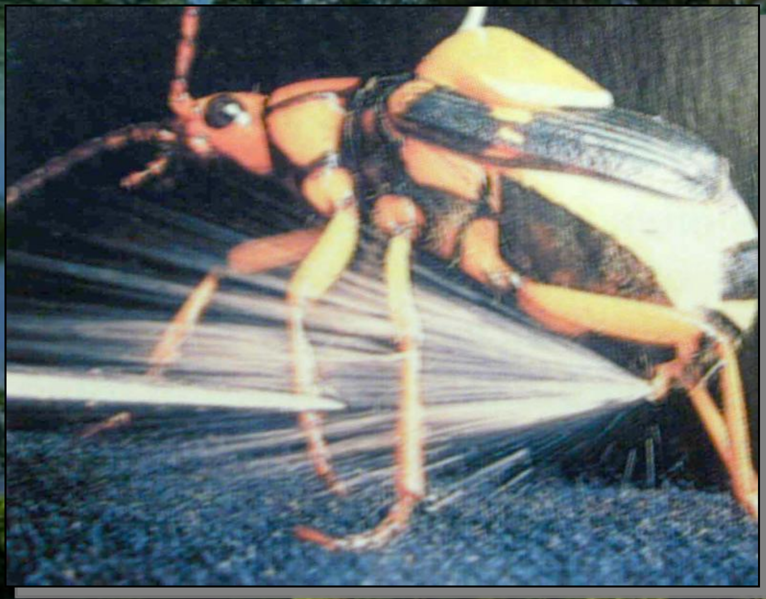
- Example: How many dm^3 of O_2 are required to burn 1 dm^3 of CH_4?

- Write the balanced equation $CH_4 + 2O_2 \rightarrow CO_2 + 2H_2O$
  - $1\ dm^3\ CH_4 \cdot \frac{1n\ CH_4}{22.4\ dm^3} \cdot \frac{2\ n\ O_2}{1n\ CH_4} \cdot \frac{22.4\ dm^3}{1n\ O_2} = 2\ dm^3\ O_2$
  - Solve by Inspection
    - » Since 22.4 dm^3 cancels out just use the gas Volume as the mole (n) ratio
    - » $1dm^3\ CH_4 \cdot \frac{2\ dm^3\ O_2}{1\ dm^3\ CH_4} = 2\ dm^3\ O_2$

Gases and Stoichiometry

2 H_2O_2 (l) ---> 2 H_2O (g) + O_2 (g)

Decompose 1.1 g of H_2O_2 in a flask with a volume of 2.50 L. What is the volume of O_2 at STP?



Bombardier beetle uses decomposition of hydrogen peroxide to defend itself.

Gases and Stoichiometry

$2\ H_2O_2\ (l) \longrightarrow 2\ H_2O\ (g) + O_2\ (g)$

Decompose 1.1 g of H_2O_2 in a flask with a volume of 2.50 dm^3. What is the volume of O_2 at STP?

Solution

1.1 g H_2O_2	1 mol H_2O_2	1 mol O_2	22.4 L O_2
	34 g H_2O_2	2 mol H_2O_2	1 mol O_2

= 0.36 L O_2 at STP

Gas Stoichiometry: Practice!

A. What is the volume at STP of 4.00 g of CH_4?

B. How many grams of He are present in 8.0 dm^3 of gas at STP?

What if it's NOT at STP?

- 1. Do the problem like it was at STP. (V_1)
- 2. Convert from STP (V_1, P_1, T_1) to the stated conditions (P_2, T_2)

Try this one!

How many dm^3 of O_2 are needed to react 28.0 g NH_3 at 24°C and 0.950 atm?

$$4\ NH_3(g) + 5\ O_2(g) \longrightarrow 4\ NO(g) + 6\ H_2O(g)$$

Limiting Reactants

- Limiting reactant is the chemical which is completely consumed in the reaction
- Example How many grams of CO_2 - are formed if 10.0 g of carbon are burned in 20.0 dm^3 of O_2
  - Write the balanced equation: $C + O_2 \rightarrow CO_2$
  - Change both quantities to moles:
    Complete the problem based on the limiting reactant