Molecular Composition of Gases

Honors chemistry – Semester 2

Objectives

Understand and use ideal gas law

Describe relationship between gas behavior and chemical formulas of gases

Apply reaction stoichiometry to gas stoichiometry

Key Terms

Ideal gas

Ideal gas law

Diffusion and Graham’s Law

Effusion

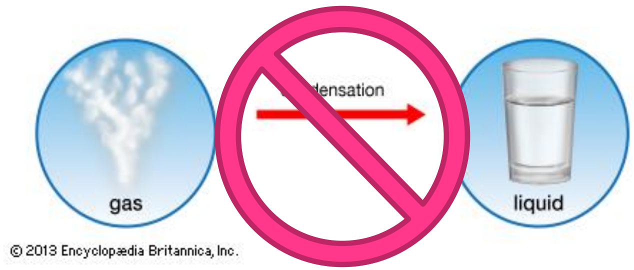
Gay-Lussac’s Law of combining volumes

Partial pressure and Dalton’s Law

Ideal Gas

= **hypothetical gas that perfectly follows gas laws**

- **Does not condense to liquid at low temp**



- **Has no attraction/repulsion between particles**
- **Particles with zero volume**

Gas Laws

No gas obeys gas laws perfectly

Gas laws good enough in most cases

What if we change temp, pressure *<u>and</u>* volume??

Boyle's Law
+ Charles' Law
+ Avogadro's Law

= Ideal Gas Law

Ideal Gas Law

Ideal gas law **combines four laws into one**

PV = nRT

P = pressure

V = volume

n = # moles

T = temperature (in kelvin)

R = constant


PV = nRT
One Law to Rule Them All.
One Law Combines Them.
One Law Defines the Terms and Makes the Students Find Them.

Ideal Gas Law

Value of R depends upon units of pressure

R = 8.314 L·kPa / mol·K

or

R = 0.0821 L·atm / mol·K

Pay attention to units ideal gas law problems!

Ideal Gas Law

Works well in most common settings

Fails under very <u>high pressure </u>or very <u>low temp</u>

Why?

- **Intermolecular forces become a factor**
- **Volume of particles becomes non-trivial**

Example

How many moles of gas are contained 22.41 L at 101.325 kPa and 0 °C?

PV = nRT

R = 8.314 L·kPa / mol·K

n = PV / RT

= (101.325 kPa)(22.41 L) / (8.314 L·kPa / mol·K)(273 K)

= 1.00 mol

Example

What is the volume of 17.5 mol of H_2 at 2.75 atm and 385 K?

PV = nRT

R = 0.0821 L·atm / mol·K

V = nRT/P

= ((17.5 mol)(0.0821 L·atm / mol·K)(385 K)) / (2.75 atm)

= 201 L

Practice

Calculate the pressure in kPa exerted by 43 mol of nitrogen in a 65 L cylinder at 5 °C.

1500 kPa

How many moles of air molecules are contained in a 2.00 L flask at 98.8 kPa and 25.0 °C?

7.98×10^{-2} mol

Gas Stoichiometry

Stoichiometry = ratios between compounds in a chemical equation

***Ratio of gas volumes* = *ratio of moles* of those gases (Avogadro's Law)**

Gas Stoichiometry

Example

$$2\ H_{2(g)} + O_{2(g)} \rightarrow 2\ H_2O_{(g)}$$

***Mole* ratio**

$H_2 : O_2 = 2:1$

$H_2 : H_2O = 1:1$

$O_2 : H_2O = 1:2$

***Volume* ratio**

$H_2 : O_2 = 2:1$

$H_2 : H_2O = 1:1$

$O_2 : H_2O = 1:2$

Gas Stoichiometry

To find volume of gas produced in reaction you may need to use:

- **mole ratio between chemicals**
- **volume ratio between gasses**
- **ideal gas law to convert moles to volume**

Example

How many liters of hydrogen gas are produced at 280.0 K and 96.0 kPa if 1.74 mol sodium react with excess water?

$$2Na_{(s)} + 2H_2O_{(l)} \rightarrow 2NaOH_{(aq)} + H_{2(g)}$$

Gather information:

R = 8.314 L·kPa/mol·K

P = 96.0 kPa

T = 280.0K

n_{Na} = 1.74 mol Na

n_{H2} = ? mol H_2

V_{H2} = ? L H_2

Example

Use mole ratio to find # moles of H_2 produced

Now use ideal gas law to find volume of H_2

Example

What volume of O_2 gas is collected at 25 °C and 101 kPa from decomposition of 37.9 g potassium chlorate?

$$2KClO_{3(s)} \rightarrow 2\ KCl_{(s)} + 3O_{2(g)}$$

Collect information:

R = 8.314 L·kPa/mol·K

T = 25 °C = 298 K

n = ? mol O_2

P = 101 kPa

m_{KClO3} = 37.9 g $KClO_3$

V = ? L O_2

Example

Convert grams $KClO_3$ to moles

Use mole ratio to find moles of O_2

Use ideal gas law to find volume of O_2

Example

$$37.9\ g\ KClO_3 \times \frac{1\ mol\ KClO_3}{122.6\ g} = 0.309\ mol$$

$KClO_3$:O_2 = 2:3

$$0.309\ mol\ KClO_3 \times \frac{3\ mol\ O_2}{2\ mol\ KClO_3} = 0.464\ mol\ O_2$$

V = nRT/P

$$= \frac{0.464\ mol\ O_2 \left(\frac{8.314\ L{\cdot}kPa}{mol{\cdot}K}\right) 298\ K}{101\ kPa} = 11.4\ L\ O_2$$

Practice

Liquid hydrogen and oxygen are burned in a rocket. What volume of water vapor at 555 °C and 76.4 kPa can be produced from 4.67 kg of H_2?

$$2H_{2(l)} + O_{2(l)} \rightarrow 2H_2O_{(g)}$$

Hint:

Convert kg H_2 to moles H_2

Use mole ratio H_2 : H_2O to find moles H_2O

Use ideal gas law to find volume of H_2O

2.1×10^5 L H_20

Practice

How many grams of sodium are needed to produce 2.24 L of hydrogen at 23 °C and 92.5 kPa?

$$2Na_{(s)} + 2H_2O_{(l)} \rightarrow 2NaOH_{(aq)} + H_{2(g)}$$

Hint:

Use ideal gas law to find moles of H_2

Use mole ratio H_2 : Na to find moles Na needed

Convert moles Na to grams Na

3.87 g Na

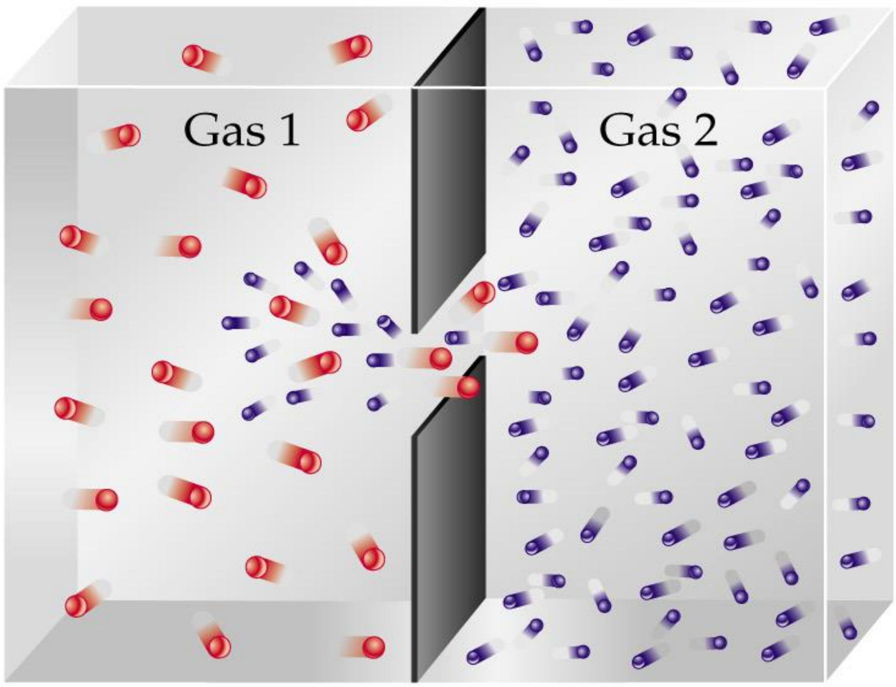
Diffusion

Diffusion = the mixing of different gases by random molecular motion and collision

Gases spread from areas of high concentration to low concentration

Increases entropy

Heavy molecules move slower than light ones

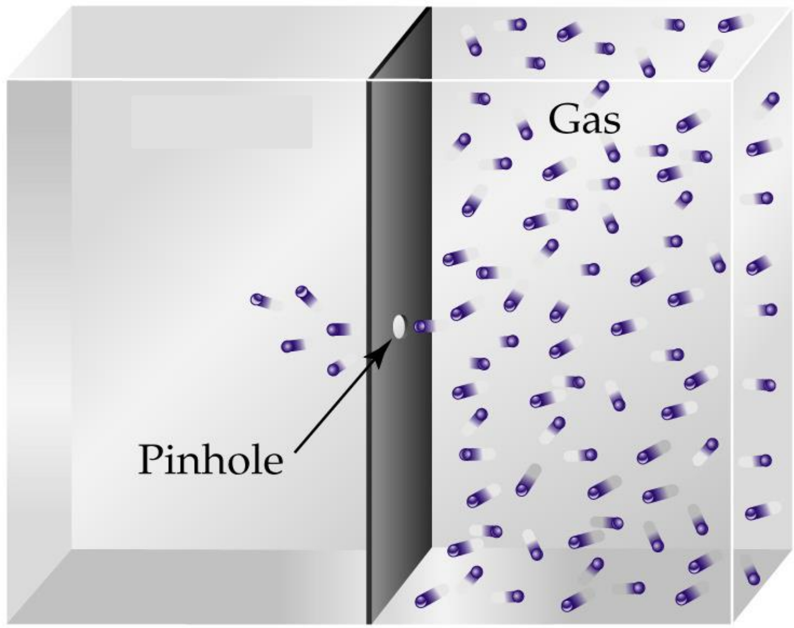


Effusion

Effusion = gas escapes through a tiny hole under pressure

Rate of effusion inversely proportional to mass of molecule (light gasses effuse faster)

Think about it:
Would H_2 or CO_2 leak out of small hole faster? Why?



(b)

Graham's Law

- Graham's Law**:** Rate of diffusion is inversely proportional to the square root of its mass

- Speed of two molecules, A and B, at same temp and pressure related by

$$\frac{V_A}{V_B} = \sqrt{\frac{M_B}{M_A}}$$

- Re-write equation as $\frac{1}{2}M_A V_A^2 = \frac{1}{2}M_B V_B^2$ (kinetic energy)

At same temp, heavy gas moves slower

Example

If O_2 moves at 480 m/s at room temp, how fast does SF_6 move?

Use Graham's Law

$$\frac{V_A}{V_B} = \sqrt{\frac{M_B}{M_A}}$$

$$\frac{V_{SF6}}{V_{O2}} = \sqrt{\frac{M_{O2}}{M_{SF6}}}$$

$V_{SF6} = 220$ m/s

Dalton's Law of Partial Pressure

In mixture of gasses, each gas exerts a partial pressure proportional to # moles of that gas

Total system pressure = sum of all the partial pressures

- $P_{total} = P_A + P_B + P_C + \ldots$

Example:

- A system has P_{O2} of 1.0 atm and P_{CO2} of 3.5 atm
- $P_{total} = P_{O2} + P_{CO2} = 1.0$ atm + 3.5 atm = 4.5 atm