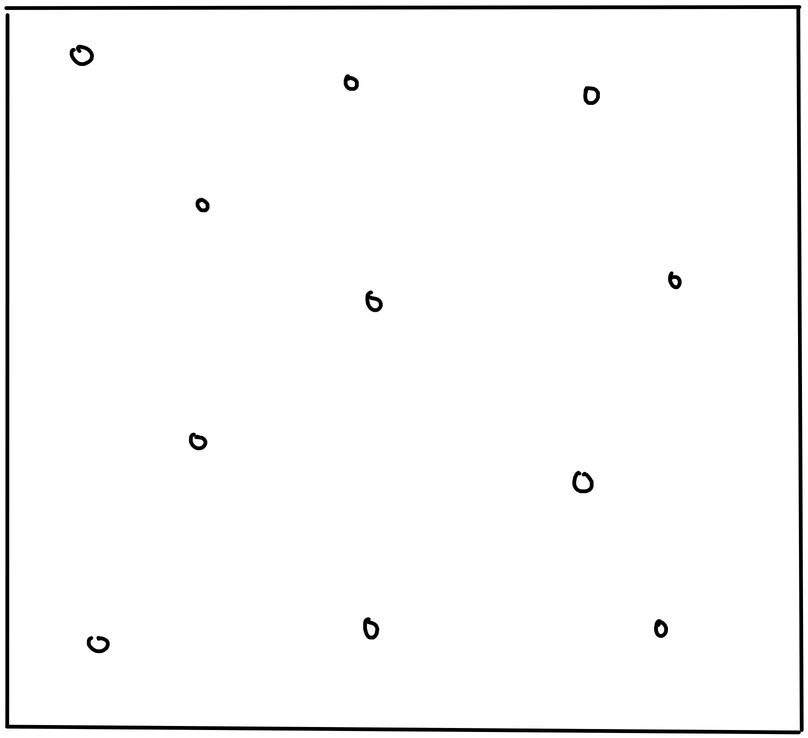
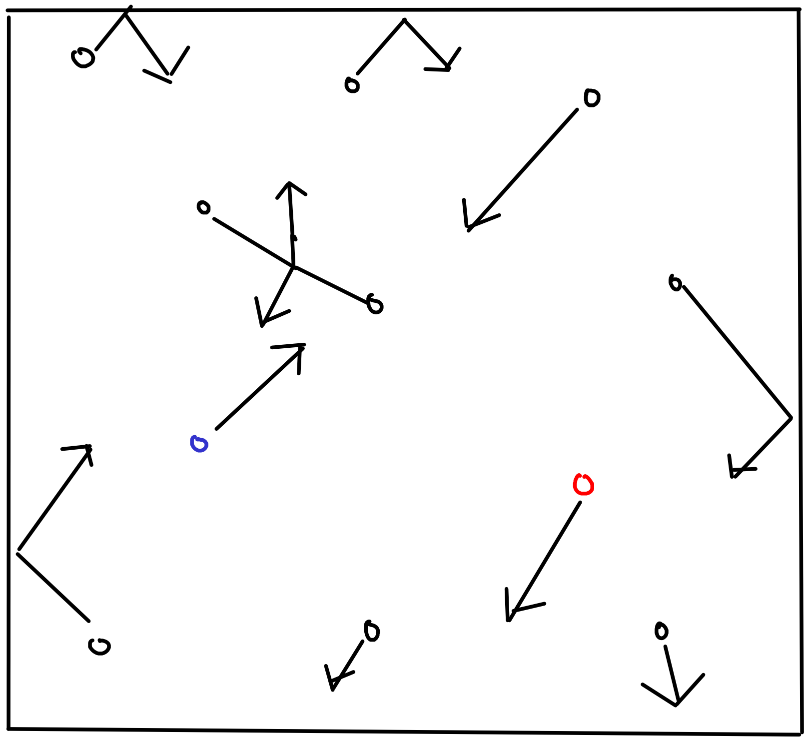
THE KINETIC PICTURE OF GASES



(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

$$P_1 V_1 = \text{constant} \qquad P_2 V_2 = \text{constant}$$

$$P_1 V_1 = P_2 V_2$$

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!

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

Must use ABSOLUTE temperature units!

amount (moles) of gas must be constant!

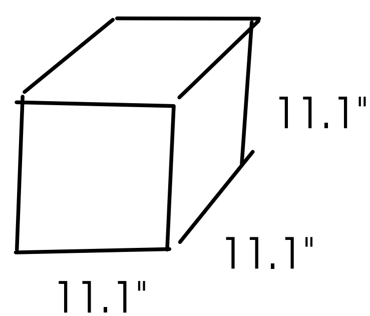
Avogadro's law:

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

1 mol gas molecules @ 0°C and 1 atm

"STP"
Standard Temperature and Pressure

volume = 22.4 L



= 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

A balloon is taken from a room where the temperature is 27.0 C to a freezer where the temperature is -5.0 C. If the balloon has a volume of 3.5 L in the 27.0 C room, what is the volume of the balloon in the freezer. Assume pressure is constant.

$\frac{P_1V_1}{T_1} = \frac{P_2V_2}{T_2}$; P constant $\frac{V_1}{T_1} = \frac{V_2}{T_2}$

$V_1 = 3.5\,L$ $V_2 = ?$

$T_1 = 27.0°C = 300.2\,K$ $T_2 = -5.0°C = 268.2\,K$

$\frac{3.5\,L}{300.2\,K} = \frac{V_2}{268.2\,K}$; $V_2 = 3.1\,L$ in freezer

2.25 L of nitrogen gas is trapped in a piston at 25.0 C and 1.00 atm pressure. If the piston is pushed in so that the gas's volume is 1.00 L while the temperature increases to 31.0 C, what is the pressure of the gas in the piston?

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

$P_1 = 1.00\,atm$ $P_2 = ?$

$V_1 = 2.25\,L$ $V_2 = 1.00\,L$

$T_1 = 25.0°C = 298.2\,K$ $T_2 = 31.0°C = 304.2\,K$

$\frac{(1.00\,atm)(2.25\,L)}{(298.2\,K)} = \frac{P_2\,(1.00\,L)}{(304.2\,K)}$; $P_2 = 2.30\,atm$

Calculate the mass of 22650* L of oxygen gas at 25.0 C and 1.18 atm pressure.

↖ O_2

O_2: 32.00 g O_2 = mol O_2

*Volume of a 10'x10'x8' room

Use the ideal gas equation to find the moles of oxygen gas. THEN, use the formula weight of oxygen to calculate the mass.

$$PV = nRT$$

$$n = \frac{PV}{RT}$$

P = 1.18 atm

V = 22650 L

T = 25.0 °C = 298.2 K

$$R = 0.08206 \frac{L\text{-}atm}{mol \cdot K}$$

$$n_{O_2} = \frac{(1.18\ atm)(22650\ L)}{\left(0.08206 \frac{L\text{-}atm}{mol \cdot K}\right)(298.2\ K)} = 1092.22357\ mol\ O_2$$

$$1092.22357\ mol\ O_2 \times \frac{32.00\ g\ O_2}{mol\ O_2} = \boxed{35\bar{0}00\ g\ O_2}$$

35.0 kg

~77 lb

CHEMICAL CALCULATIONS WITH THE GAS LAWS

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

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

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 25.0 g sodium bicarbonate to moles. Use FORMULA WEIGHT.
2 - Convert moles sodium bicarbonate to moles carbon dioxide. Use CHEMICAL EQUATION.
3 - Convert moles carbon dioxide to volume. Use IDEAL GAS EQUATION.

(1) $84.007 \text{ g } NaHCO_3 = \text{mol } NaHCO_3$ | (2) $2 \text{ mol } NaHCO_3 = 2 \text{ mol } CO_2$

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

(1) (2)

$PV = nRT$

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

$n = 0.2975942481 \text{ mol } CO_2$

$T = 25.0°C = 298.2 \text{ K}$

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

$P = 0.950 \text{ atm}$

$$V = \frac{(0.2975942481 \text{ mol } CO_2)(0.08206 \frac{L \cdot atm}{mol \cdot K})(298.2 \text{ K})}{(0.950 \text{ atm})} = 7.67 \text{ L of } CO_2 \text{ @ } 25.0°C, 0.950 \text{ atm}$$

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

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

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

$P_1 = 0.950\ \text{atm}$

$V_1 = 7.67\ \text{L}$

$T_1 = 298.2\ \text{K}$

$P_2 = 1\ \text{atm}$

$V_2 = ?$

$T_2 = 273.2\ \text{K}$

$$\frac{(0.950\ \text{atm})(7.67\ \text{L})}{(298.2\ \text{K})} = \frac{(1\ \text{atm})\ V_2}{(273.2\ \text{K})}$$

$$V_2 = \boxed{6.67\ \text{L at STP}}$$

Alternatively, you could calculate this volume using the ideal gas equation. We already know the number of moles and can just plug that and the T and P from STP into the ideal gas law.