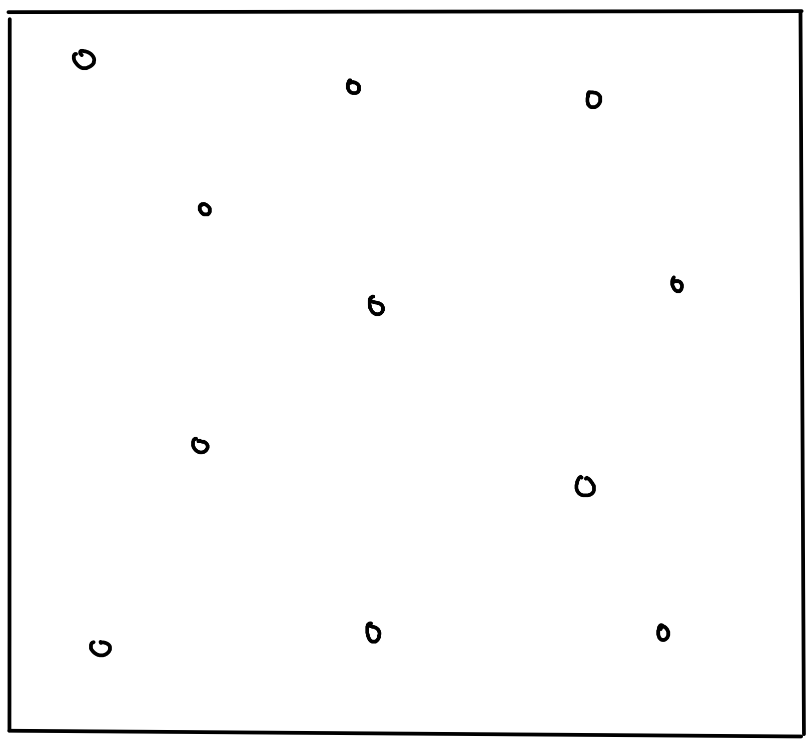
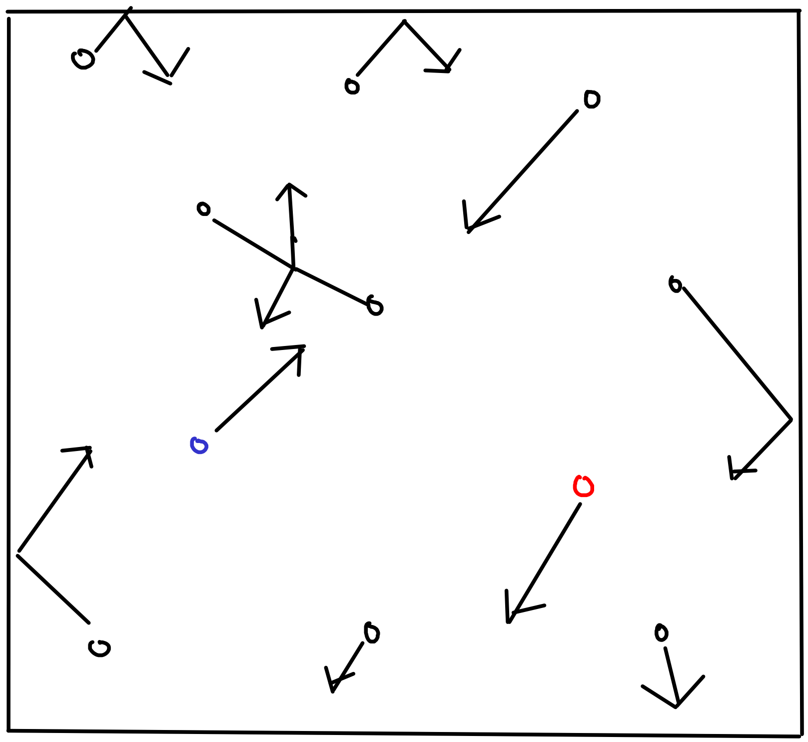
# THE KINETIC PICTURE OF GASES



1. Gas molecules are small compared to the space between the gas molecules!

LOW DENSITY!



(2) Gas molecules are constantly in motion. They move in straight lines in random directions and with various speeds.

(3) Attractive and repulsive forces between gas molecules are so small that they can be neglected except in a collision.

- Each gas molecule behaves independently of the others.

(4) Collisions between gas molecules and each other or the walls are ELASTIC.

(5) The average kinetic energy of gas molecules is proportional to the absolute temperature.

How does this picture explain the properties of gases?

- Gases expanding to fill their container? Agrees with kinetic picture, since gas molecules are independent
- Thermal expansion of gas at constant pressure? Agrees, because the container has to EXPAND to keep the pressure (from collisions) constant when the gas molecules move faster.
- Pressure increases with temperature at constant volume: Agrees, because the number and force of collisions increases with molecular speed.

GAS LAWS

- were derived by experiment long before kinetic theory, but agree with the kinetic picture!

Boyle's Law:

$$PV = \text{constant}$$

True at constant temperature

$$P_1V_1 = \text{constant} \qquad P_2V_2 = \text{constant}$$

$$P_1V_1 = P_2V_2$$

True at constant temperature

Charles's Law:

$$\frac{V}{T} = \text{constant}$$

True at constant pressure, and using ABSOLUTE temperature

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

True at constant pressure, and using ABSOLUTE temperature

Combined gas law: $\frac{PV}{T} = \text{constant}$

Must use ABSOLUTE temperature units!

↓

$$\frac{P_1 V_1}{T_1} = \frac{P_2 V_2}{T_2}$$

Must use ABSOLUTE temperature units!

↑ amount (moles) of gas must be constant!

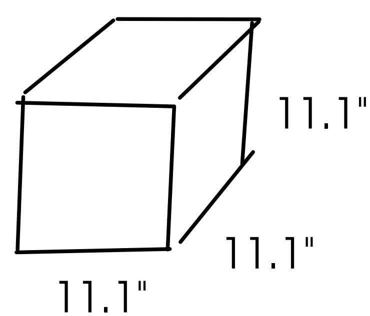
Avogadro's law:

- a mole of any gas at the same conditions has the same volume.

1 mol gas molecules @ 0°C and 1 atm

volume = 22.4 L

"STP"
Standard Temperature and Pressure




= 22.4 L

Ideal gas law:

$$\frac{PV}{T} = \text{constant}$$

... but this constant actually depends on the amount of gas!

$$= n \times \text{"}R\text{"}$$

The ideal gas constant.

$$0.08206 \ \frac{L \cdot atm}{mol \cdot K}$$

... combining these together ...

$$\frac{PV}{T} = nR$$

$$PV = nRT$$

P = pressure atm

V = volume L

T = ABSOLUTE temperature K

R = ideal gas constant

n = number of moles of gas molecules

# CHEMICAL CALCULATIONS WITH THE GAS LAWS

$FW_{NaHCO_3} = 84.007\ g/mol$

$H_2SO_4(aq) + 2NaHCO_3(s) \rightarrow 2H_2O(l) + 2CO_2(g) + Na_2SO_4(aq)$

Given 25.0 g of sodium bicarbonate and sufficient sulfuric acid, what volume of carbon dioxide gas would be produced at 25.0 C and 0.950 atm pressure?

1 - Convert grams of sodium bicarbonate to moles; use formula weight.

2 - Convert moles sodium bicarbonate to moles carbon dioxide; use chemical equation

3 - Convert moles carbon dioxide gas to volume; use ideal gas equation

$84.007\ g\ NaHCO_3 = mol\ NaHCO_3$ | $2\ mol\ NaHCO_3 = 2\ mol\ CO_2$

$$25.0\ g\ NaHCO_3 \times \underset{①}{\frac{mol\ NaHCO_3}{84.007\ g\ NaHCO_3}} \times \underset{②}{\frac{2\ mol\ CO_2}{2\ mol\ NaHCO_3}} = 0.2975942481\ mol\ CO_2$$

③ $PV = nRT$

$\downarrow$

$V = \frac{nRT}{P}$

$n = 0.2975942481\ mol\ CO_2$ $\quad P = 0.950\ atm$

$R = 0.08206\ \frac{L \cdot atm}{mol \cdot K}$ $\quad V = ???\ L$

$T = 25.0\,^{\circ}C = 298.2\ K$

$$V = \frac{(0.2975942481\ mol\ CO_2)\left(0.08206\ \frac{L \cdot atm}{mol \cdot K}\right)(298.2\ K)}{(0.450\ atm)} = 7.67\ L\ CO_2\ gas$$

What volume would the gas in the last example problem have at STP?

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STP: "Standard Temperature and Pressure" (0 C and 1 atm)

We can solve this one using the combined gas law:

$$\frac{P_1V_1}{T_1} = \frac{P_2V_2}{T_2} \quad ; \quad \frac{P_1V_1T_2}{T_1P_2} = V_2$$

$P_1 = 0.950$ atm $\quad P_2 = 1.00$ atm

$V_1 = 7.67$ L $\quad T_2 = 0°C = 273.2$ K

$T_1 = 298.2$ K $\quad V_2 = ???$ L

$$V_2 = \frac{P_1V_1T_2}{T_1P_2} = \frac{(0.950\text{ atm})(7.67\text{ L})(273.2\text{ K})}{(298.2\text{ K})(1.00\text{ atm})} = 6.67\text{ L } CO_2 \text{ at STP}$$

Alternate solution: Since we knew the number of moles of carbon dioxide in the previous problem, we could have also used the ideal gas law to find the new volume. (The answer will, of course, be the same number!)

$FW_{NH_4NO_3} = 80.0434\ g/mol$

$$2\,NH_4NO_3(s) \longrightarrow 2\,N_2(g) + O_2(g) + 4\,H_2O(g)$$

At 300°C, ammonium nitrate violently decomposes to produce nitrogen gas, oxygen gas, and water vapor. What is the total volume of gas that would be produced at 1.00 atm by the decomposition of 15.0 grams of ammonium nitrate?

Hint: Since this problem asks for the TOTAL volume of gas, calculate the total from the total number of moles of all the gases together. We don't need to treat water vapor, nitrogen, and oxygen separately.

1 - Convert mass of ammonium nitrate to moles using formula weight.
2 - Convert moles ammonium nitrate to TOTAL MOLES OF GAS using chemical equation
3 - Convert TOTAL MOLES OF GAS to TOTAL VOLUME OF GAS using ideal gas equation

$80.0434\ g\ NH_4NO_3 = mol\ NH_4NO_3$ | $2\ mol\ NH_4NO_3 = 7\ mol\ gas\quad (2+1+3)$

$$15.0\ g\ NH_4NO_3 \times \underset{①}{\frac{mol\ NH_4NO_3}{80.0434\ g\ NH_4NO_3}} \times \underset{②}{\frac{7\ mol\ gas}{2\ mol\ NH_4NO_3}} = 0.655894\ mol\ gas$$

$V = \frac{nRT}{P}$ | $n = 0.655894\ mol\ gas \quad T = 300\,^\circ C = 573\ K \quad V = ?\ L$

$R = 0.08206\ \frac{L \cdot atm}{mol \cdot K} \quad P = 1.00\ atm$

$$③\quad V = \frac{(0.655894\ mol\ gas)\left(0.08206\ \frac{L \cdot atm}{mol \cdot K}\right)(573\ K)}{(1.00\ atm)} = \boxed{30.8\ L\ gas}$$