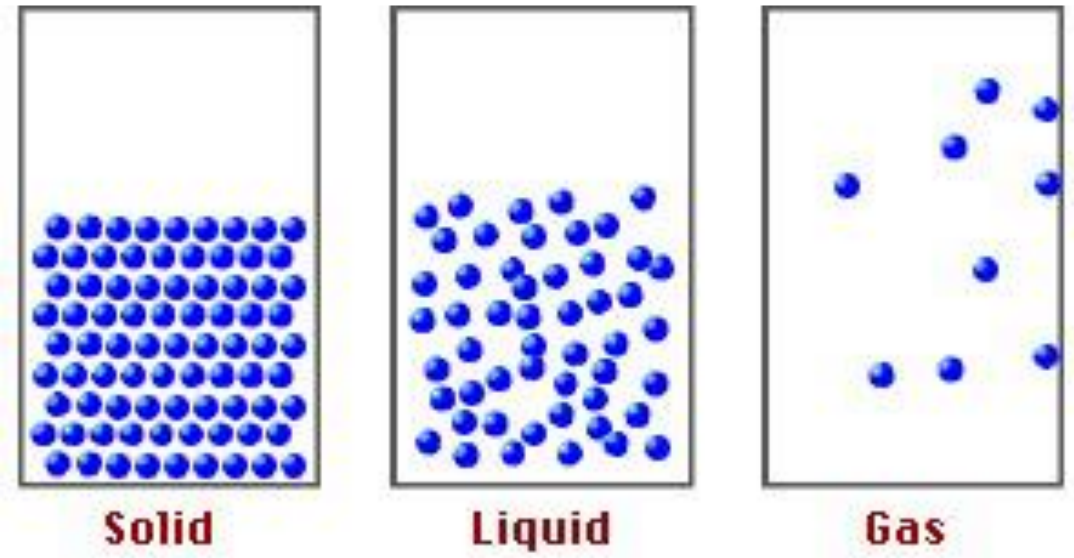
Chapter 5: Gases

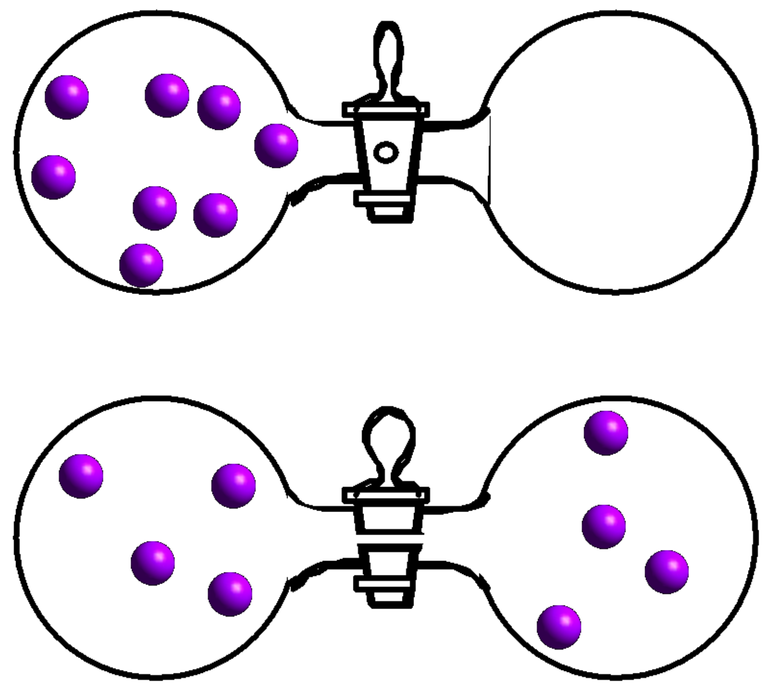
Comparison of Solids, Liquids, and Gases

Density (g/mL)	Solid	Liquid	Gas
H_2O	0.917	0.998	0.000588
CCl_4	1.70	1.59	0.00503



Properties of Gases

- Relatively low density
- Easily compressed
- Expand without limits to fill the volume of any container
- Described by temperature, volume, and the number of moles present



Ideal Gases

"An ideal gas is defined as one for which both the volume of the molecules and the forces between the molecules are so small that they have no effect on the behavior of the gases"

1. We assume that the gas molecules are so tiny compared to the empty space they occupy, that they can be ignored.
2. We assume that the molecules DO NOT interact with one another.

Ideal Gases

Any gas can be ideal if:

The pressure is low.

The temperature is high.

Pressure

Dimensions of force/area

SI unit is N/m^2 or Pascals

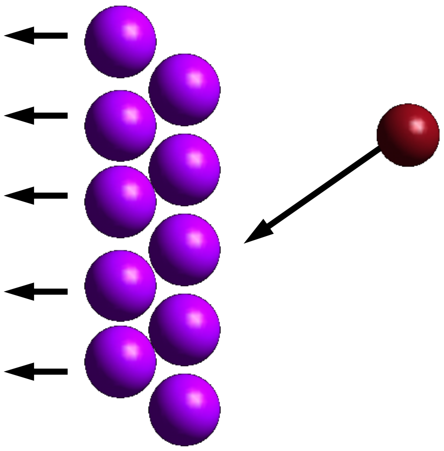
Other more common units:

atmospheres: 1 atm=101,325 Pa

torr (mmHg): 760 torr=1 atm

lbs/in^2: 14.7 psi=1 atm

Pressure



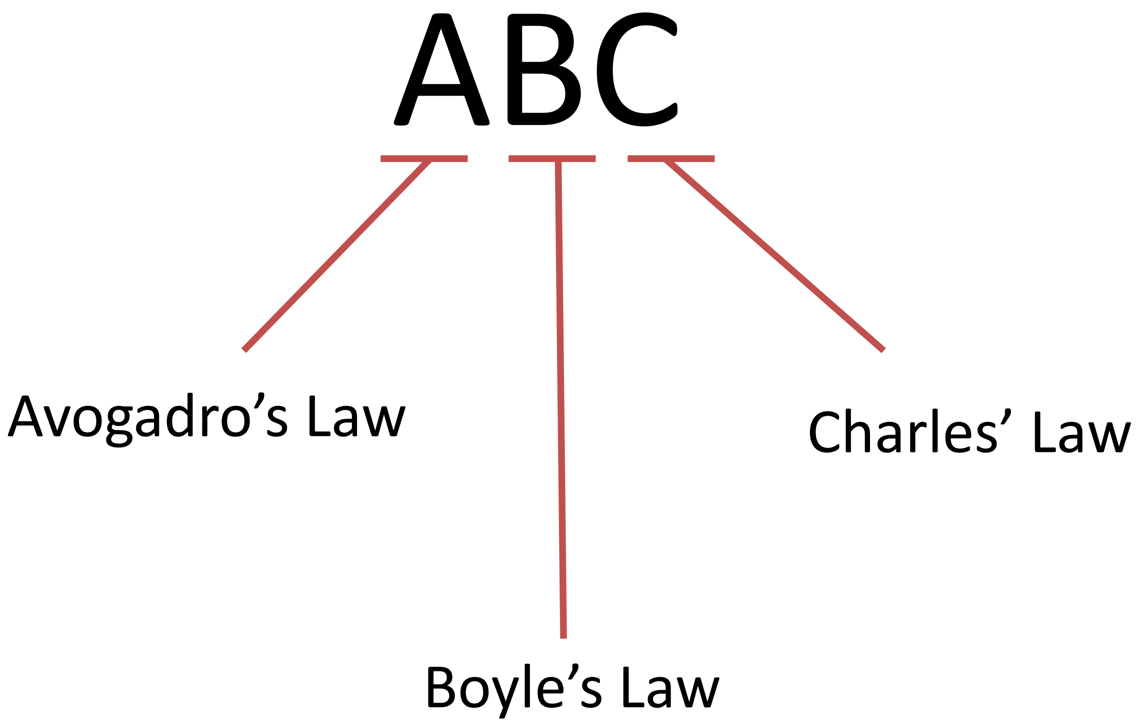
$$P = \frac{F}{A}$$

Force (gas collisions with surface)

Pressure

Area (over which the force acts)

The ABC's of the Gas Law



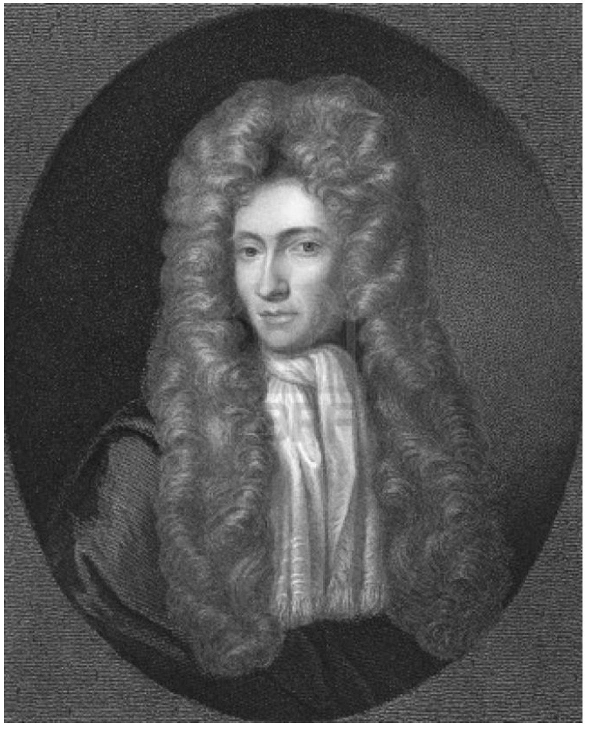
Gas Laws

Boyle's Law (~1660)

$$P \times V = \text{Constant}$$

or

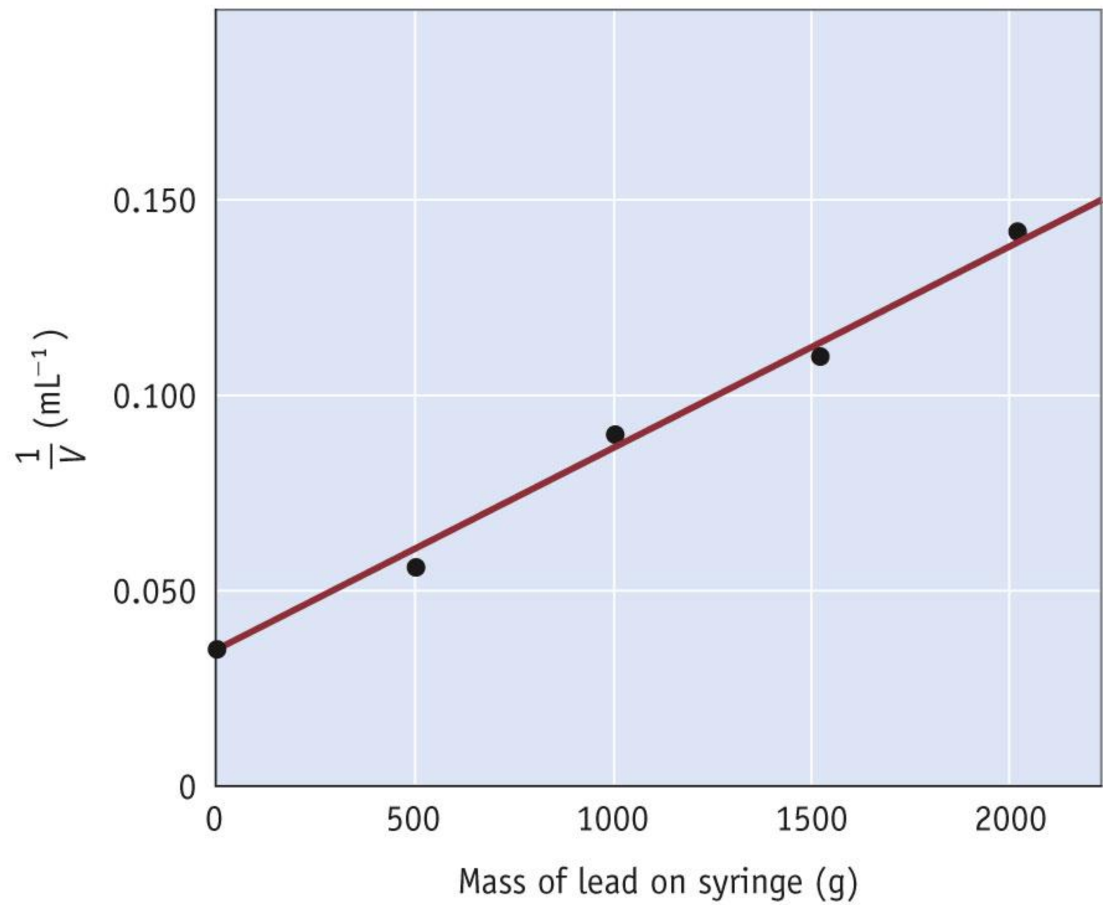
$$P_1 V_1 = P_2 V_2$$



(at constant n and T)

Gas Laws

Boyle's Law (~1660)



Temperature

We find that as $T \rightarrow 0$ then $V \rightarrow 0$ WHY??

Must use absolute temperature (Kelvin not ^oC)

$0\ ^oC = 273.15$ K

$T_K = T_{oC} + 273.15$

Gas Laws

Charles' Law (~1787)

$$V = Constant \times T$$

or

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

(at constant n and P)

Gas Laws

Avogadro's Law

Avogadro's Law states that at the same temperature and pressure, equal volumes of two gases contain the same number of molecules (or moles) of gas

$$V = \text{Constant} \times n$$

or

$$\frac{V_1}{n_1} = \frac{V_2}{n_2}$$

(at constant T and P)

The ABC's of the Gas Law

ABC

Avogadro's Law

V = constant x n

Boyle's Law

P x V = constant

Charles' Law

V = constant x T

Combined Gas Law

The Ideal Gas Law

$$P \times V = \text{Constant} \times n \times T$$

or

$$PV = nRT$$

(*memorize*)

Combined Gas Law

Universal Gas Constant

SI Units:

$R=8.314\ J\ mol^{-1}K^{-1}$

Alternative Units:

$R=0.08206\ L\ atm\ mol^{-1}\ K^{-1}$

$R=63.36\ L\ torr\ mol^{-1}\ K^{-1}$

‘Ideal’ Gas Law

Any gas will behave ideally in the limits of

1. Low pressure
2. High temperature

Ideal Gas Law is reasonable for most gases at ordinary pressure and temperature

Deviations occur at high P and low T (but actual limits depends on the identity of the gas)

Using the Ideal Gas Law

$$PV = nRT \quad \text{or} \quad \frac{PV}{T} = nR$$

Constant (for a constant number of moles present)

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

Summary of the Ideal Gas Laws

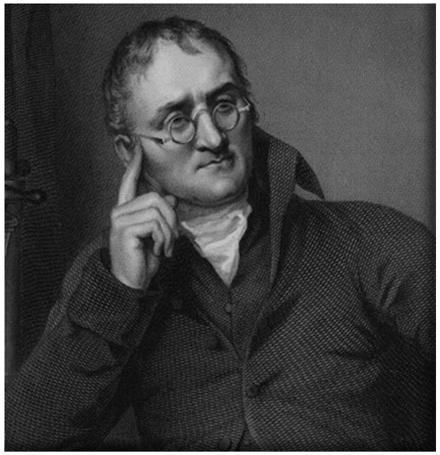
Boyle's Law	$P \times V = \text{Constant}$	or	$P_1 V_1 = P_2 V_2$
Charles' Law	$V = \text{Constant} \times T$	or	$\frac{V_1}{T_1} = \frac{V_2}{T_2}$
Avogadro's Law	$V = \text{Constant} \times n$	or	$\frac{n_1}{V_1} = \frac{n_2}{V_2}$
Combined Gas Law	$PV = nRT$	or	$\frac{P_1 V_1}{T_1} = \frac{P_2 V_2}{T_2}$

Dalton's Law of Partial Pressures

Partial pressure is the pressure exerted by a single component in a gas mixture

'what the pressure would be if only that gas were present in the container'

John Dalton
1766-1844



Dalton's Law of Partial Pressures

$$P_{tot} = P_1 + P_2 + P_3 + P_4 + ...$$

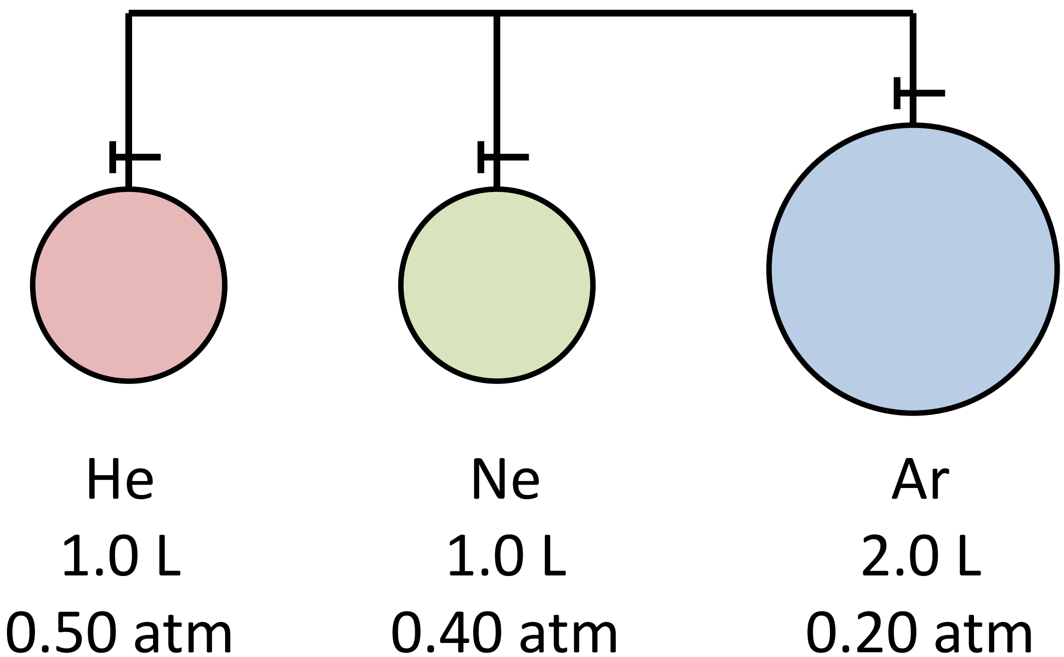
number of moles of species 1

$$P_1 = X_1 P_{tot} \qquad \text{where} \qquad X_1 = \frac{n_1}{n_{tot}}$$

mole fraction

total number of moles

Dalton's Law of Partial Pressures



If the gases above are allowed to mix, what are the partial pressures of the gases?

Dalton's Law of Partial Pressures

1. Each gas has fixed n, R, and T

2. So PV = constant, or $P_iV_i=P_fV_f$

3. For helium: $P_i=0.50$ atm, $V_i=1.0$ L, $V_f=4.0$ L

   $P_f=P_iV_i/V_f=(0.5 \text{ atm})(1 \text{ L})/(4 \text{ L})=0.125 \text{ atm}$

4. For others: $P_{Ne}=0.1 \text{ atm}=P_{Ar}$

5. $P_{tot}=0.325$ atm

Gas Stoichiometry

Chemical equations relate numbers of moles, as always

The Gas Law relates number of moles to P, V, and T

Allows us to find the amount of gas produced or consumed in a reaction in terms of P, V, and T

Gas Laws and Stoichiometry

Bombardier beetle uses decomposition of hydrogen peroxide to defend itself.

If 0.11 g of H_2O_2 decomposes in a 2.50 L flask at 25 ^oC, what is the pressure of O_2 and H_2O?

Gas Stoichiometry: Air Bags

Automobile air bag systems involve chemical generation of gas to fill bag

Some requirements:

Rapid generation of gas (bag fills in 30 ms)

‘Safe’ gas: cool, non-toxic

Easily triggered in response to impact

Gas Stoichiometry: Air Bags

The decomposition of sodium azide into sodium and nitrogen is used to inflate automobile air bags:

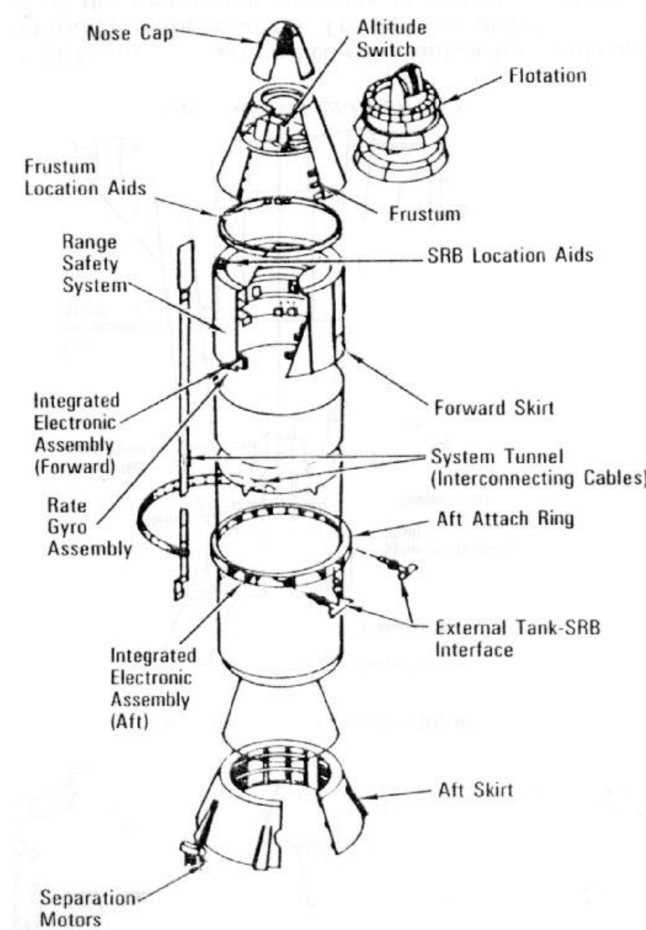
$$2\ NaN_3\ (s) \longrightarrow 2\ Na\ (s) + 2\ N_2\ (g)$$

Estimate the mass of solid sodium azide needed to produce enough N_2 to fill a typical air bag (40 L to a pressure of 1.3 atm)

Space Shuttle: Booster Engine

$2\ NH_4ClO_4\ (s) \longrightarrow N_2\ (g) + Cl_2\ (g) + 2\ O_2\ (g) + 4\ H_2O\ (g)$

Volume of gas produced from 75,000 kg of NH_4ClO_4?
(assume final gas at 125^{o}C and 1 atm)



Solid Rocket Booster—Exploded View

8.34×10^7 L

Kinetic Theory of Gases

The basic assumptions of the kinetic-molecular theory are:

Postulate 1:

- Gases consist of discrete molecules that are relatively far apart
- Gases have few intermolecular attractions
- The volume of individual molecules is very small compared to the gas's volume

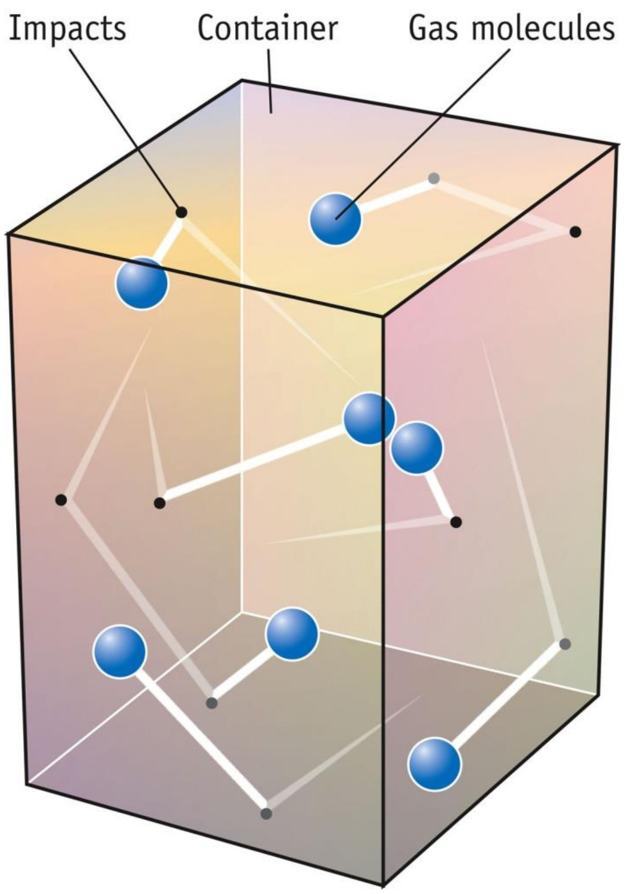
Postulate 2:

- Gas molecules are in constant, random, straight-line motion with varying velocities

Kinetic Theory of Gases

Postulate 3:

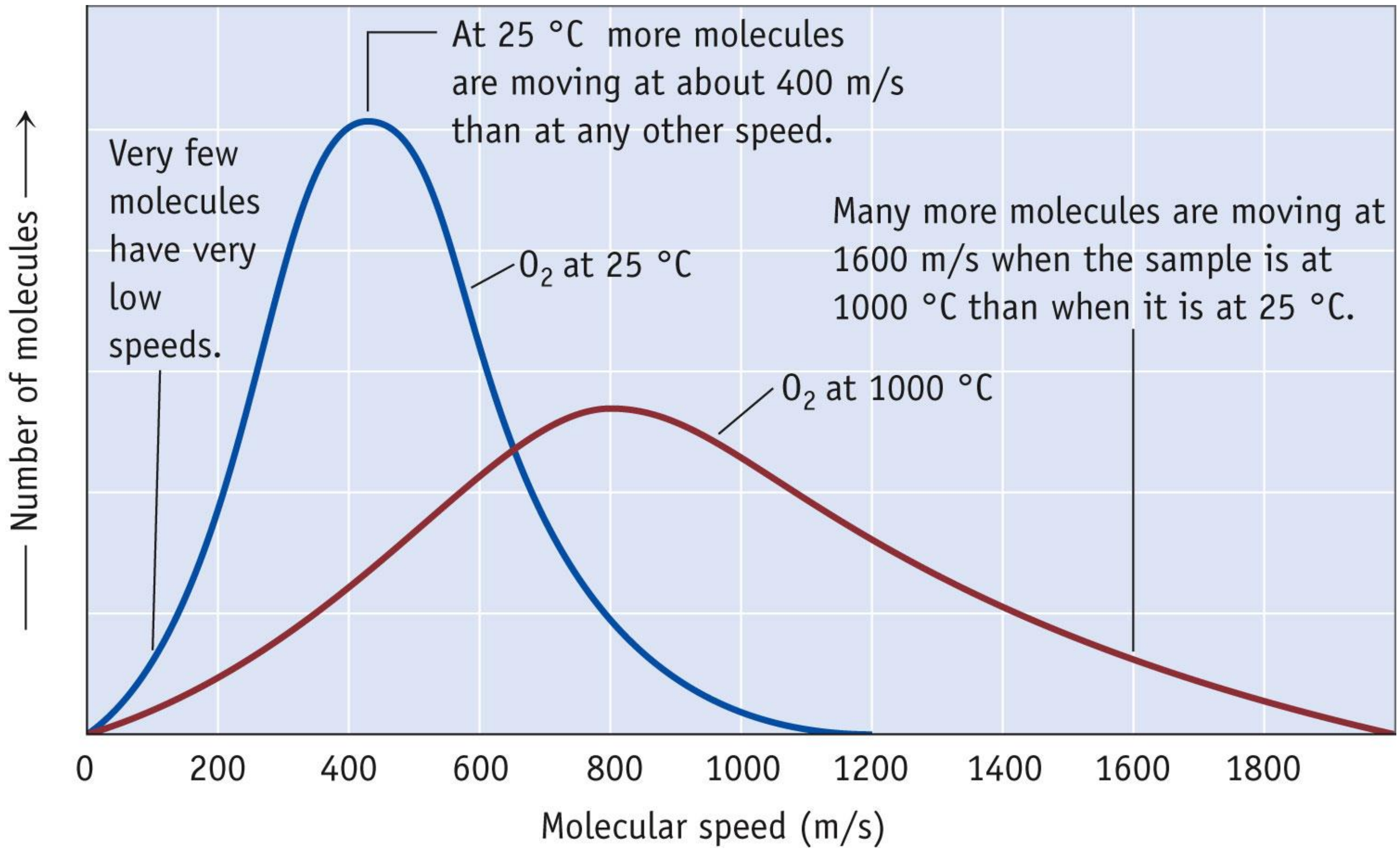
- Gas molecules have elastic collisions with themselves and the container
- Total energy is conserved during a collision



Postulate 4:

- The kinetic energy of the molecules is proportional to the absolute temperature
- The average kinetic energies of the molecules of different gases are equal at a given temperature

Molecular Velocity Distribution



Density of a Gas

- To calculate a density, you need: mass, and volume of a sample.

- Calculate the density of a gas at STP

(P=1.00atm, T = 273 K)

  - Start with an assumption about your sample: 1 mole.
    - What is the volume of 1 mole?
    - What is the mass of 1 mole?

Density of a Gas

- What is the pressure of a sample of N_2O that has a density of 2.85 g/L?

Calculate the Molar Mass of a Gas

- You are trying to determine the identity of an unknown gas sample.
- The gas sample has a mass of 0.311g, a volume of 0.225L, a temperature of 328.15K, and a pressure of 1.166 atm.