UNIT 4 GASES AND ATMOSPHERIC CHEMISTRY
(McGraw-Hill Chemistry 11 Text Chapters 11 & 12)

Chapter 11 *Behaviour of Gases*

KINETIC MOLECULAR THEORY
(11.1, pp. 516+)

The **kinetic molecular theory** of gases makes the following assumptions:

1. The volume of particles (molecules) is negligible compared to volume of container (i.e. mostly empty space)
2. There are neither attractive nor repulsive forces between gas molecules.
3. Gas molecules move randomly in all directions, in straight lines
4. Collisions are perfectly elastic. There is no loss of energy.
5. At any given temperature, the average kinetic energy of particles in all gases is the same. Increase temp., increase motion, increase K.E.

The kinetic molecular theory describes a hypothetical gas called an ideal gas.

STATES OF MATTER AND THE KMT

STATE	DESCRIPTION, CHARACTERISTICS AND FORCES
SOLID	- definite shape and volume - do not flow easily & are virtually incompressible - positions of particles relatively fixed - held together in a framework - vibrational motion only
LIQUID	- definite volume, take shape of container - flow readily & are virtually incompressible. - particles can move around more but not independently - vibrational & rotational motion
GAS	- take shape and volume of container - flow readily & are highly compressible - particles move independently of one another. - more space, more compressibility - vibrational, rotational & translational motion

Homework Assignment: p. 519 11.1 Questions #1-10

2.

GAS PRESSURE AND VOLUME GAS LAWS (11.7-11.9) pp. 541-562

Define **pressure:** force exerted on an object per unit of surface area

Atmospheric pressure: results from air molecules being pulled down by gravity and exerting pressure on all objects on Earth. If atmospheric pressure decreases suddenly, a storm may be on the way. At higher elevations, atmospheric pressure is lower and therefore water boils at a lower temperature and therefore it takes longer for food to cook in boiling water on a mountain top than at sea level.

Units of pressure: Pa (pascal), kPa (kilopascal), torr, atm, mm Hg

1 atm = 760 torr = 101.3 kPa = 760 mm Hg

BOYLE'S LAW: ***Relationship between Pressure and Volume***

Volume of a given amount of gas, at a constant temperature, varies inversely with the applied pressure

Formula: $P_1V_1 = P_2V_2$

Sample Problem

In Vancouver, a balloon with a volume of 5.0 L is filled with air at 101 kPa pressure. The balloon is then taken to Banff, where the atmospheric pressure is only 91 kPa. Will the balloon's volume be larger or smaller at Banff? If the temperature is the same in both places, what will the new volume of the balloon be?

Given:
$V_1 = 5.0\ L$
$P_1 = 101\ kPa$
$P_2 = 91\ kPa$

$$P_1V_1 = P_2V_2$$
$$101(5) = 91(V_2)$$
$$V_2 = \frac{101(5)}{91}$$
$$= 5.5\ L$$

Assignment: p. 543 Practice #1.
p. 559 Practice #1, 2.

GASES AND TEMPERATURE CHANGES

CHARLES' LAW: ***Relationship between Temperature and Volume***

Volume of a fixed mass of gas is proportional to its temperature when the pressure is kept constant.

Formula:

$$\frac{V_1}{T_1} = \frac{V_2}{T_2}$$

Temperature must be in "Kelvin" units:

$$T_K = {}^\circ C + 273$$

Sample Problem:

A balloon is filled with helium gas to a volume of 1.20 L and at a temperature of 15 ^{0}C. If the pressure remains constant and the temperature rises to 30 ^{0}C, what will the new volume of the balloon be?

Given:

$V_1 = 1.20 L$

$T_1 = 15^\circ C + 273 = 288 K$

$T_2 = 30 + 273 = 303 K$

$$\frac{V_1}{T_1} = \frac{V_2}{T_2}$$

$$\frac{1.20}{288} = \frac{V_2}{303}$$

$$V_2 = \frac{1.20(303)}{288}$$

$$V_2 = 1.26 L$$

***Assignment:* Practice** p. 552 #1, 2

GAY-LUSSAC'S LAW: ***Relationship between Temperature and Pressure***

Pressure of a fixed amount of gas, at constant volume, is directly proportional to its Kelvin temperature

Formula:

$$\frac{P_1}{T_1} = \frac{P_2}{T_2}$$

Sample Problem:

At a temperature of 10^{0}C, a container is filled with gas at a pressure of 225 kPa. What will the pressure be if the container is placed in the hot sun to reach a temperature of 42^{0}C?

Given:

$P_1 = 225 kPa$

$T_1 = 10^\circ C + 273 = 283 K$

$T_2 = 42 + 273 = 315 K$

$$\frac{P_1}{T_1} = \frac{P_2}{T_2}$$

$$\frac{225}{283} = \frac{P_2}{315}$$

$$P_2 = \frac{225(315)}{283} = 250 kPa$$

4.

COMBINED GAS LAW

STP 0°C (273 K) and 1 atm (101.3 kPa)

SATP 25°C and 100 kPa

Formula:

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

Sample Problem:

A weather balloon with a volume of 55.0 L is filled with hydrogen gas at a pressure of 98.5 kPa and a temperature of 13°C. When the balloon is released, it rises to the stratosphere where the temperature is - 48°C and the pressure is 19.7 kPa. What is the volume of the balloon under these conditions?

Given:

$V_1 = 55.0 L$

$P_1 = 98.5 kPa$

$T_1 = 13°C + 273 = 286 K$

$T_2 = -48 + 273 = 225 K$

$P_2 = 19.7 kPa$

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

$$\frac{98.5(55)}{286} = \frac{19.7(V_2)}{225K}$$

$$\frac{98.5(55)(225)}{286(19.7)} = V_2$$

$$V_2 = 216 L$$

Assignment: p. 560 Practice #1-3

DALTON'S LAW OF PARTIAL PRESSURES

Total Pressure of a mixture of gases is the sum of the pressures of each of the individual gases.

Formula:

$$P_{TOTAL} = P_1 + P_2 + P_3 + ... + P_n$$

Sample Problem:

What is the pressure contribution of CO_2 to the atmospheric pressure on a very dry day when the barometer reads 0.98 atm and CO_2 contributes 0.03% of the atmospheric pressure?

$$\frac{0.03}{100} \times 0.98 = 2.9 \times 10^{-4} atm$$

In kPa? $2.9 \times 10^{-4} atm \times \frac{101.3 kPa}{1 atm} = 0.03 kPa$

Assignment: p. 594 Practice #1-4

THE IDEAL GAS LAW (12.1, 12.2 pp. 576–588)

Molar Volume of Gases at STP = 22.4 L/mol

Avogadro's Law: $\frac{n_1}{V_1} = \frac{n_2}{V_2}$ n = no. of moles, V = volume

Sample Problems:

1. What is the molar volume of hydrogen gas at 255°C and 102 kPa, if a 1.09 L volume of the gas has a mass of 0.0513 g?

$$\text{Molar Volume} = \frac{L}{mol} \qquad n = \frac{0.0513\,g}{2.02} = 0.0254\ mol$$

$$\frac{L}{mol} = \frac{1.09\,L}{0.0254\,mol} = 42.9\ \frac{L}{mol}$$

2. Suppose you have 44.8 L of methane gas at STP.

a) How many moles are present?

b) What is the mass of the gas?

c) How many molecules of gas are present?

a) $\frac{22.4\,L}{1\,mol} = \frac{44.8\,L}{x\,mol}$ ∴ $x = 2$ mol

b) $CH_4 \rightarrow 16.05$ g/mol

∴ $2\,mol \times 16.05\,g/mol = 32.1\,g$

c) $2\,mol \times 6.02 \times 10^{23}\ \frac{molecules}{mol} = 1.204 \times 10^{24}$ molecules

Assignment: p. 579 Practice # 1–3
p. 580 Practice # 1–3

IDEAL GAS LAW FORMULA:

$$PV = nRT$$

P (pressure) – kPa
V (volume) – L
n (moles) – mol
T (temperature) – K

$R = 8.314\ \frac{kPa \cdot L}{mol \cdot K}$

Guidelines for Using the Ideal Gas Law:

1. Convert temperature to K (Kelvins)
2. Convert mass to moles
3. Convert volume to litres (L)
4. Convert pressure to kPa (kilopascals)
5. Use $R = 8.314\ kPa \cdot L / mol \cdot K$

6.

Sample Problems:

1. A 2.50 L container is filled with sulfur dioxide gas at a pressure of 120 kPa and a temperature of 26°C. Calculate the mass of sulfur dioxide gas in the container.

$n = \frac{m}{M}$

$SO_2 \Rightarrow 64.1 g/mol$

V = 2.50 L
P = 120 kPa
T = 26 + 273 = 299 K
m = ?
R = 8.314

$PV = nRT$

$120(2.5) = n(8.314)(299)$

$n = \frac{120(2.5)}{8.314(299)} = 0.121 mol$

$m = n \times M = 0.121 \times 64.1 \frac{g}{mol} = 7.76 g$

2. Find the volume of 1.00 g of water in the gas phase at its boiling point (100°C) at 101 kPa.

V = ?
m = 1 g
T = 100 + 273 = 373
P = 101 kPa

$n = \frac{m}{M}$ $M_{H_2O} = 18.02 g/mol$

$= \frac{1}{18.02} = 0.0555 mol$

$PV = nRT$

$101(V) = 0.0555(8.314)(373)$

$V = \frac{0.0555(8.314)(373)}{101}$

$= 1.7 L$

3. In the middle layer of the stratosphere, the ozone concentration is about 5.0 x 10^{15} molecules/L at a temperature of about - 42°C. What is the pressure in Pa of the ozone under these conditions?

# molecules = 5.0×10^{15}
V = 1 L
T = -42 + 273 = 231
P = ?
R = 8.314

$\frac{5 \times 10^{15}}{6.02 \times 10^{23}} = 8.3 \times 10^{-9} mol$

$PV = nRT$

$P(1) = 8.3 \times 10^{-9}(8.314)(231)$

$P = 1.59 \times 10^{-5} kPa$

$= 1.59 \times 10^{-2} Pa$

Assignment: Practice Problems, p. 587 #1-4

APPLICATIONS OF THE IDEAL GAS LAW

	Molar Volume	Density	Molar Mass
Unit	L/mol	g/L	g/mol
Meaning	volume/amount	mass/volume	mass/amount
Calculations	$MV = \frac{V}{n}$ molar volume = volume / # moles	$D = \frac{m}{V}$ Density = mass / volume	$M = \frac{m}{n}$ Molar Mass = Mass / # moles

Sample Problems:

1. Nitrogen gas makes up almost 80% of our atmosphere. What is the density of pure nitrogen gas, in g/L, at 12.50°C and 126.63 kPa?

$P = 126.63\ kPa$

$T = 12.5 + 273 = 285.5\ K$

① $M_{N_2} = 2 \times 14.01 = 28.02\ g/mol$

② $PV = nRT$

$126.63(1) = n(8.314)(285.5)$

$n = \frac{126.63}{8.314(285.5)} = 0.0533\ mol$

③ $m = M \times n = 28.02 \times .0533 = 1.495\ g$

④ $D = \frac{m}{V} = \frac{1.495\ g}{1\ L} = 1.495\ g/L$

2. A scientist isolates 2.366 g of a gas. The sample occupies a volume of 800 mL at 78.0°C and 103 kPa. Use these data to calculate the molar mass of the gas. Which noble gas is this likely to be?

$P = 103\ kPa$

$T = 78 + 273 = 351\ K$

$m = 2.366\ g$

$V = 0.8\ L$

$R = 8.314$

$PV = nRT$

$103(0.8) = n(8.314)(351)$

$n = 0.0282\ mol$

$M = \frac{m}{n} = \frac{2.366\ g}{0.0282\ mol} = 83.9\ g/mol$

∴ Krypton

Assignment: p. 589 #4–9

8. **GAS LAW STOICHIOMETRY** (12.5 pp.598-603)

When gases react, the volumes of the reactants and the products, measured at equal temperatures and pressures, are always in whole number ratios.

How to Solve Gas Stoichiometry Problems

1. Write a balanced equation
2. Write given info. under appropriate reactants & products. Put "?" for unknown.
3. Convert all amounts to moles
4. Compare mole ratios and solve for unknown molar amount
5. Convert new molar amount into units required.

Sample Problems:

1. Hydrogen gas is produced when sodium metal is added to water. What mass of sodium is necessary to produce 20.0 L of hydrogen at STP?

$2Na + 2H_2O \rightarrow H_2 + 2NaOH$

? g — 20 L

1.786 mol — 22.4 L/mol (at STP)

$\therefore \frac{20}{22.4} = \frac{0.89\ mol}{1} \times 2 = 1.786$ mol Na

$M_{Na} = 22.99$ g

$m = n \times M = 1.786 \times 22.99 = 41.1$ g

2. In the presence of manganese (IV) oxide, hydrogen peroxide decomposes to form oxygen gas and water. What volume of oxygen gas will be produced at 21°C and 103 kPa from 125 mL of 6.00 mol/L hydrogen peroxide solution?

$T = 21 + 273 = 294\ K$

$P = 103\ kPa$

$2H_2O_2 \xrightarrow{MnO_2} 2H_2O + O_2$

$C = 6\ mol/L$ — ? L

$V = 0.125\ L$

$n = C \times V = 0.75\ mol$

$\div 2 \times 1 = 0.375\ mol\ O_2$

$PV = nRT$

$103(V) = 0.375(8.314)(294)$

$V = 8.9\ L$

Assignment: p. 599 Practice #1-3

p. 602 Practice #1-3