Chapter 10
Gases

- Earth is surrounded by a layer of gaseous molecules - the atmosphere - extending out to about 50 km.

10.1 Characteristics of Gases

- Gases
  - low density; compressible
  - volume and shape of container
  - expand when heated
  - large distance between particles
- Model of a gas:
  - rapidly moving particles: vol. & shape of container
  - no attraction between particles
  - moving about freely
  - large space between particles: low density & high compressibility

Liquids and Solids

- Liquids
  - higher density, lower compressibility
  - characteristic volume; shape of container
  - particles closer together; moving about; experience attractive forces
- Solids
  - high density; low compressibility
  - particles are close together; little empty space; strong attractive forces
  - characteristic volume and shape

Atomic View of the States of Matter

- Note distance between particles and order of arrangement of particles

10.2 Pressure

- Pressure = force/area
- Units: lb/ft^2
  $Pa = N/m^2 = kg/ms^2$
  torr = mm Hg
  atm
- 1 atm = 760 torr
  1 atm = 29.9 in Hg = 14.7 lb/in^2
  1 atm = 101.3 kPa
- Measure pressure with barometer or U-tube or manometer

Pressure

- Demo: soft drink can
- Why does a pin hurt?

- Why don't snowshoes sink?

Barometer

- What is in a vacuum? What is the weight of the atmosphere?

10.3 The Gas Laws

- How can we change the volume of a gas enclosed in a balloon?
- Variables: V, P, T, n (or m and MM or d)
- How do each of the other variables affect the volume of a gas?
- Ideal Gas: properties are independent of the identity of the gas
- What is the relationship between the variables for an ideal gas?

P-V at constant n,T

- Boyle's Law
  PV = constant

Charles' Law

- Investigation of Balloons

V-T at constant n,P

- Charles' Law
- V/T = constant

Avogadro's Law

- Gay-Lussac's Law of combining volumes: at a given temperature and pressure, the volumes of gases which react are ratios of small whole numbers.
- Explained by Avogadro's Hypothesis: equal volumes of gas at the same temperature and pressure will contain the same number of molecules.
- Avogadro's Law: the volume of gas at a given temperature and pressure is directly proportional to the number of moles of gas.
- Mathematically: $V = \text{constant} \times n$.
- Why did the blimp deflate?

Molar Volume at STP

We can show that 22.414 L of any gas at 0°C and 1 atm contain 6.02×10^{23} gas molecules.

10.4 The Ideal-Gas Equation

- PV = nRT
- Boyle's Law: PV = constant at constant n,T
  $P_1V_1 = P_2V_2$
- Charles' Law: V = constant x T at constant P, n
  $V_1T_2 = V_2T_1$
- Avogadro's Hypothesis: V = constant x n at constant P, T
- 1 mole occupies 22.414 L at STP (0^oC, 1 atm)

- $V_1n_2 = V_2n_1$

Ideal Gas Problems

- PV = nRT
- Universal Gas Constant:
  R = 0.08206 L atm/mol K
- Convert variables to these units to simplify problem solving.
- n = m/MM
- With these relationships, you should be able to solve problems involving the variables that determine the physical properties of gases.

Practice Problem

- The volume of an oxygen cylinder is 1.85 L. What mass of oxygen gas remains in the cylinder when it is "empty" if the pressure is 755 torr and the temperature is 18.1^{o}C?

10.5 Further Applications of the Ideal-Gas Equation

Gas Densities and Molar Mass

- Density has units of mass over volume.
- Rearranging the ideal-gas equation with M as molar mass we get

$$\frac{n}{V} = \frac{P}{RT}$$

$$\frac{nM}{V} = d = \frac{PM}{RT}$$

Practice Problem

- Bromine gas has the formula Br_2. Calculate the density of bromine gas at 50.0^{o}C and 785.0 torr.

Further Applications of the Ideal-Gas Equation
Gas Densities and Molar Mass

- The molar mass of a gas can be determined as follows:

$$M = \frac{dRT}{P}$$

Practice Problem

- If 1.48 g of an unknown gas occupies 132 mL at 25.0^{o}C and 722 torr, what is its molar mass?

Further Applications of the Ideal-Gas Equation
Volumes of Gases in Chemical Reactions

- The ideal-gas equation relates P, V, and T to number of moles of gas.
- The n can then be used in stoichiometric calculations.

Practice Problem

- A tank of hydrogen gas has a volume of 7.49 L and an internal pressure of 22.0 atm at a temperature of 32.0°C. What volume of gaseous water is produced by the following reaction at 100.0°C and 0.975 atm if all the hydrogen gas reacts with iron(III) oxide? $Fe_2O_3(s) + 3H_2(g) \rightarrow 2Fe(s) + 3H_2O(g)$

10.6 Gas Mixtures and Partial Pressures

- Dalton's Law of Partial Pressures: In a mixture of gases, each exerts a partial pressure the same as it would exert alone.
- $P_{total} = P_A + P_B + P_C + ...$
- The amount of each type of gas in air is proportional to its partial pressure.

Gas Mixtures

- It is common to synthesize gases and collect them by displacing a volume of water.
- To calculate the amount of gas produced, we need to correct for the partial pressure of the water: $P_{total} = P_{gas} + P_{water}$

9.7 Kinetic Molecular Theory

- What causes the observed ideal gas behavior?
- Model of gases is Kinetic Molecular Theory
  1. Small, widely-separated particles
     - low density
     - compressible
     - Example: Xe at STP, only 0.025% of the volume is occupied by the atoms
  2. Molecules behave independently
     - no intermolecular forces
     - Dalton's Law
  3. Rapid, straight-line motion
     - diffusion of gases
     - expansion of gases
     - no net energy loss from collisions
  4. Pressure arises from collisions with the walls of the container
     - Boyle's Law
     - Pressure proportional to number of moles
  5. Average kinetic energy (KE) depends only of the absolute temperature (T)
     - See distribution of KE
     - Distribution of velocities of gaseous particles depends on temperature

10.8 Molecular Effusion and Diffusion

- Average behavior is described by two equations:
  $KE_{av} = 3/2\ kT$ (k = R/N = Boltzmann Constant)
  $KE_{av} = 1/2\ mv_{av}^2$
- Pressure is proportional to temperature (more collisions)
- Graham's Law: $3/2\ kT = 1/2\ m_1v_1^2 = 1/2\ m_2v_2^2$

- $v_1/v_2 = (m_2/m_1)^{1/2}$

Effusion and Diffusion

- Effusion - escape of a gas through a pinhole
- Diffusion - motion of a gas through space
- Gas motion: rate is inversely proportional to the square root of the mass of the particles
- $r_1/r_2 = (M_2/M_1)^{1/2} = (d_2/d_1)^{1/2}$
- Demo: Gassim (available in the Learning Resource Center)
- Which molecules will escape from a leaky balloon fastest?

10.9 Real Gases: Deviations from Ideal Behavior

- Gases can be liquefied by application of pressure (or cooling)
  - not predicted by gas laws
  - real gases deviate from the gas laws
- Ideal gas assumptions about gas particles:
  - no volume
  - no attractive forces
- Near STP, these are good assumptions.
- At high pressure, molecules become closer together.
- How will the actual (measured) volume compare to the ideal (predicted) volume?
- At low temperature, molecules are moving slowly and attractions between particles may become important.
- How will the actual (measured) pressure compare to the ideal (predicted) pressure ?

Intermolecular Forces

- What is the source of attractions between molecules?
- Molecules have variable polarizability - the ability to deform the electron cloud with a nearby charge.
- Larger molecules are easier to deform.
- Temporary polarity arises from momentary electron cloud deformation. This induces temporary polarity in nearby molecules.
- Attractions between adjacent temporary dipoles are called London dispersion forces.

Real Gases

- The van der Waals Equation
- We add two terms to the ideal gas equation, one to correct for volume of molecules and the other to correct for intermolecular attractions
- The correction terms generate the van der Waals equation:

$$P = \frac{nRT}{V - nb} - \frac{n^2 a}{V^2}$$

where a and b are empirical constants.