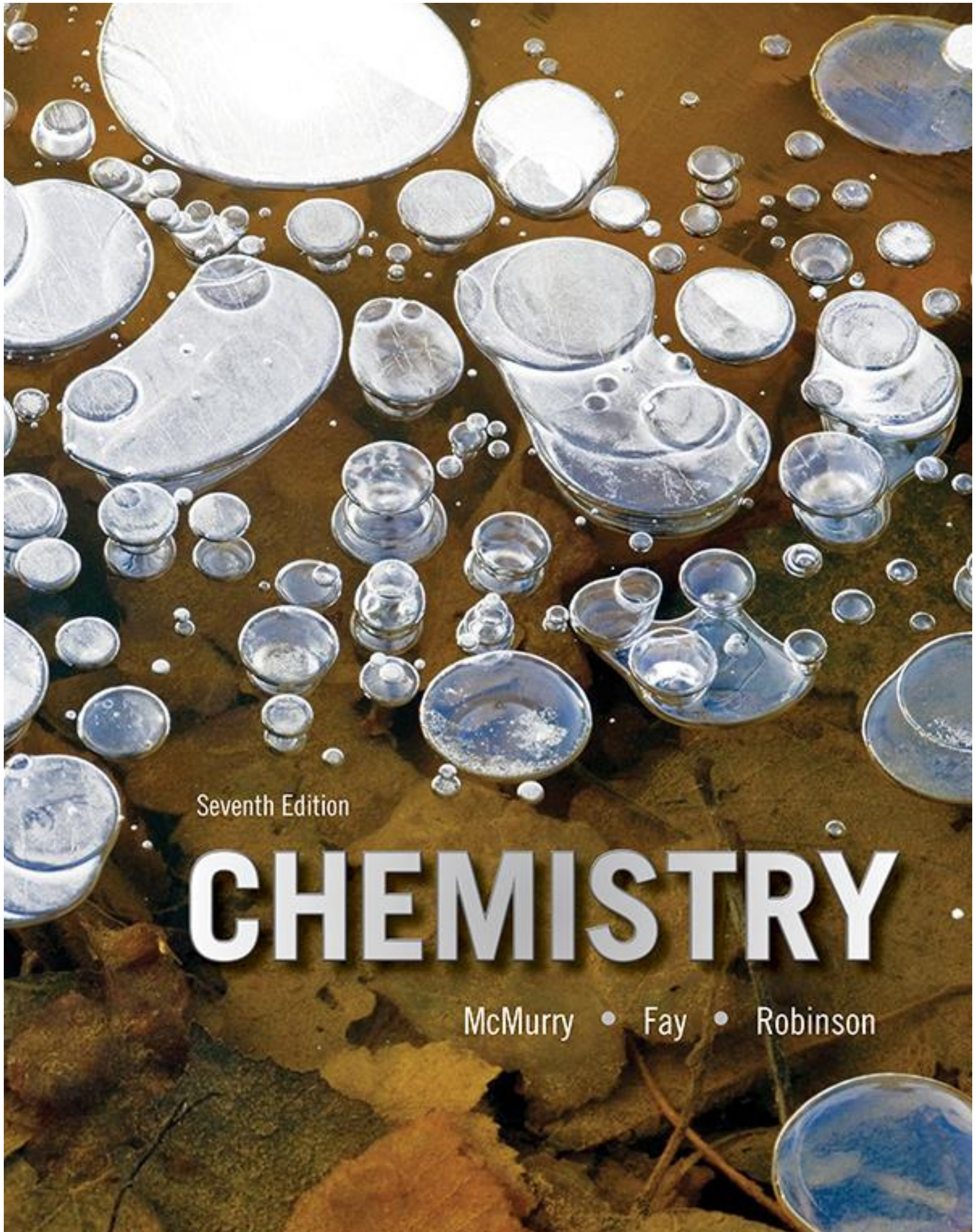


Lecture Presentation

Chapter 10

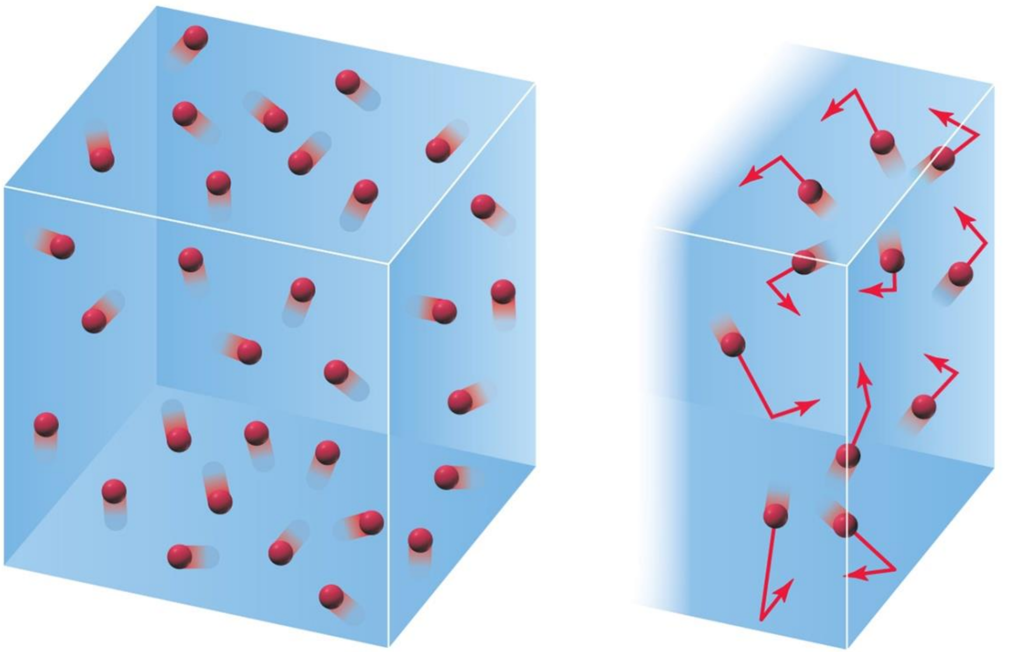
Gases: Their Properties and Behavior

HW: 10.1, 10.7, 10.9, 10.11, 10.13, 10.15, 10.17, 10.28, 10.30, 10.34, 10.52, 10.64, 10.72, 10.74, 10.86, 10.88,10.90, 10.102

John E. McMurry
Robert C. Fay

Gases and Gas Pressure (lots of empty space)
(pressure = gases hitting each other & wall of container)

Gas mixtures are **homogeneous** and **compressible**.

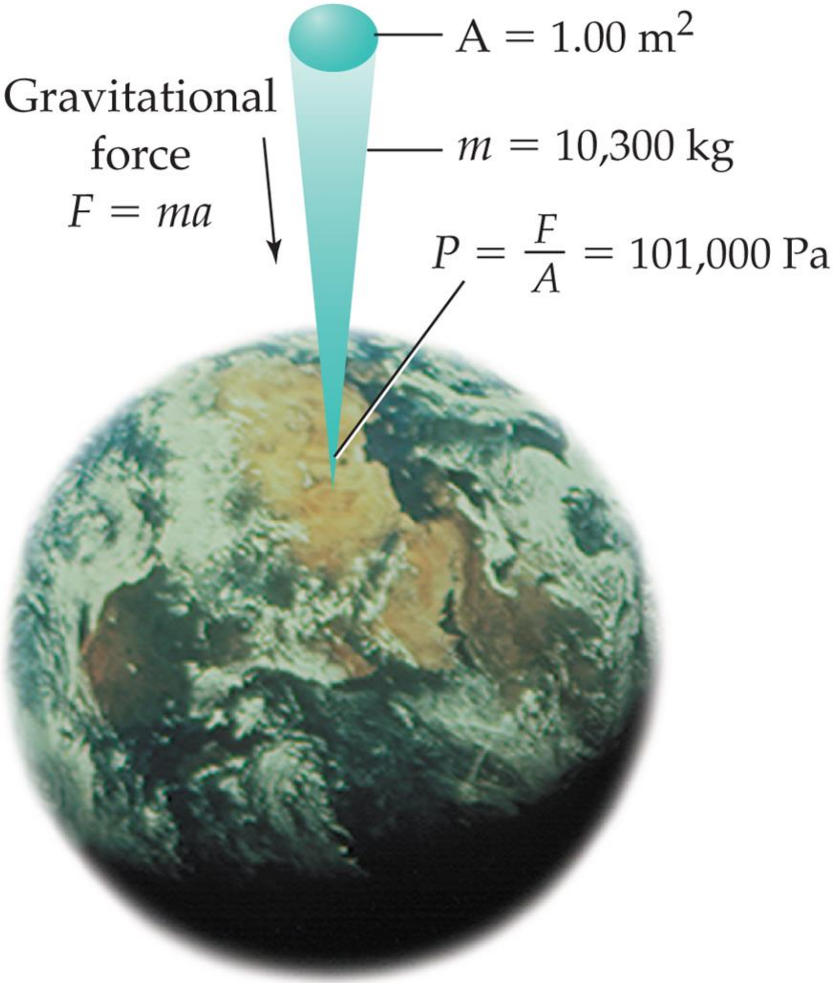


A gas is a large collection of particles moving at random through a volume that is primarily empty space.

Collisions of randomly moving particles with the walls of the container exert a force per unit area that we perceive as gas pressure.

Gases and Gas Pressure

$$\textbf{Pressure} = \frac{\text{Force}}{\text{Unit area}}$$

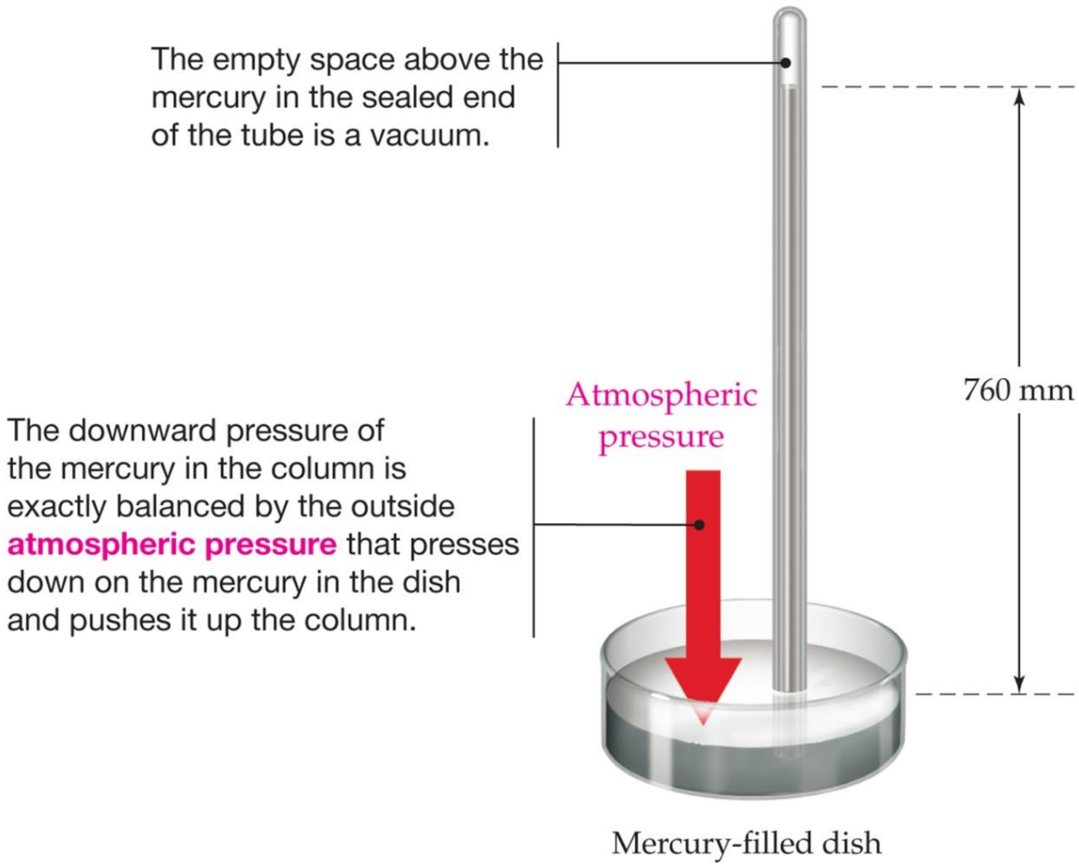


P on 1 m^2 air column is 10,300 kg = 101,000 Pa   Force = ma = gravity on mass (where a = 9.81 m/s^2)

Pa = pascal pressure unit [kg/(m*s) = Pa]

Gases and Gas Pressure – how measure P ?

Barometer



Gases and Gas Pressure

Conversions (conversion factor)

1 atm = 760 mm Hg (exact)

1 torr = 1 mm Hg (exact)

chemists use

1 bar = 1×10^5 Pa (exact)

1 atm = 101 325 Pa

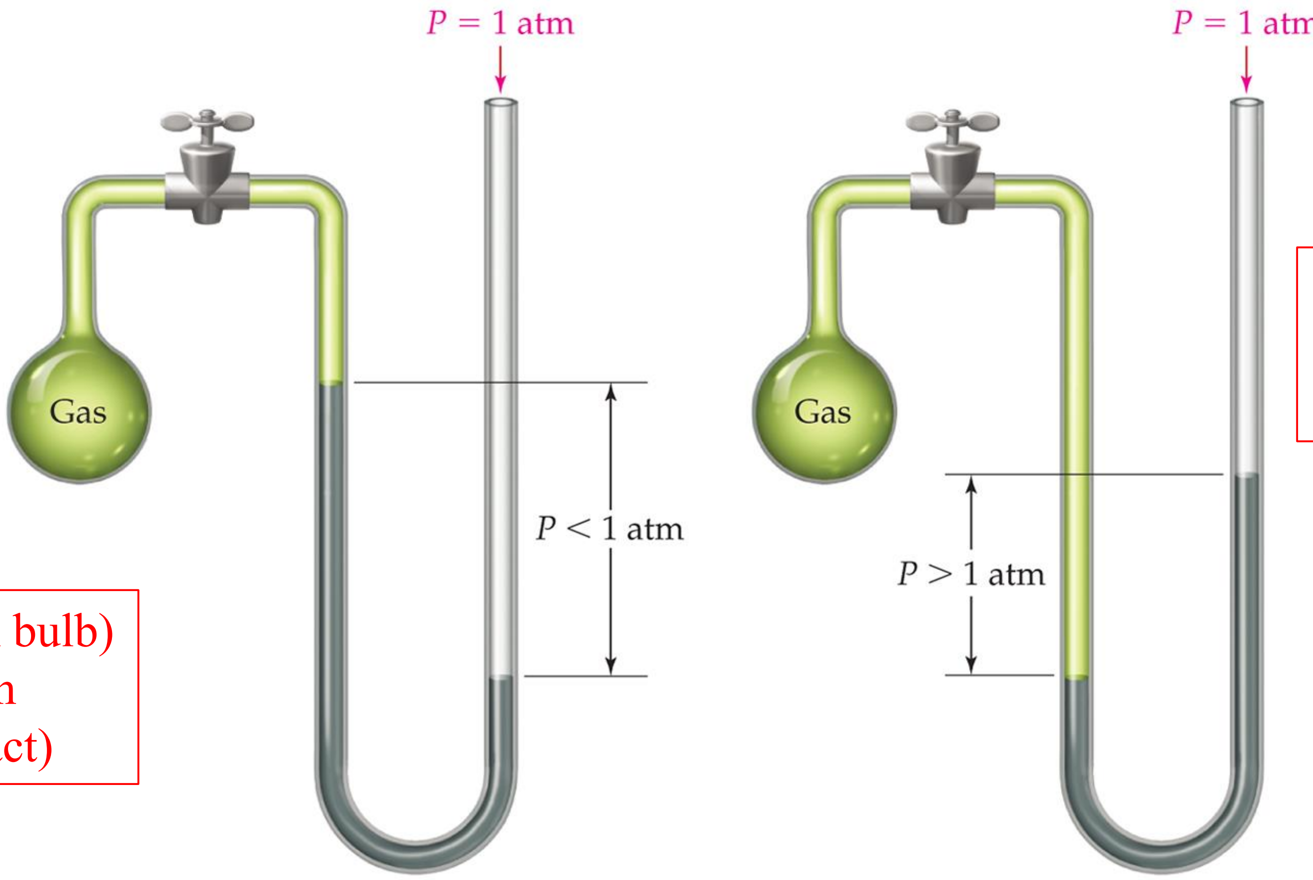
exact means infinite # of sig. fig.
Put this slide on to memorize / info sheet.

Gases and Gas Pressure – open end manometer

End 11/25 D, F section

if P (in bulb) < 1 atm (subtract)

if P (in bulb) > 1 atm (add)



(a) The mercury level is higher in the arm open to the bulb because the pressure in the bulb is lower than atmospheric.

(b) The mercury level is higher in the arm open to the atmosphere because the pressure in the bulb is higher than atmospheric.

The Gas Laws

The physical properties of a gas can be defined by four variables:

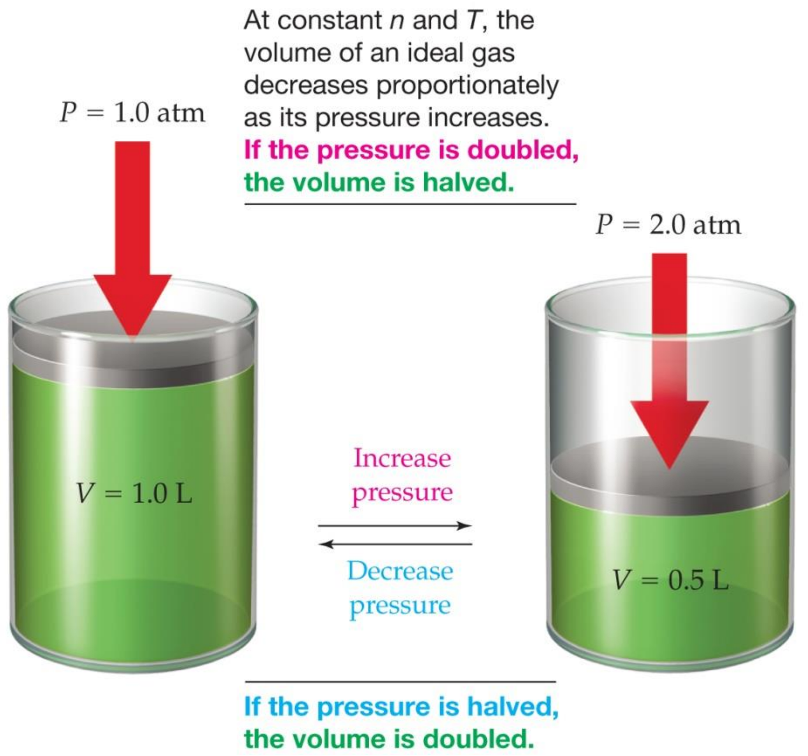
P	Pressure
T	Temperature
V	Volume
n	number of moles

The Gas Laws

Boyle's Law

Squeeze balloon (higher P) – lower volume

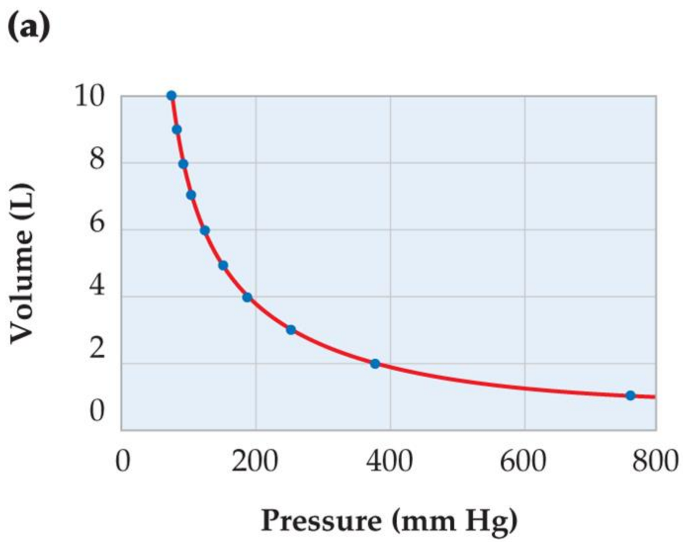
$$V \propto \frac{1}{P} \quad \text{(constant } n \text{ and } T\text{)}$$



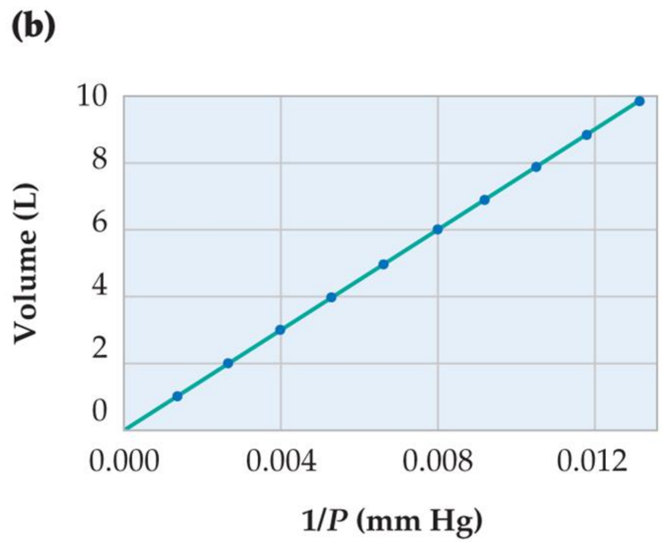
The Gas Laws

Boyle's Law

$$V \propto \frac{1}{P} \quad \text{(constant } n \text{ and } T\text{)}$$



A plot of *V* versus *P* for a gas sample is a **hyperbola**.



A plot of *V* versus 1/*P* is a **straight line**. Such a graph is characteristic of equations having the form $y = mx + b$.

The Gas Laws

Boyle's Law

$$V \propto \frac{1}{P} \quad \text{(constant } n \text{ and } T\text{)}$$

$$PV = k$$

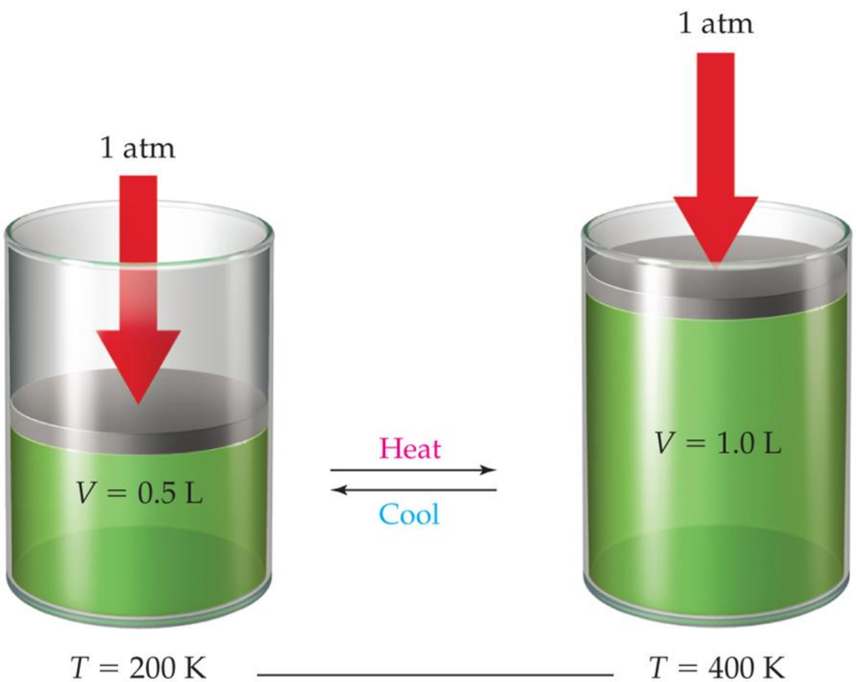
$$\boxed{P_{\text{initial}}V_{\text{initial}} = P_{\text{final}}V_{\text{final}}}$$

The Gas Laws

heat balloon (higher T) – higher volume

Charles's Law

$V \propto T$ (constant n and P)



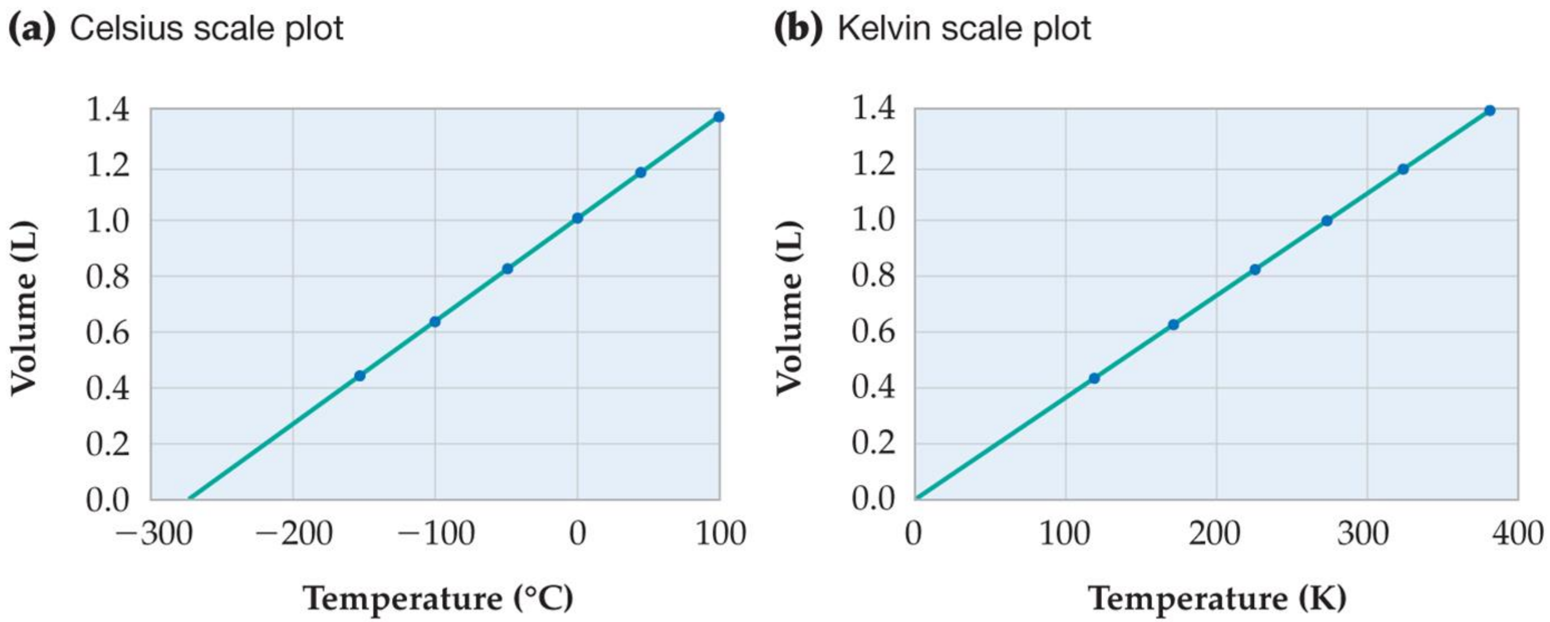
At constant *n* and *P*, the volume of an ideal gas changes proportionately as its absolute temperature changes. If the absolute **temperature doubles**, the **volume doubles.**

If the absolute **temperature is halved**, the **volume is halved.**

The Gas Laws

Charles’s Law

$$V \propto T \qquad \text{(constant } n \text{ and } P\text{)}$$



A plot of V versus T for a gas sample is a straight line that can be extrapolated to absolute zero, 0 K = −273.15 °C.

The Gas Laws

Charles's Law

$V \propto T$ (constant *n* and *P*)

$$\frac{V}{T} = k$$

$$\boxed{\frac{V_{\text{initial}}}{T_{\text{initial}}} = \frac{V_{\text{final}}}{T_{\text{final}}}}$$

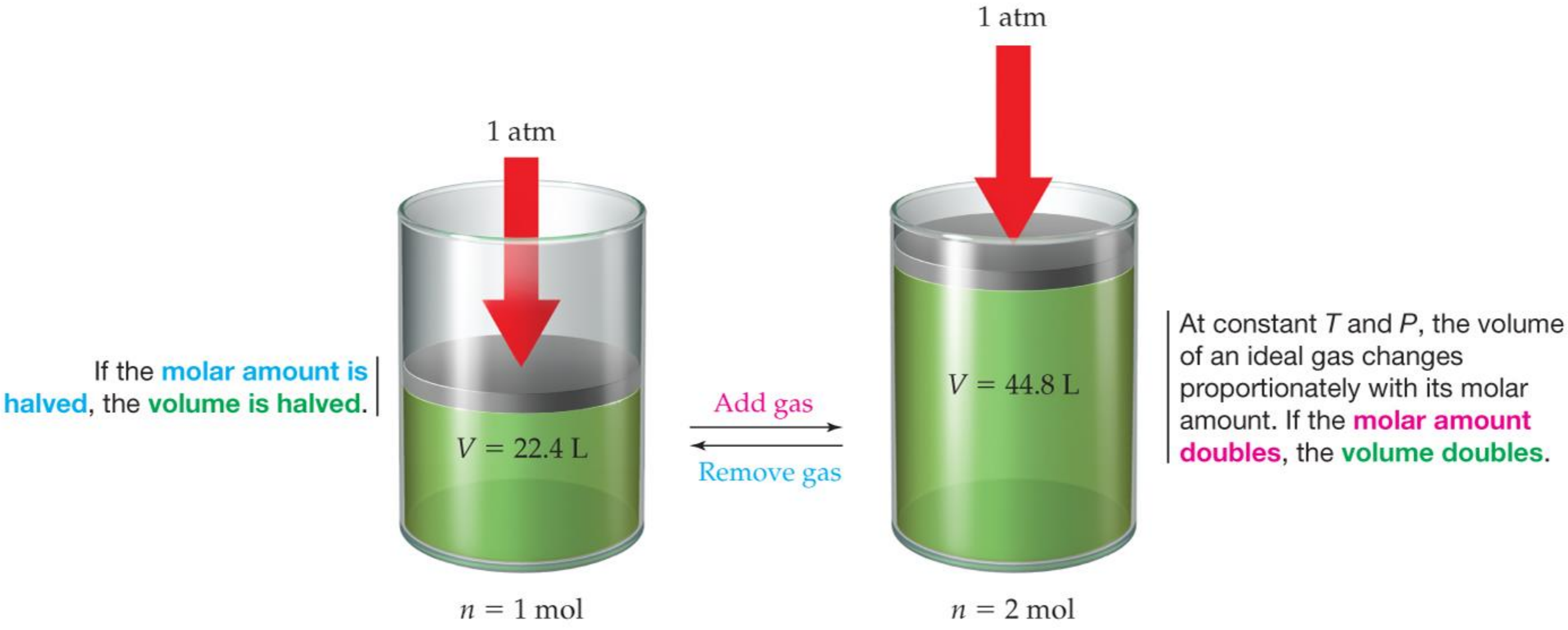
The Gas Laws

End G section 11/25 Monday

blow air into balloon
(higher n)– higher volume

Avogadro's Law

$V \propto n$ (constant T and P)



The Gas Laws

Avogadro's Law

$V \propto n$ (constant T and P)

$$\frac{V}{n} = k$$

$$\boxed{\frac{V_{\text{initial}}}{n_{\text{initial}}} = \frac{V_{\text{final}}}{n_{\text{final}}}}$$

The Ideal Gas Law

Summary (to memorize card)

Boyle's Law: $P_{\text{initial}}V_{\text{initial}} = P_{\text{final}}V_{\text{final}}$

$V \propto \frac{1}{P}$ (constant n and T)

Charles' Law: $\frac{V_{\text{initial}}}{T_{\text{initial}}} = \frac{V_{\text{final}}}{T_{\text{final}}}$

$V \propto T$ (constant n and P)

Avogadro's Law: $\frac{V_{\text{initial}}}{n_{\text{initial}}} = \frac{V_{\text{final}}}{n_{\text{final}}}$

$V \propto n$ (constant T and P)

The Ideal Gas Law

Ideal Gas Law: $PV = nRT$

R is the gas constant and is the same for all gases.

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

Standard Temperature and Pressure (STP) for Gases

$$\begin{cases} T = 0\ °\text{C}\ (\mathbf{273.15\ K}) \\ P = 1\ \text{atm} \end{cases}$$

to memorize card

P = atmosphere must use these units if use R above

V = liter R # will be provided on periodic table

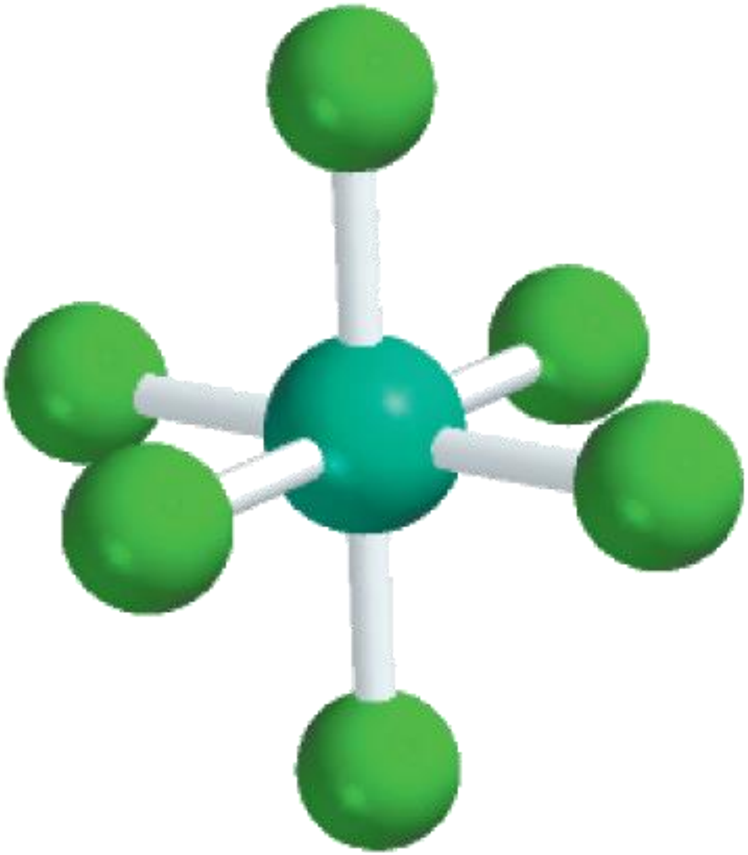
T = Kelvin

Example Using Ideal Gas Law: $PV = nRT$

Sulfur hexafluoride (SF_6) is a colorless and odorless gas.

Due to its lack of chemical reactivity, it is used as an insulator in electronic equipment.

Calculate the pressure (in atm) exerted by 1.82 moles of the gas in a steel vessel of volume 5.43 L at 69.5° C.



SF_6

***Solution* (watch units)**

P = ?
V = 5.43 Liter
n = 1.82 mol
T = 69.5 ^{o}C
(convert to K + 273)

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

$$= \frac{(1.82\ \mathrm{mol})(0.08206\ \mathrm{L \cdot atm/K \cdot mol})(69.5 + 273)\mathrm{K}}{5.43\ \mathrm{L}}$$

$$= 9.42\ \mathrm{atm}$$

Ideal Gas Equations

Ideal gas law

$$\boxed{PV = nRT}$$

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

Combined gas law (constant n)

Example: using the combined gas law $\boxed{\dfrac{P_2V_2}{P_1V_1} = \dfrac{T_2}{T_1}}$

A small bubble rises from the bottom of a lake, where the temperature and pressure are 8° C and 6.4 atm, to the water's surface, where the temperature is 25° C and the pressure is 1.0 atm. Calculate the final volume (in mL) of the bubble if its initial volume was 2.1 mL.

Example: using the combined gas law $\boxed{\frac{P_2V_2}{P_1V_1} = \frac{T_2}{T_1}}$

A small bubble rises from the bottom of a lake, where the temperature and pressure are 8° C and 6.4 atm, to the water's surface, where the temperature is 25° C and the pressure is 1.0 atm. Calculate the final volume (in mL) of the bubble if its initial volume was 2.1 mL.

$T_1 = 8\ ^oC$	$T_2 = 25\ ^oC$
$P_1 = 6.4$ atm	$P_2 = 1.0$ atm
$V_1 = 2.1$ mL	$V_2 = ?$

Example: using the combined gas law

A small bubble rises from the bottom of a lake, where the temperature and pressure are 8° C and 6.4 atm, to the water's surface, where the temperature is 25° C and the pressure is 1.0 atm. Calculate the final volume (in mL) of the bubble if its initial volume was 2.1 mL.

$T_1 = 8\ ^oC + 273 = 281\ K$

$P_1 = 6.4\ atm$

$V_1 = 2.1\ mL$

$T_2 = 25\ ^oC + 273 = 298\ K$

$P_2 = 1.0\ atm$

$V_2 = ?$

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

$$\frac{(1.0\ atm)V_2}{(6.4\ atm)(2.1\ mL)} = \frac{281\ K}{298K}$$

$V_2 = 13\ mL$

End D, F, G section 12/2M

HW 10.1: Ideal Gas Equations

$$\boxed{PV = nRT}$$

Which ?

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

If P = 740.2 mm Hg, T = 35.2 ^{o}C for 2.2 moles, what is the volume in Liters. (only one P,T, n) (watch units) [R= (0.08206 L atm) / (mol K)] [K = ^{o}C + 273.15][1 atm=760 mm Hg = 760 torr]

HW 10.1 : Ideal Gas Equations

$$\boxed{PV = nRT}$$

Which ?

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

If P = 740.2 mm Hg, T = 35.2 ^oC for 2.2 moles, what is the volume in Liters. (watch units)

P = 740.2 mm Hg * (1 atm / 760 mmHg) = 0.9739 atm
T = 35.2 ^oC + 273.15 K = 308.4 K
n = 2.2 moles

$$V = \frac{(2.2 \text{ moles})\ \{0.08206\ (\text{liter atm})/(\text{mol K})\} * 308.4\ \text{K}}{0.9739\ \text{atm}}$$

V = 57.15 Liters (s.f. 57 Liters)

HW 10.2 : Ideal Gas Equations

$$\boxed{PV = nRT}$$

Which ?

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

If a 37.2 liters of a gas at 1.2 atm. and 287.2 K is in a piston that moves to give 7.82 liters at 2.4 atm. What is the new temperature ? (2 sets of V, P and T)

HW 10.2 : Ideal Gas Equations

$$\boxed{PV = nRT}$$

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

If a 37.2 liters of a gas at 1.2 atm. and 287.2 K is in a piston that moves to give 7.82 liters at 2.4 atm. What is the new temperature ?

P_2 = 1.27 atm
V_2 = 37.2 liter
T_2 = 287.2 K

P_2 = 2.42 atm
V_2 = 7.82 liters
T_2 = ?

HW 10.2 : Ideal Gas Equations

$$\boxed{PV = nRT}$$

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

If a 37.2 liters of a gas at 1.2 atm. and 287.2 K is in a piston that moves to give 7.82 liters at 2.4 atm. What is the new temperature ?

P_1 = 1.27 atm
V_1 = 37.2 liter
T_1 = 287.2 K

$$\frac{(2.42\ \text{atm})(7.82\ \text{Liter})}{(1.27\ \text{atm})\ (37.2\ \text{Liter})} = \frac{T_2}{287.2\text{K}}$$

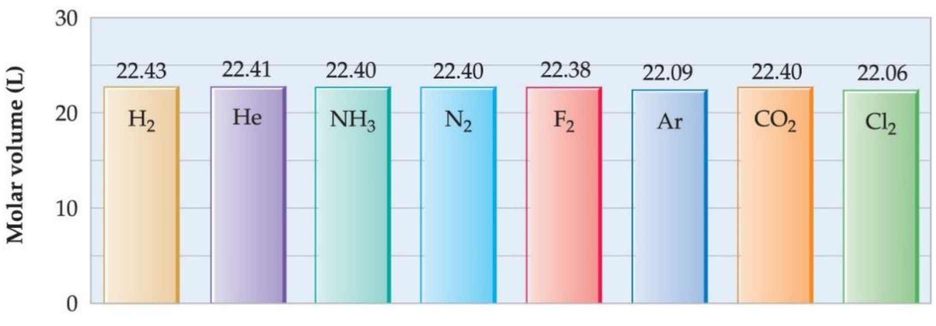
$115\ \text{K} = T_2$

P_2 = 2.42 atm
V_2 = 7.82 liters
T_2 = ?

The Ideal Gas Law

Molar Volume for ALL gases = 22.4 Liter at STP
(STP = standard T & P or 0°C and 1 atm)

TABLE 9.4 Molar Volumes of Some Real Gases at 0 °C and 1 atm



What is the volume of 1 mol of gas at STP?

$$V = \frac{nRT}{P} = \frac{(1\ \text{mol})\left(0.08206\frac{\text{L atm}}{\text{K mol}}\right)(273.15\ \text{K})}{(1\ \text{atm})} = 22.41\ \text{L}$$

Stoichiometric Relationships with Gases

The reaction used in the deployment of automobile airbags is the high-temperature decomposition of sodium azide, NaN_3, to produce N_2 gas. How many liters of N_2 at 1.15 atm and 30.0 °C are produced by decomposition of 102.2 g NaN_3? (stoichiometry + ideal gas laws)

$$2NaN_3(s) \longrightarrow 2Na(s) + 3N_2(g)$$

Not STP

Stoichiometric Relationships with Gases

$$2NaN_3(s) \longrightarrow 2Na(s) + 3N_2(g)$$

Not STP

102.2 g ? moles

? liters

Moles of N_2 produced: (just normal stoichiometry)

$$102.2 \text{ g } NaN_3 \times \frac{1 \text{ mol } NaN_3}{65.0 \text{ g } NaN_3} \times \frac{3 \text{ mol } N_2}{2 \text{ mol } NaN_3} = 2.36 \text{ mol } N_2$$

Volume of N_2 produced: (30.0°C + 273.15=303.2 K)

$$V = \frac{nRT}{P} = \frac{(2.36 \text{ mol) } N_2 \left(0.08206 \frac{\text{L atm}}{\text{K mol}}\right)(303.2 \text{ K})}{(1.15 \text{ atm})} = 51.1 \text{ L } N_2$$

Stoichiometric Relationships with Gases

The reaction used in the deployment of automobile airbags is the high-temperature decomposition of sodium azide, NaN_3, to produce N_2 gas. How many liters of N_2 at STP (T = 0 °C & P= 1 atm) (**<u>at STP 1 mole any ideal gas = 22.4 Liters</u>**) are produced by decomposition of 102.2 g NaN_3?

$$2NaN_3(s) \longrightarrow 2Na(s) + 3N_2(g)$$

At STP

Stoichiometric Relationships with Gases

$$2NaN_3(s) \longrightarrow 2Na(s) + 3N_2(g)$$

at STP

102.2 g ? moles

? liters

Moles of N_2 produced: (just normal stoichiometry)

$$102.2\text{ g } NaN_3 \times \frac{1\text{ mol } NaN_3}{65.0\text{ g } NaN_3} \times \frac{3\text{ mol } N_2}{2\text{ mol } NaN_3} = 2.36\text{ mol } N_2$$

Volume of N_2 produced: (at STP)

$$(2.36\text{ mol})\ N_2 \times \frac{22.4\text{ L}}{\text{mole } N_2} = 52.9\text{ L } N_2$$

Mixtures of Gases: Partial Pressure and Dalton's Law

Dalton's Law of Partial Pressures: The total pressure exerted by a mixture of gases in a container at constant *V* and *T* is equal to the sum of the pressures of each individual gas in the container.

$$P_{\text{total}} = P_1 + P_2 + \ldots + P_N$$

$$\textbf{Mole fraction } (\boldsymbol{X}) = \frac{\text{Moles of component}}{\text{Total moles in mixture}}$$

$$X_i = \frac{n_i}{n_{\text{total}}} \quad \text{or} \quad X_i = \frac{P_i}{P_{\text{total}}}$$

Example Dalton's Law

- Mixtures of helium and oxygen can be used in scuba diving tanks to help prevent the bends
  - For a particular dive, He and O_2 were combined to give a total pressure of 11.7 atm. If the pressure due to the oxygen was 2.4 atm, what is the pressure from the Helium ?
  - What is the mole fraction of oxygen in the mixture ?
  - What is the mole fraction of helium in the mixture ?

$$\boxed{P(\text{total}) = P_{O2} + P_{He}}$$

$$\boxed{\chi_{O2} = \frac{P_{O2}}{P_{TOTAL}}}$$

$$\boxed{\chi_{He} = \frac{P_{He}}{P_{TOTAL}}}$$

For a particular dive, He and O_2 were combined to give a total pressure of 11.7 atm. If the pressure due to the oxygen was 2.4 atm, what is the pressure from the Helium ?
What is the mole fraction of oxygen (χ_{O2}) in the mixture ?
What is the mole fraction of helium (χ_{He}) in the mixture

$$P(\text{total}) = P_{O2} + P_{He}$$

$$\chi_{O2} = \frac{P_{O2}}{P_{TOTAL}}$$

$$\chi_{He} = \frac{P_{He}}{P_{TOTAL}}$$

$$11.7 \text{ atm} = 2.4 \text{ atm} + P_{He}$$

$$P_{He} = 11.7 \text{ atm} - 2.4 \text{ atm} = 9.3 \text{ atm}$$

$$\chi_{O2} = \frac{2.4\ atm}{11.7\ atm}$$

$$\chi_{He} = \frac{9.3\ atm}{11.7\ atm}$$

HW 10-3 Example Dalton's Law (mole fraction)

- Partial pressure of oxygen was observed to be 156 torr (P_{O2}) in air with a total atmospheric pressure of 743 torr (P_{total}) Calculate the mole fraction of O_2 present. Calculate the pressure due to the other gases.

$$\chi_1 = \frac{P_1}{P_{\text{TOTAL}}}$$

$$P(\text{total}) = P_{O2} + P_{\text{other gases}}$$

10-3 Example Dalton's Law (mole fraction)

- Partial pressure of oxygen was observed to be 156 torr (P_{O2}) in air with a total atmospheric pressure of 743 torr (P_{total}) Calculate the mole fraction of O_2 present

$$\boxed{\chi_1 = \frac{P_1}{P_{\text{TOTAL}}}} \qquad \chi_{O_2} = \frac{P_{O_2}}{P_{\text{TOTAL}}} = \frac{156\ \cancel{\text{torr}}}{743\ \cancel{\text{torr}}} = 0.210$$

$$\boxed{P(\text{total}) = P_{O2} + P_{\text{other gases}}}$$

$$743 \text{ torr} = 156 \text{ torr} + P_{\text{other gases}}$$

$$743 \text{ torr} - 156 \text{ torr} = P_{\text{other gases}}$$

The Kinetic-Molecular Theory of Gases

1. A gas consists of tiny particles, either atoms or molecules, moving about at random.

2. The volume of the particles themselves is negligible compared with the total volume of the gas. Most of the volume of a gas is empty space.

3. The gas particles act independently of one another; there are no attractive or repulsive forces between particles.

The Kinetic-Molecular Theory of Gases

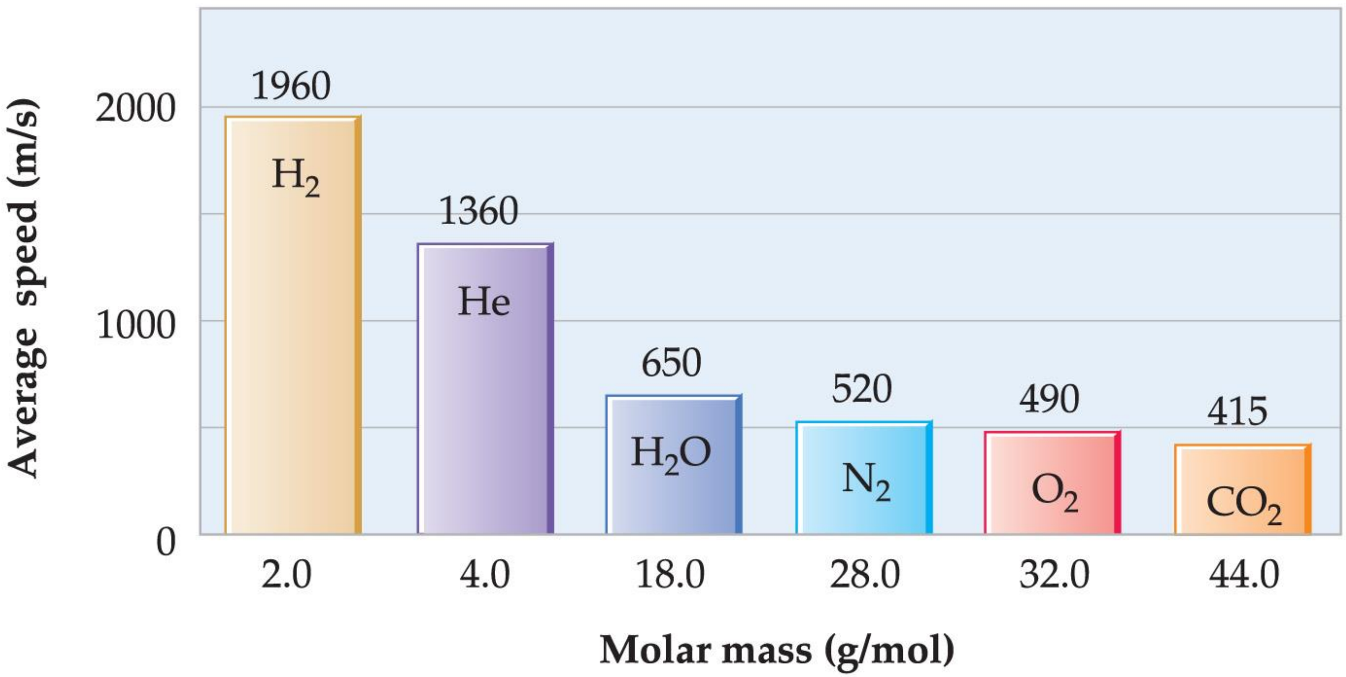
4. Collisions of the gas particles, either with other particles or with the walls of a container, are elastic (constant temperature).

5. The average kinetic energy of the gas particles is proportional to the Kelvin temperature of the sample.

The Kinetic-Molecular Theory of Gases

bigger gas molecule, slower speed of gas molecule

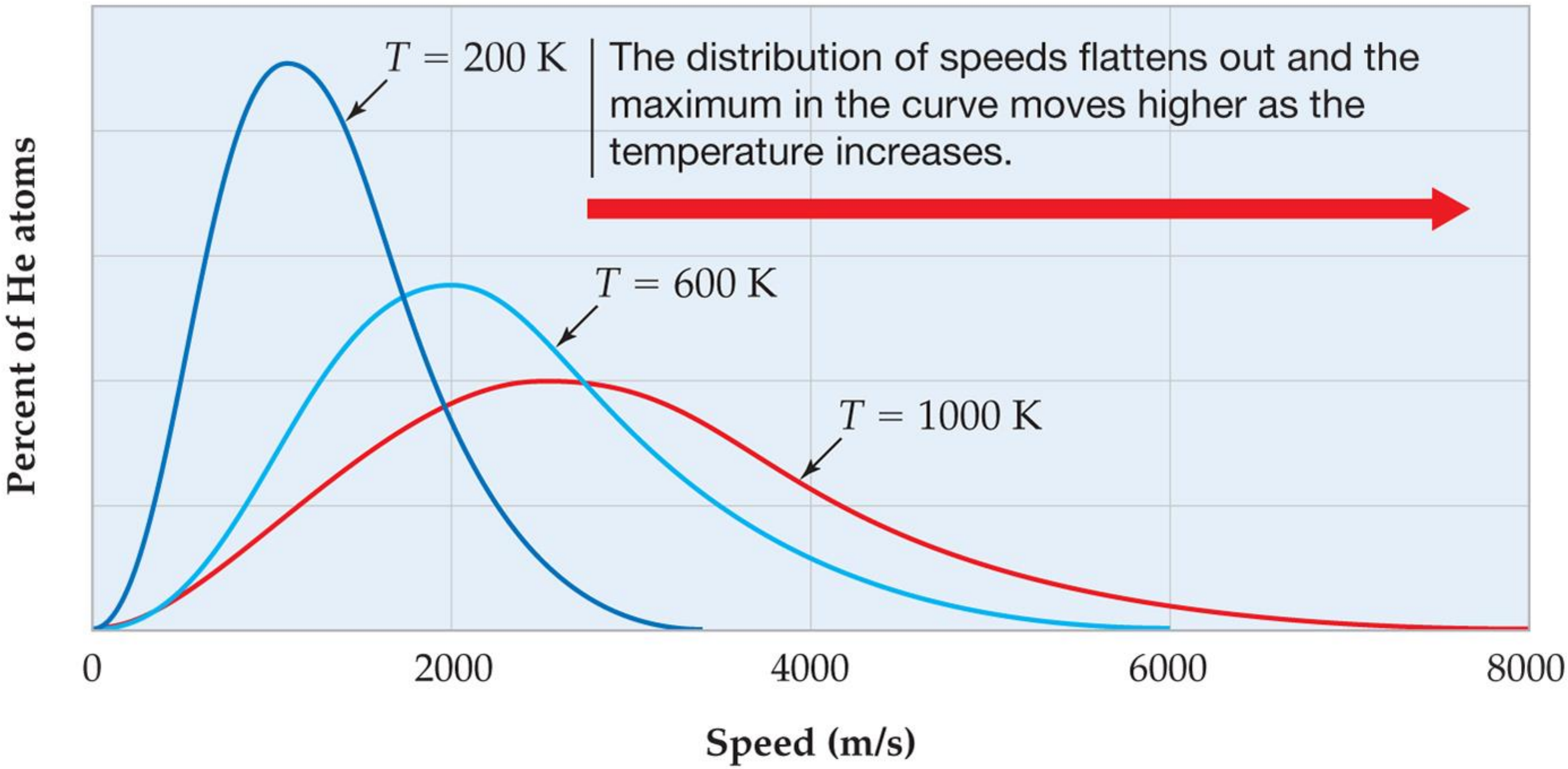
TABLE 9.5 Average Speeds (m/s) of Some Gas Molecules at 25 °C



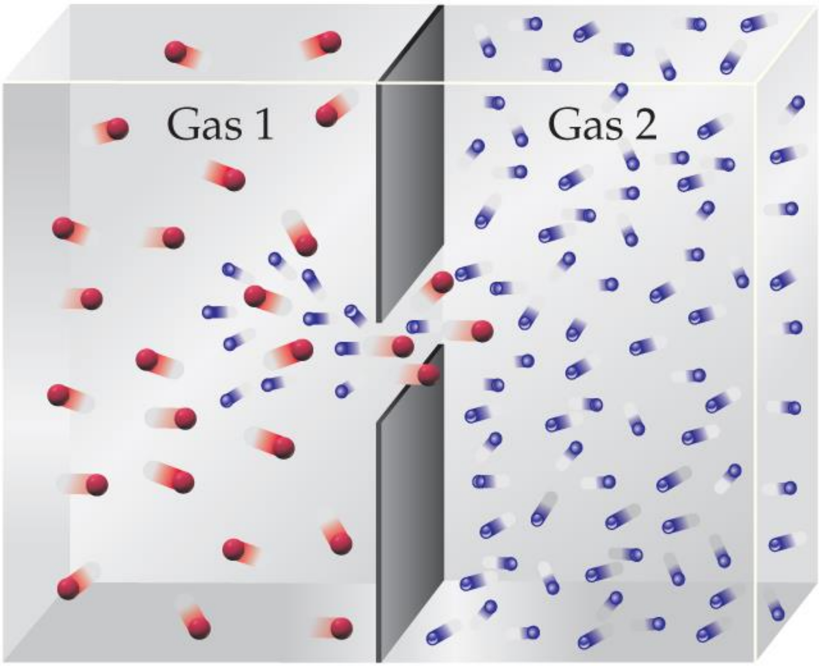
Molar mass

Average speed

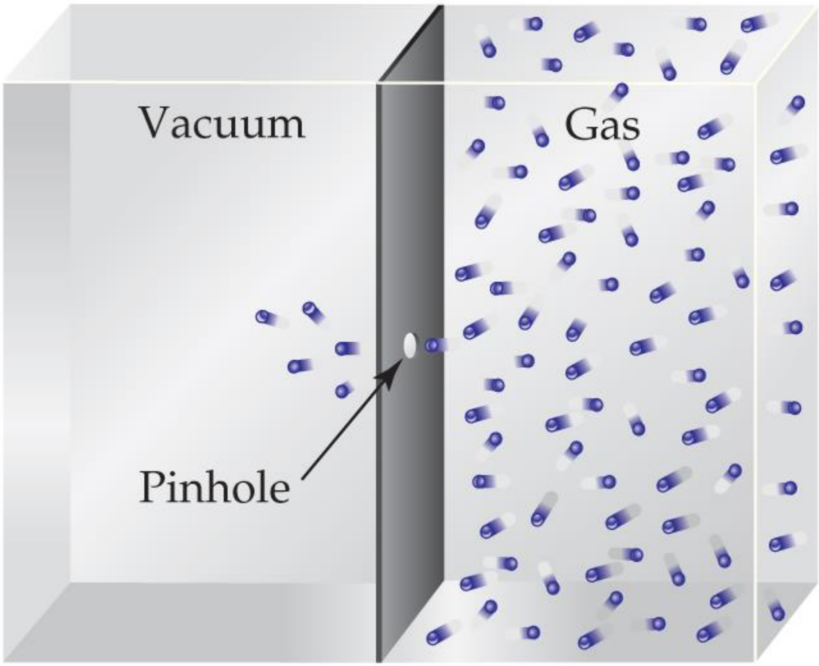
The Kinetic-Molecular Theory of Gases



Diffusion and Effusion of Gases: Graham's Law



Diffusion is the mixing of gas molecules by random motion under conditions where molecular collisions occur.



Effusion is the escape of a gas through a pinhole into a vacuum without molecular collisions.

Effusion is good approximation of diffusion because volume in ideal gases is mostly empty space almost same as vacuum.

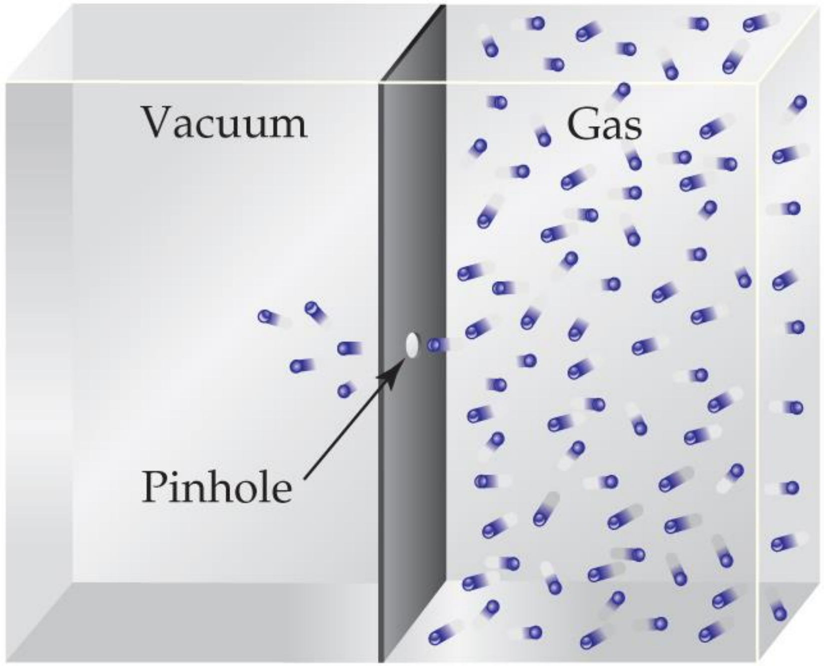
Diffusion and Effusion of Gases: Graham's Law

Graham's Law

$$\text{Rate} \propto \frac{1}{\sqrt{m}}$$

End 12/5 D section
End 12/6 F, G section

lighter the molecule, faster molecule effuses (bc lighter molecule has faster speed)



Effusion is the escape of a gas through a pinhole into a vacuum without molecular collisions.