

GASES

- Gases differ from the other two phases of matter in many ways:

- They have very low viscosity (resistance to flow), so they flow from one place to another very easily.
- They will take the volume of their container. In other words, gas volumes are variable.
- They are the least dense of all three phases.
- Most gases are transparent, and many are invisible.
- Gases show a much larger change of volume on heating or cooling than the other phases.

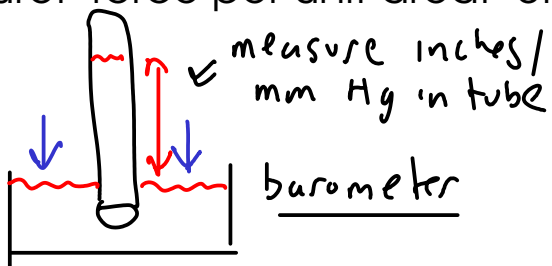
↙ thermal expansion!

- Gases react to changes in temperature and pressure in a very similar way. This reaction often does not depend on what the gas is actually made of.

KINETIC THEORY

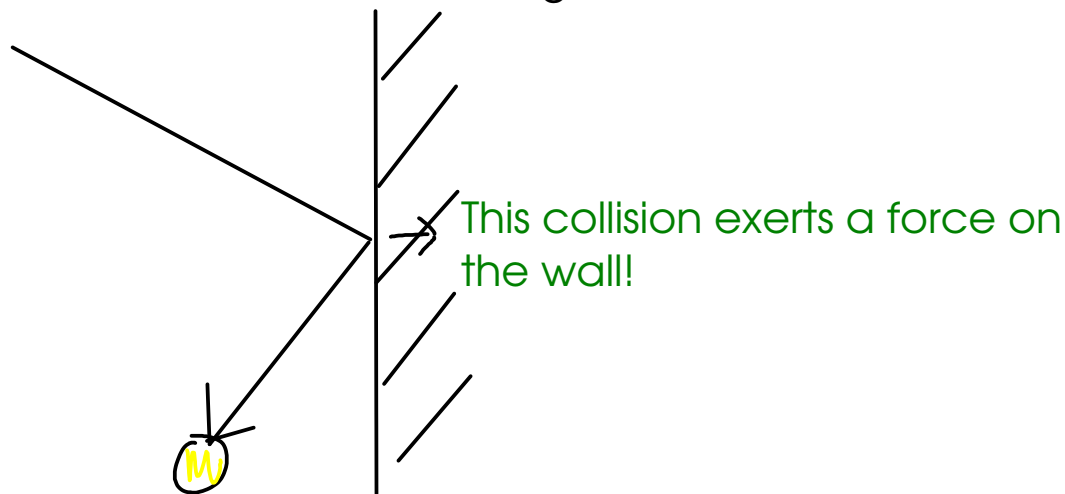
- is a way to explain the behavior of gases.
- views the properties of gases as arising from them being molecules in motion.

- Pressure: force per unit area. Units: Pascal, bar, mm Hg, in Hg, atm, etc.



$$760 \text{ mm Hg} = 1 \text{ atm}$$

- According to kinetic theory, pressure is caused by collisions of gas molecules with each other and the walls of the container the gas is in.



133 - Temperature:

- a measure of the average kinetic energy of the molecules of the gas

$$E_k = \frac{1}{2} m v^2$$

velocity
mass

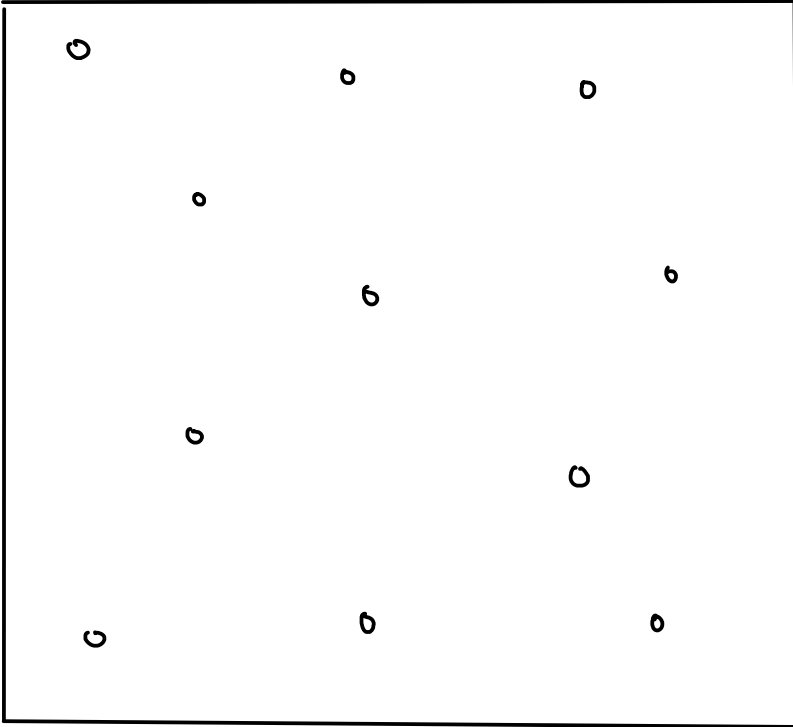
- The faster the gas molecules move, the higher the temperature!
- The temperature scales used when working with gases are ABSOLUTE scales.
 - ABSOLUTE: scales which have no values less than zero.
 - KELVIN: metric absolute temperature scale.

Quick comparison of temperature scales!

$$K = 273.15 + ^\circ C$$

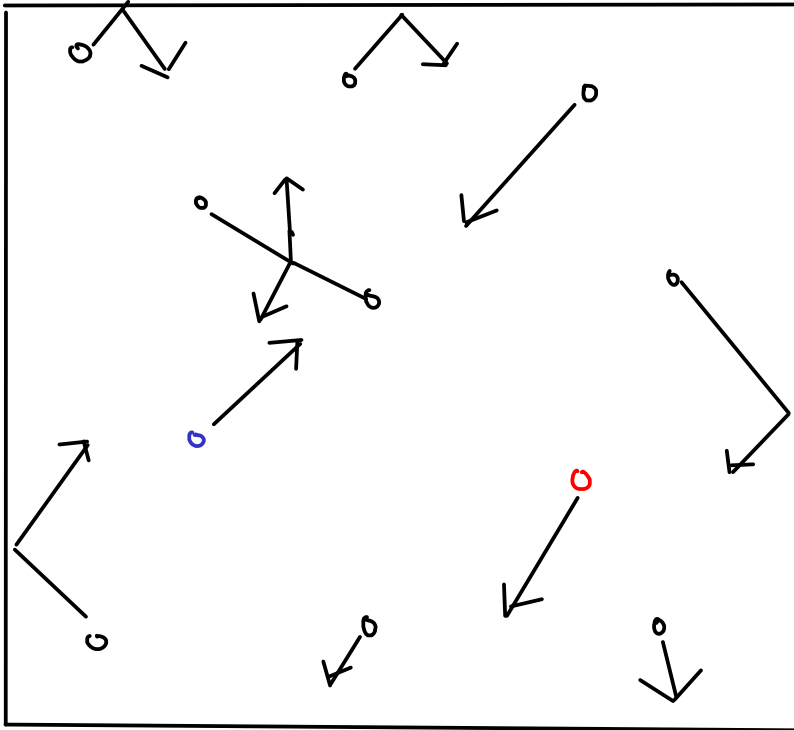
212	100	373	Water boils
77	25	298	Room temperature
32	0	273	Water freezes
-460	-273	0	Absolute zero!
°F	°C	K	

THE KINETIC PICTURE OF GASES



LOW DENSITY!

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



- 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:

$$P V = \text{constant} \quad \left. \vphantom{P V = \text{constant}} \right\} \text{True at constant temperature}$$

$$P_1 V_1 = \text{constant}$$

$$P_2 V_2 = \text{constant}$$

$$\left. \vphantom{P_1 V_1 = P_2 V_2} \right\} \rightarrow \boxed{P_1 V_1 = P_2 V_2} \quad \text{True at constant temperature}$$

Charles's Law:

$$\frac{V}{T} = \text{constant} \quad \left. \vphantom{\frac{V}{T} = \text{constant}} \right\} \text{True at constant pressure, and using ABSOLUTE temperature}$$

$$\left. \vphantom{\frac{V_1}{T_1} = \frac{V_2}{T_2}} \right\} \rightarrow \boxed{\frac{V_1}{T_1} = \frac{V_2}{T_2}} \quad \text{True at constant pressure, and using ABSOLUTE temperature}$$

137 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!

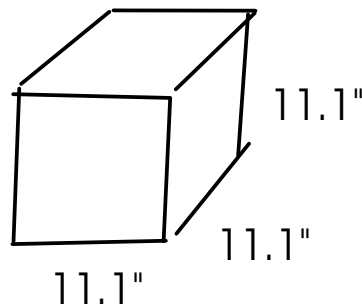
Avogadro's law:

↑ amount (moles) of gas must be constant!

- 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



= 22.4 L

"STP"
Standard
Temperature
and
Pressure

Ideal gas law:

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

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

$$\rightarrow = n \times "R"$$

The ideal gas constant.

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

... combining this together ...

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

↓

$$PV = nRT$$

P = pressure atm

V = volume L

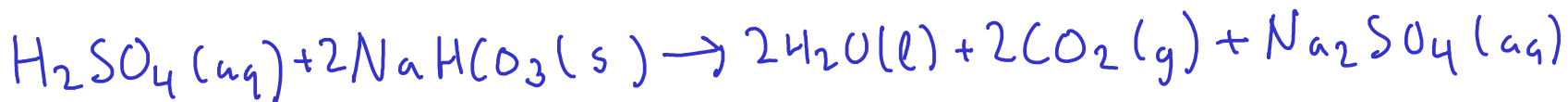
T = ABSOLUTE temperature K

R = ideal gas constant

n = number of moles of gas molecules

CHEMICAL CALCULATIONS WITH THE GAS LAWS

$$FW_{\text{NaHCO}_3} = 84.007 \text{ g/mol}$$



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 mass sodium bicarbonate to moles (formula weight of sodium bicarbonate)
- 2 - Convert moles sodium bicarbonate to moles carbon dioxide using chemical equation
- 3 - Convert moles carbon dioxide to volume using the ideal gas equation

$$84.007 \text{ g NaHCO}_3 = 1 \text{ mol NaHCO}_3 \quad \left\} \quad 2 \text{ mol NaHCO}_3 = 2 \text{ mol CO}_2$$

$$25.0 \text{ g NaHCO}_3 \times \frac{1 \text{ mol NaHCO}_3}{84.007 \text{ g NaHCO}_3} \times \frac{2 \text{ mol CO}_2}{2 \text{ mol NaHCO}_3} = 0.297594 \text{ mol CO}_2$$

$$\textcircled{3} \quad PV = nRT$$

$$\downarrow$$

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

$$n = 0.297594 \text{ mol CO}_2 \quad P = 0.950 \text{ atm}$$

$$R = 0.08206 \frac{\text{L} \cdot \text{atm}}{\text{mol} \cdot \text{K}} \quad T = 25.0^\circ\text{C} = 298.2 \text{ K}$$

$$V = ??? \text{ L}$$

$$V = \frac{(0.297594 \text{ mol CO}_2) \left(0.08206 \frac{\text{L} \cdot \text{atm}}{\text{mol} \cdot \text{K}}\right) (298.2 \text{ K})}{(0.950 \text{ atm})} = 7.67 \text{ L CO}_2$$

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

STP: 0°C , 1 atm

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

Solve this one using the combined gas law. We know all the initial conditions (P, V, and T)

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

$P_1 = 0.950\text{ atm}$	$T_1 = 25.0^{\circ}\text{C} = 298.2\text{ K}$
$V_1 = 7.67\text{ L}$	$P_2 = 1\text{ atm}$
$T_2 = 0^{\circ}\text{C} = 273\text{ K}$	

$$V_2 = \frac{P_1 V_1 T_2}{T_1 P_2} = \frac{(0.950\text{ atm})(7.67\text{ L})(273\text{ K})}{(298.2\text{ K})(1\text{ atm})} = \boxed{6.67\text{ L CO}_2\text{ @ STP}$$

Alternate solution: Since we knew the number of moles, we could also use the ideal gas equation to solve this problem. You'll get the same answer doing it that way.