Chapter 10 - Gases

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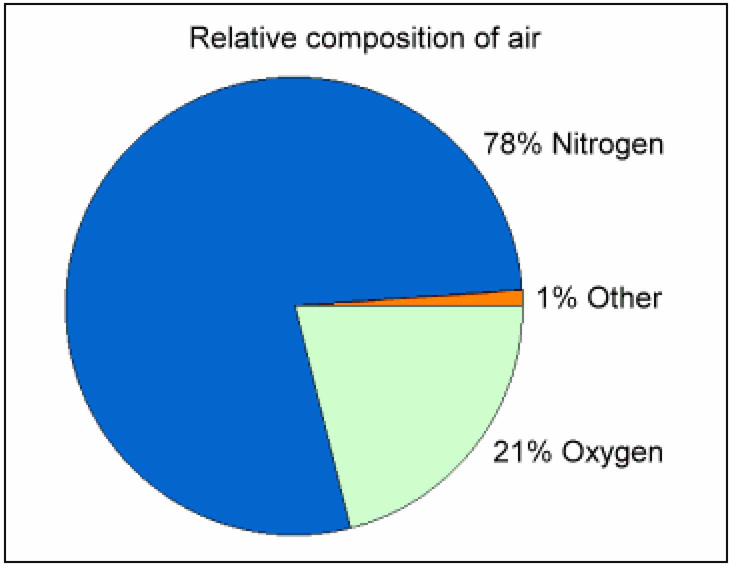
Section 10.1 – Characteristics of Gases

- Air is a complex mixture of several substances, primarily N_2 (78%) and O_2 (21%), with small amounts of several other gases.

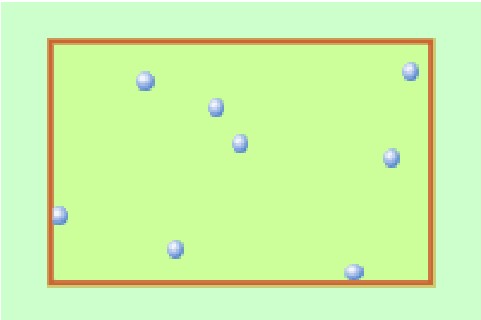


Gases

- Most compounds that exist as gases are molecular, have low molar masses, and made of only nonmetals. Ex: CO, CO_2, CH_4, NO_2, and SO_2.
- A vapor is a substance in the gaseous state that exists as a liquid or solid under ordinary conditions. Ex: O_2 = gas, H_2O = vapor

Properties of Gases

- A gas expands to fill its container, so the volume of a gas always equals the volume of the container.
- Gases are highly compressible.
- Gases form homogeneous mixtures with each other regardless of the identities or relative proportions of the component gases.
- Gas particles are far apart and act independently of one another.



Section 10.2 - Pressure

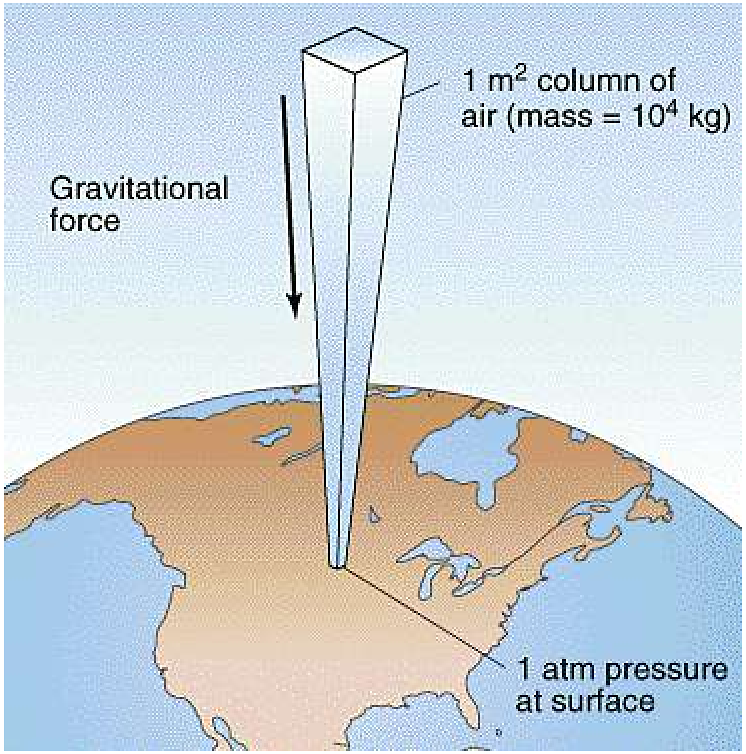
- Pressure is a force that acts on a given area.

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

P = Pressure (Pa)

F = force (N)

A = area (m^2)



Pressure

- The SI unit for pressure is the pascal (Pa).

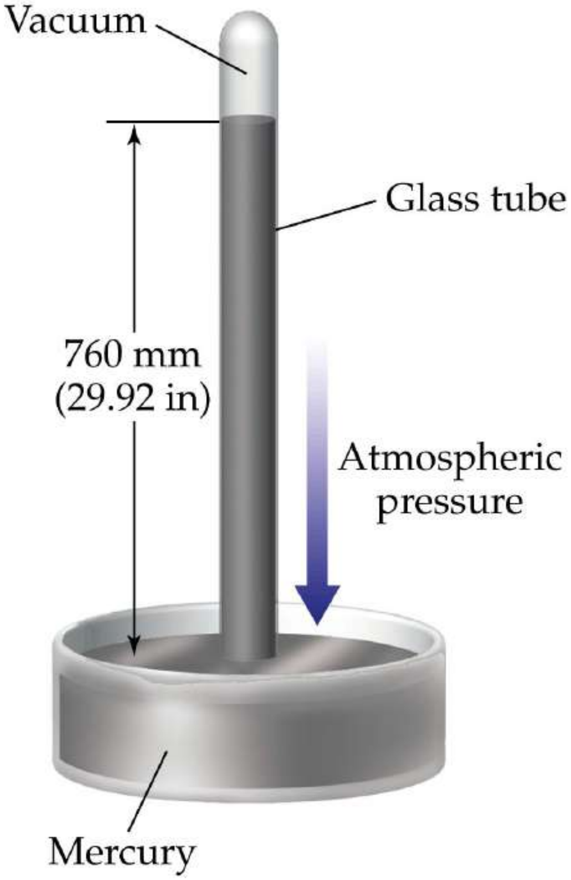
$$1\ \text{Pa} = 1\ \text{N/m}^2$$

- Other units of pressure can be used and are shown below:

1 atm = 760 mm Hg = 760 torr = 101.3 kPa

Barometer

- A barometer is a device used to measure atmospheric pressure.
- Standard atmospheric pressure is the pressure at sea level and can support a column of mercury 760mm high.



Sample Exercise 10.1

a. Convert 0.357 atm to torr.

b. Convert 6.6×10^{-2} torr to atm.

c. Convert 147.2 kPa to torr.

Practice Exercise

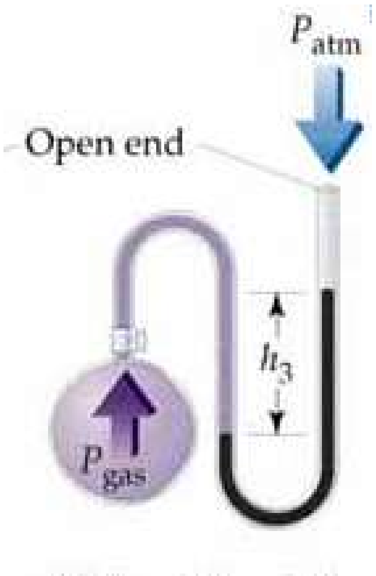
a. In countries that use the metric system, atmospheric pressure in weather reports is given in kPa. Convert a pressure of 745 torr to kPa.

b. An English unit of pressure used in engineering is pounds per square inch or psi: 1atm = 14.7 lb/in^2. If a pressure is reported as 91.5 psi, express the measurement in atm.

Manometer

- A manometer is a device that we use in the lab to measure pressure.
- Pressure is based on the difference in the heights of the two arms.

$$P_{gas} = P_{atm} + P_h$$



(c) $P_{gas} = P_{atm} + P_{h_3}$

Sample Exercise 10.2

- A sample of gas is placed in a flask attached to a manometer and the level of mercury in the open-end arm has a height of 136.4 mm, and the are that is in contact with the gas has a height of 103.8 mm. What is the pressure of the gas in atm if the atmospheric pressure was 764.7 torr?

Practice Exercise

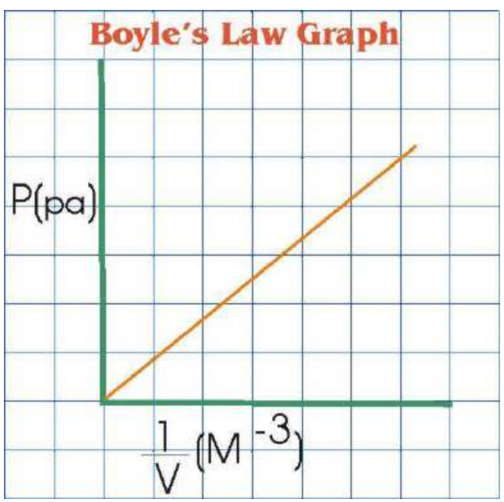
- Convert a pressure of 0.975 atm into Pa and kPa.

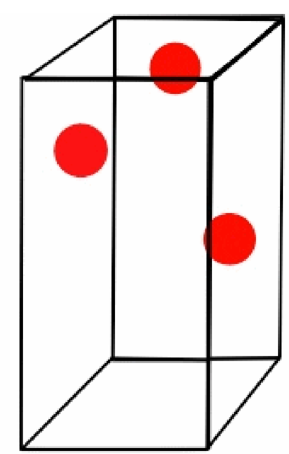
Section 10.3 – The Gas Laws

- Boyle's Law states that the volume of a fixed quantity of gas maintained at constant temperature is inversely proportional to the pressure.

$$PV = \text{constant}$$

$$V_1P_1 = V_2P_2$$



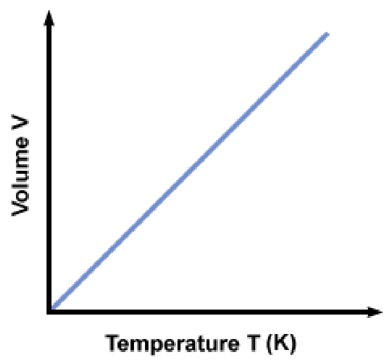


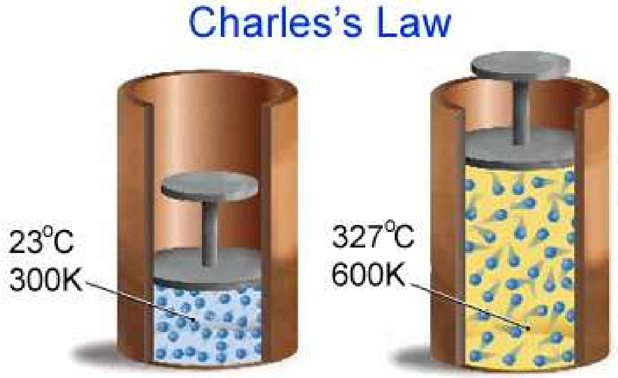
Charles' Law

- Charles' law states that the volume of a fixed amount of gas maintained at constant pressure is directly proportional to its absolute (Kelvin) temperature.

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

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





Avogadro

- Avogadro's hypothesis states that equal volumes of gases at the same temperature and pressure contain equal numbers of molecules.
- 1 mole of any gas a 0^oC and 1 atm will contain 6.02×10^{23} particles and will occupy a volume of 22.4L.

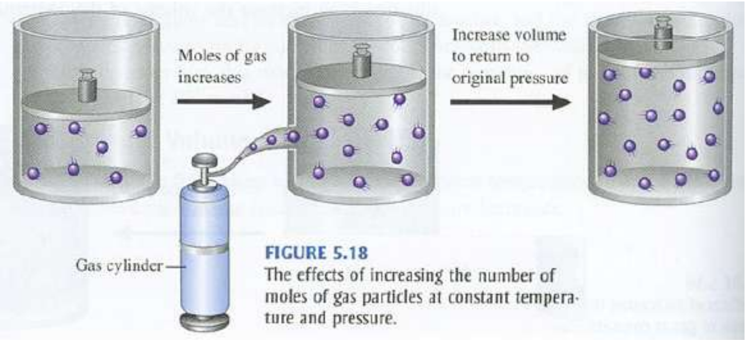


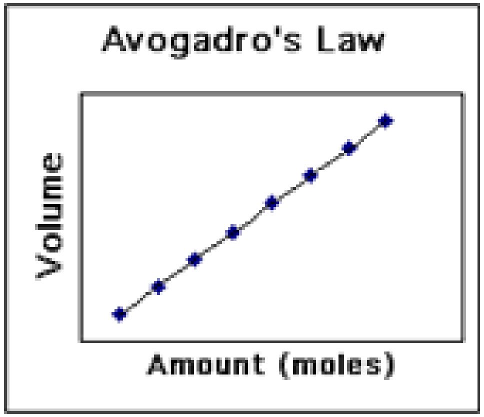
FIGURE 5.18
The effects of increasing the number of moles of gas particles at constant temperature and pressure.

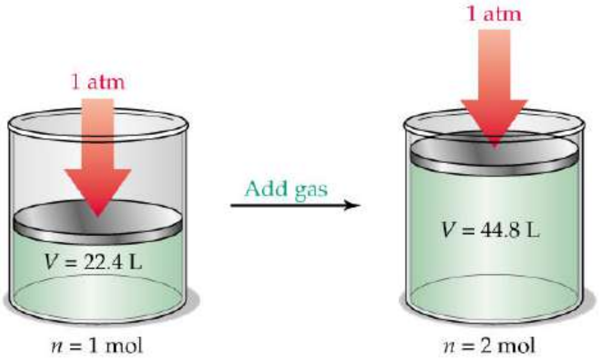
Avogadro

- Avogadro's law states that the volume of a gas maintained at constant temperature and pressure is directly proportional to the number of moles of the gas.

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

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





Sample Exercise 10.3

- Suppose we have a gas confined to a cylinder with a piston and inlet valve. Consider the following changes:

a. Heat the gas from 298K to 360K, while maintaining the piston's position.

Sample Exercise 10.3

b. Move the piston to reduce the volume of gas from 1L to 0.5L.

c. Inject additional gas through the gas inlet valve.

Practice Exercise

- What happens to the density of a gas as

a. the gas is heated in a constant-volume container?

b. the gas is compressed at constant temperature?

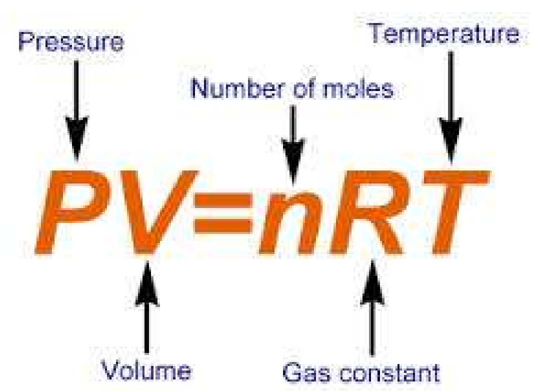
c. additional gas is added to a constant-volume container?

Section 10.4 – The Ideal Gas Equation

- The ideal gas equation related all of the calculated values of a gas: pressure, temperature, volume, and number of moles.

$$PV = nRT$$

- R = 0.0821 L·atm/mol·K (8.31 L·kPa/mol·K)



STP

- STP means standard temperature and pressure.
- The values for STP are 0ºC and 1 atm.

Name	Value	Unit
Standard Pressure	101.3 kPa 1 atm	kilopascal atmosphere
Standard Temperature	273 K 0°C	kelvin degree Celsius

Sample Exercise 10.4

- A sample of $CaCO_3$ is decomposed, and the carbon dioxide is collected in a 250mL flask. After the decomposition is complete, the gas has a pressure of 1.3 atm at a temperature of 31^{o}C. How many moles of CO_2 gas were generated?

Practice Exercise

- Tennis balls are usually filled with air or N_2 gas to a pressure above atmospheric pressure to increase their bounce. If a particular tennis ball has a volume of 144 cm^3 and contains 0.33g of N_2 gas, what is the pressure inside the ball at 24^oC?

Sample Exercise 10.5

- The gas pressure in an aerosol can is 1.5 atm at 25^{o}C. Assuming that the gas inside obeys the ideal gas equation, what would the pressure be if the can were heated to 450^{o}C?

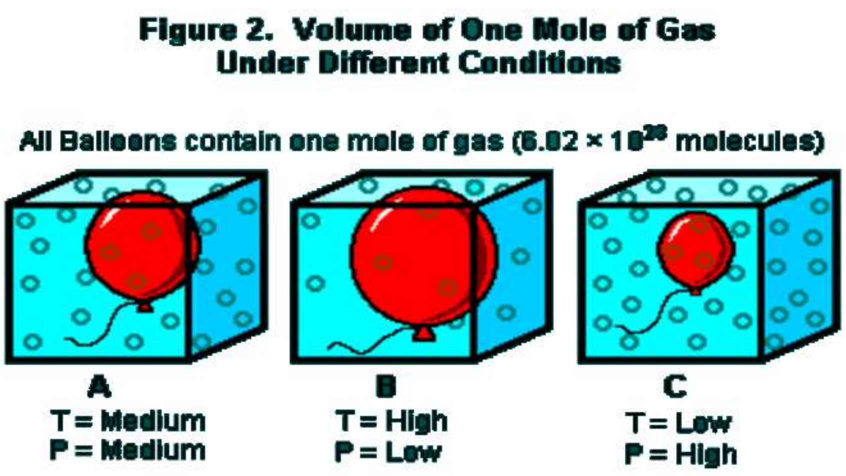
Practice Exercise

- A large natural gas storage tank is arranged so that the pressure is maintained at 2.20 atm. On a cold day in December when the temperature is -15°C, the volume of gas in the tank is 3.25×10^3 m^3. What is the volume of the same quantity of gas on a warm July day when the temperature is 31°C?

Combined Gas Law

- The combined gas law combines pressure, volume, and temperature for a gas with a constant number of particles.

$$\frac{V_1P_1}{T_1} = \frac{V_2P_2}{T_2}$$



Sample Exercise 10.6

- An inflated balloon has a volume of 6.0L at sea level (1 atm) and is allowed to ascend in altitude until the pressure is 0.45 atm. During ascent the temperature of the gas falls from 22°C to -21°C. Calculate the volume of the balloon at its final altitude.

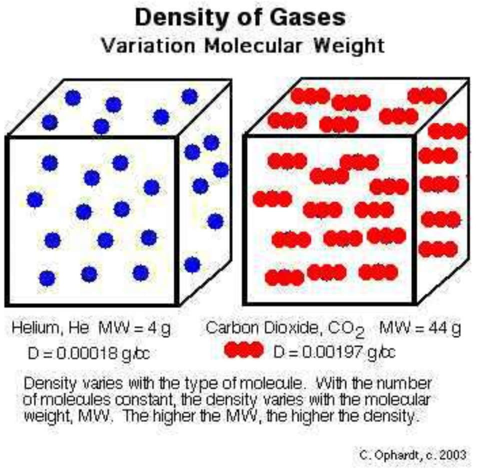
Sample Exercise

- A 0.50 mol sample of oxygen gas is confined at 0^{o}C in a cylinder with a moveable piston. The gas has an initial pressure of 1.0 atm. The piston then compresses the gas so that its final volume is half the initial volume. The final pressure of the gas is 2.2 atm. What is the final temperature of the gas in degrees Celsius?

Section 10.5 – Further Applications of the Ideal Gas Equation

- The ideal gas equation can be used to calculate density or molar mass.

$$D = m/V \text{ and } \mathcal{M} = g/mol \text{ so,}$$



$$D = \frac{P\mathcal{M}}{RT}$$

Sample Exercise 10.7

- What is the density of carbon tetrachloride vapor at 714 torr and 125^{o}C?

Practice Exercise

- The molar mass of the atmosphere at the surface of Titan, Saturn's largest moon, is 28.6 g/mol. The surface temperature is 95K, and the pressure is 1.6 atm. Assuming ideal behavior, calculate the density of Titan's atmosphere.

Sample Exercise 10.8

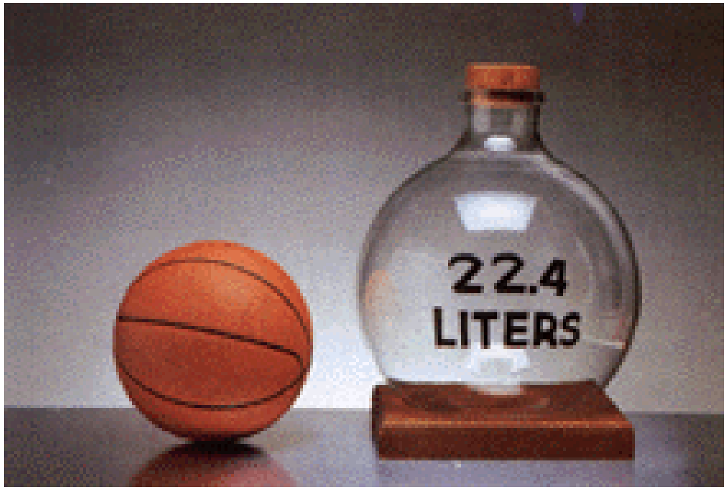
- A series of measurements are made to determine the molar mass of an unknown gas. First, a large flask is evacuated and found to weigh 134.567g. It is then filled with the gas to a pressure of 735 torr at 31^{o}C and reweighed. Its mass is now 137.456g. Finally, the flask is filled with water at 31^{o}C and found to weigh 1067.9g. (The density of water at this temperature is 0.997 g/mL.) Calculate the molar mass of the unknown gas.

Practice Exercise

- Calculate the average molar mass of dry air if it has a density of 1.17 g/L at 21^{o}C and 740 torr.

Stoichiometry

- One mole of any gas occupies a volume of 22.4L at STP, so 1 mol = 22.4L can by used in stoichiometric calculations.
- Sometimes the ideal gas equation must be used to calculate a value for a stoichiometric question.



Sample Exercise 10.9

- The safety air bags in automobiles are inflated by nitrogen gas generated by the rapid decomposition of sodium azide, NaN_3. If an air bag has a volume of 36L and is to be filled with nitrogen gas at a pressure of 1.15 atm at a temperature of 26.0°C, how many grams of NaN_3 must be decomposed?

$$2NaN_{3(s)} \rightarrow 2Na_{(s)} + 3N_{2(g)}$$

Practice Exercise

- How many liters of $NH_{3(g)}$ at 850°C and 5.00 atm are required to react with 1.00 mol of $O_{2(g)}$ in this reaction?

$$4NH_{3(g)} + 5O_{2(g)} \rightarrow 4NO_{(g)} + 6H_2O_{(g)}$$

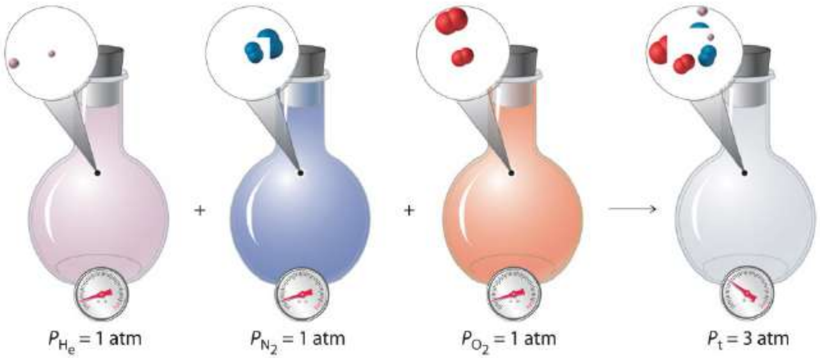
Section 10.6 – Gas Mixtures and Partial Pressures

- Dalton's law of partial pressures states that the total pressure of a mixture of gases equals the sum of the pressures that each would exert if it were present alone.

$$P_T = P_1 + P_2 + P_3 \ldots$$

- This formula can also be written as follows:

$$P_T = \frac{n_T RT}{V}$$



Sample Exercise 10.10

- A gaseous mixture made gram 6.00g O_2 and 9.00g CH_4 is placed in a 15.0L vessel at 0^oC. What is the partial pressure of each gas, and what is the total pressure in the vessel?

Practice Exercise

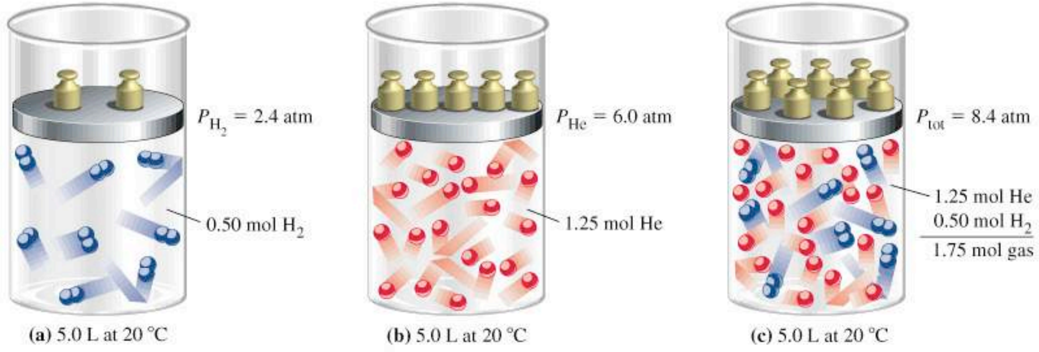
- What is the total pressure exerted by a mixture of 2.00g H_2 and 8.00g of N_2 at 273K in a 10.0L vessel?

Mole Fraction

- The mole fraction, X, is a dimensionless number that expresses the ratio of the number of moles of one component to the total number of moles in the mixture.

$$X_1 = \frac{n_1}{n_t}$$

$$P_1 = X_1 P_t$$



Sample Exercise 10.11

- A study of the effects of certain gases on plant growth requires a synthetic atmosphere composed of 1.5 mol percent CO_2, 18.0 mol percent O_2, and 80.5 mol percent Ar.

a. Calculate the partial pressure of O_2 in the mixture if the total pressure of the atmosphere is to be 745 torr.

Sample Exercise 10.11 con't

b. If this atmosphere is to be held in a 121L space at 295K, how many moles of O_2 are needed?

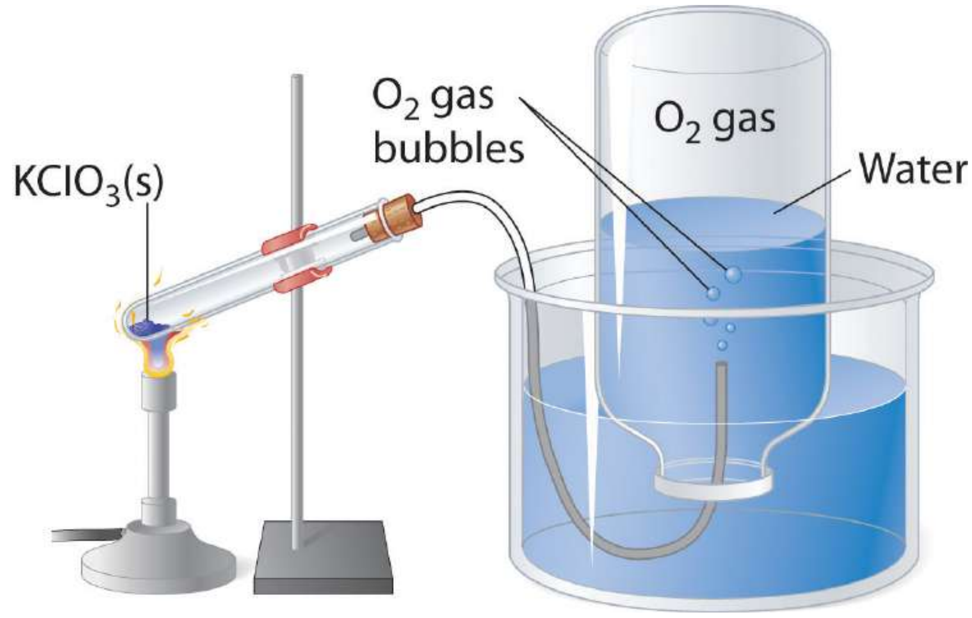
Practice Exercise

- From the data gathered by Voyager 1, scientists have estimated the composition of the atmosphere or Titan. The total pressure on the surface of Titan is 1220 torr. The atmosphere consists of 82 mol percent N_2, 12 mol percent Ar, and 6.0 mol percent CH_4. Calculate the partial pressures of each of these gases in Titan's atmosphere.

Collecting Gas Over Water

- Sometimes gases are collected in a lab by water displacement. However, some of the gas would be water vapor, so that must be subtracted to get an accurate pressure.

$$P_T = P_{gas} + P_{H2O}$$



Sample Exercise 10.12

- A sample of $KClO_3$ is decomposed, producing O_2 gas that is collected over water. The volume of gas collected is 0.250L at 26°C and 765 torr total pressure. (P_{H2O} for 26°C = 25 torr)

a. How many moles of O_2 are collected?

b. How many grams of $KClO_3$ are decomposed?

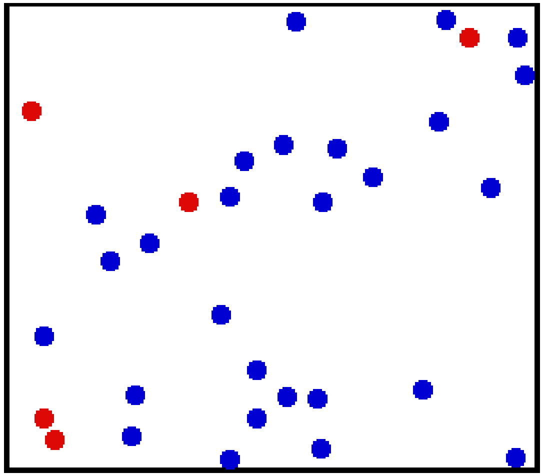
Practice Exercise

- When a sample of NH_4NO_3 is decomposed in a test tube, 511mL of N_2 gas is collected over water at 26°C and 745 torr total pressure. How many grams of NH_4NO_3 were decomposed? (P_{H2O} for 26°C = 25 torr)

$$NH_4NO_{3(g)} \rightarrow N_{2(g)} + 2H_2O_{(l)}$$

Section 10.7 – Kinetic-Molecular Theory

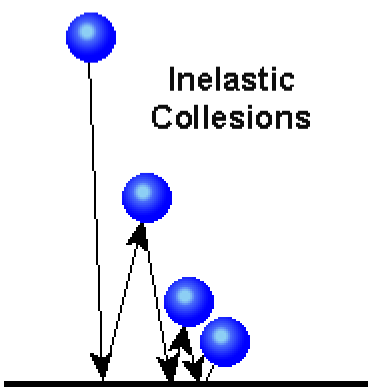
- The kinetic-molecular theory is summarized by the following statements:

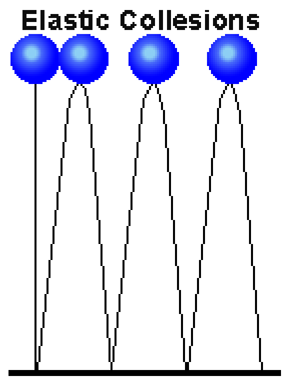


1. Gases consist of large numbers of particles that are in constant, random motion.
2. The volume of the gas particles is negligible compared to the total volume in which the gas is contained.

Kinetic-Molecular Theory

3. Attractive and repulsive forces between the gas molecules are negligible.
4. Collisions between gas particles are perfectly elastic (energy is conserved).
5. The average kinetic energy of the gas particles is directly proportional to the absolute (Kelvin) temperature.

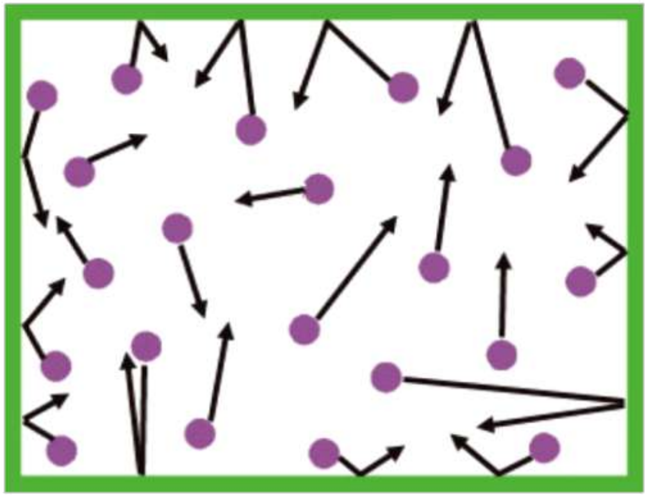




← I know that they spelled collisions wrong, but these are still good pictures.

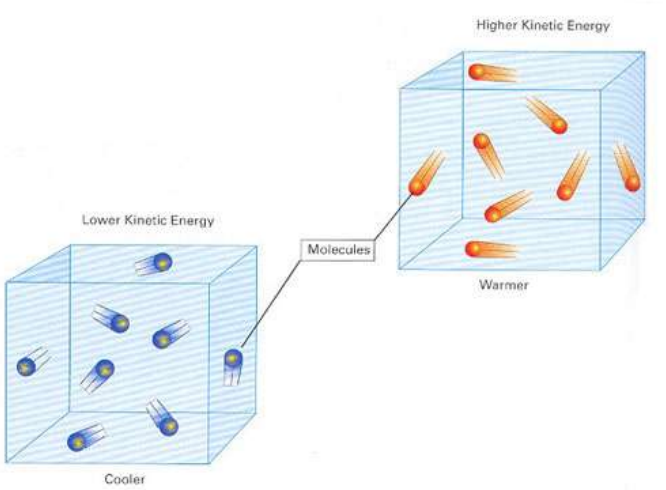
Gas Pressure

- The pressure of a gas is caused by the collisions of the particles with the wall of the container.
- The magnitude of the pressure is determined by both how often and how forcefully the molecules strike the walls.



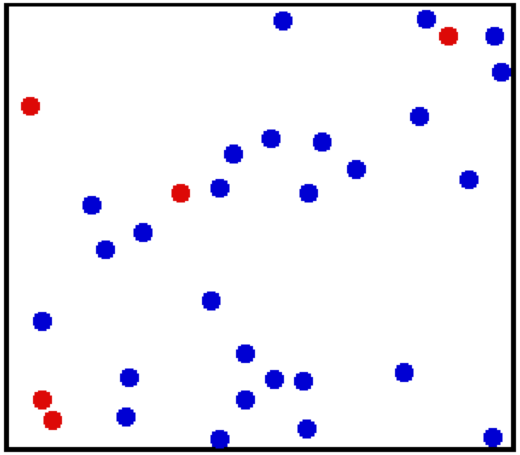
Temperature

- The absolute (Kelvin) temperature of a gas is a measure of the average kinetic energy of its particles.
- Two different gases at the same temperature have the same average kinetic energy regardless of the molar masses or identities of the gases.



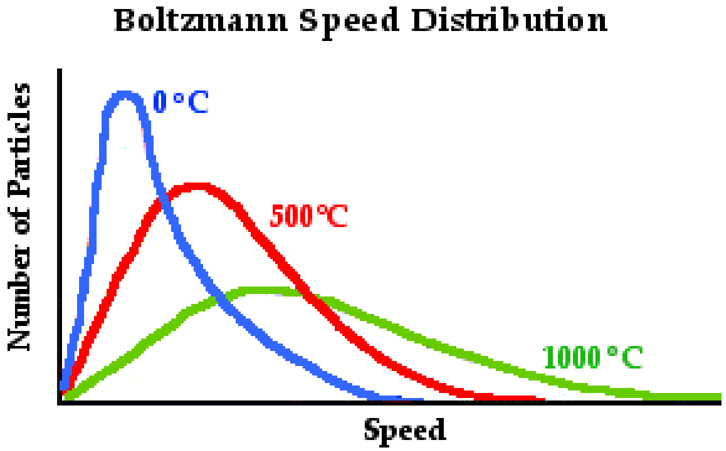
Molecular Speed

- Although the particles in a sample of gas have an average kinetic energy and hence an average speed, the individual particles move at varying speeds.
- The root-mean-square (rms) speed, u, is the speed of a molecule possessing average kinetic energy.



rms Speed

- The rms speed is not quite the same as the average speed, but the difference between the two is small.
- As temperature increases rms speed increases.



For any given temperature, there is a distribution of speeds with which particles within the sample can move. As the temperature is increased, there is a greater percentage of particles moving at the higher speeds.

Sample Exercise 10.13

- A sample of O_2 gas initially at STP is compressed to a smaller volume at constant temperature. What effect does this change have on

a. the average kinetic energy of the O_2 molecules?

b. The average speed of the O_2 molecules?

Sample Exercise 10.13 Con't

c. the total number of collisions of O_2 molecules with the container walls in a unit time?

d. the number of collisions of O_2 molecules with a unit area of container wall per unit time?

Practice Exercise

- How is the rms speed of N_2 molecules in a gas sample changed by

a. an increase in temperature?

b. an increase in volume?

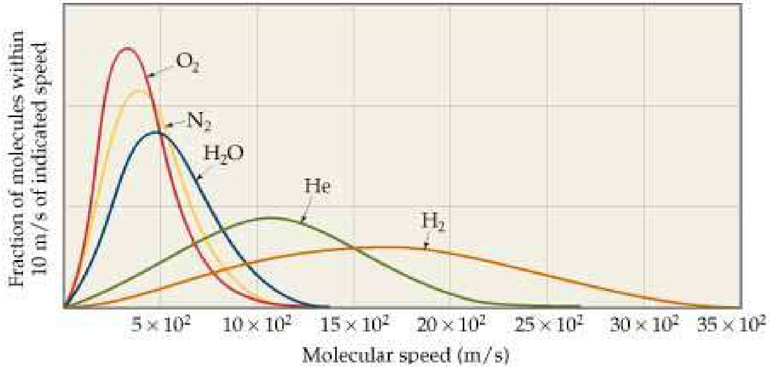
c. mixing with a sample of Ar at the same temperature?

Section 10.8 – Molecular Effusion and Diffusion

$$u = \left(\frac{3RT}{\mathcal{M}} \right) \text{ square root}$$

$$R = 8.314\ kg \cdot m^2/s^2 \cdot mol \cdot K$$

- Since molar mass, $\mathcal{M}$, appears in the denominator, the less massive the gas molecules, the higher the rms speed, u.



Sample Exercise 10.14

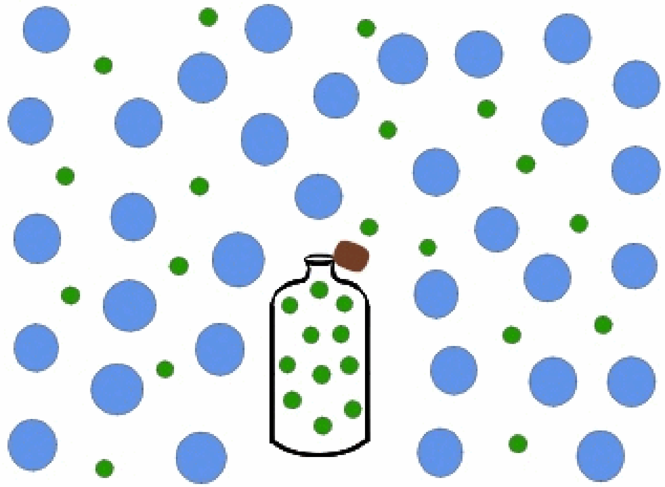
- Calculate the rms speed, u, of an N_2 molecule at 25^oC.

Practice Exercise

- What is the rms speed of an He atom at 25°C?

Effusion vs. Diffusion

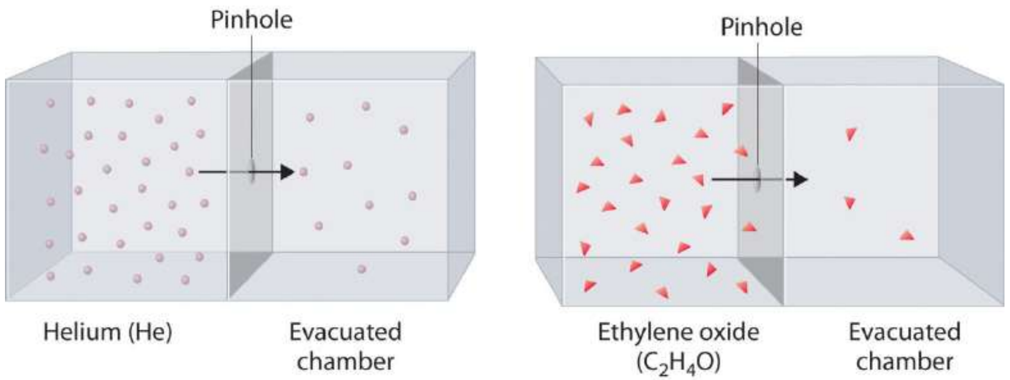
- Effusion is the escape of gas particles through a tiny hole into an evacuated space.
- Diffusion is the spread of one substance throughout a space or throughout a second substance.
- In both cases, the gas particles move from high to low concentration.



Graham's Law

$$\frac{r_1}{r_2} = \left(\frac{\mathcal{M}_2}{\mathcal{M}_1}\right) \text{ square root}$$

- r = the rate of diffusion/effusion
- $\mathcal{M}$ = molar mass
- A gas with a lower molar mass will effuse or diffuse faster than a heavier gas.



Sample Exercise 10.15

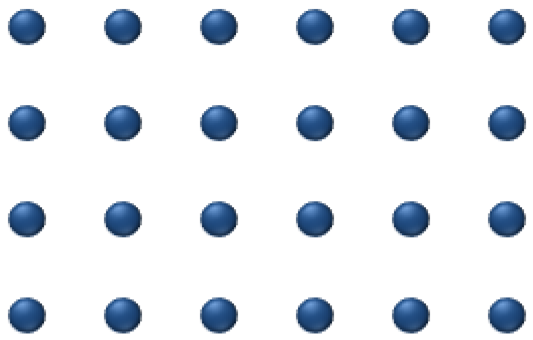
- An unknown gas composed of homonuclear diatomic molecules effuses at a rate that is only 0.355 times that of O_2 at the same temperature. Calculate the molar mass of the unknown gas, and identify it.

Practice Exercise

- Calculate the ratio of the effusion rates of N_2 and O_2.

Diffusion and Molecular Speed

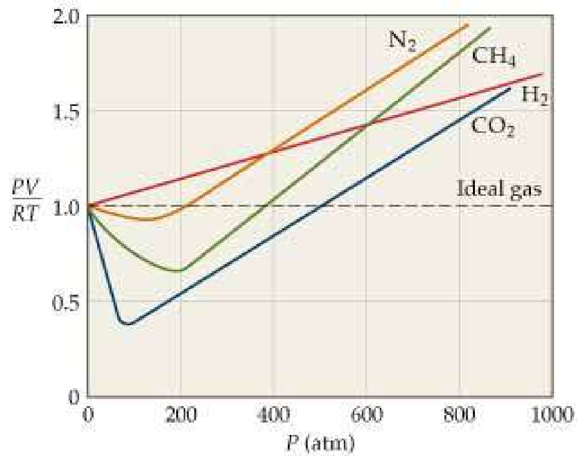
- The diffusion of gases is much slower than molecular speeds because of molecular collisions.
- The average distance traveled by a particle between collisions is called the mean free path.



← This is an example of surface diffusion for a solid.

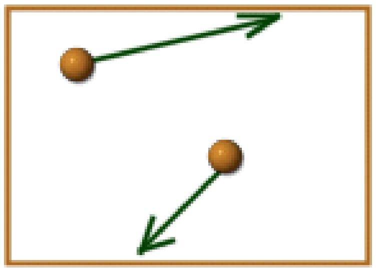
Section 10.9 – Real Gases: Deviations from Ideal Behavior

- Real gases do not behave ideally at high pressures and at low temperatures.
- Ideal gases are gases at all conditions while real gases turn into liquids and solids at high pressures and low temperatures.

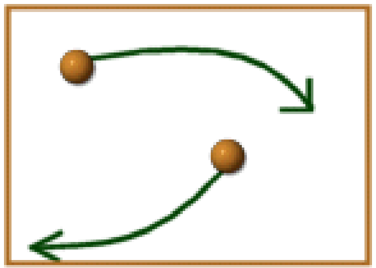


Real Gases

- Real gas particles have a volume.
- Real gas particles experience attractions and repulsions.



Ideal - no IMF
straight paths



Real - with IMF
curved paths

Sample Integrative Exercise

- Cyanogen, a highly toxic gas, is composed of 46.2% C and 53.8% N by mass. At 25^{o}C and 751 torr, 1.05g of cyanogen occupies 0.500L.

  a. What is the molecular formula of cyanogen?

Sample Integrative Exercise

b. Predict its molecular structure.

c. Predict the polarity of the compound.