The Gas Laws

Objectives

- List five observed properties of gases.
- Convert a given gas pressure into a different unit of measure.
- Use Boyle's Law to determine the new pressure or volume when one of the two quantities is changed.
- Use Charles's Law to determine the new temperature or volume when one of the two quantities is changed.
- Use Gay-Lussac's Law to determine the new pressure or temperature when one of the two quantities is changed.
- Use the combined gas Law to determine the new pressure, volume, or temperature when one or more of the quantities is changed.

Objectives

- Explain the concept of vapor pressure.
- Use a table of vapor pressures to determine the vapor pressure of water at a given temperature.
- List five characteristics of an ideal gas.
- Calculate the pressure, volume, temperature, or number of moles of a gas from the ideal gas equation.

Properties of Gases

- Gases have an indefinite shape.
- Gases expand to fill the container they occupy.
- Gases are compressible.
- Gases have low densities.
- Gases diffuse uniformly throughout a container to form homogeneous mixtures.
- Gases exert pressure against the walls of a container.

Pressure

- Pressure depends on the number of particles that hit the wall of the container.
- Pressure depends on the energy of the particles that hit the wall of the container.
- Pressure Units
  - Atmospheres (Atm)
  - Inches of Mercury (in Hg)
  - Millimeters of Mercury (mm Hg)
  - Torr
  - Pounds per square inch (PSI)
  - Kilopascals (Kpa)

Boyle’s Law

- The volume of a gas is inversely proportional to the pressure, all other factors remaining constant.
- $P_1V_1 = P_2V_2$
  - P_1 - First Pressure (Atm, inHg, mm Hg, Kpa, PSI, Torr)
  - V_1 - First Volume (L, ml, cm^3, m^3, ft^3,)
  - P_2 - Second Pressure (Atm, inHg, mm Hg, Kpa, PSI, Torr)
  - V_2 - Second Volume (L, ml, cm^3, m^3, ft^3,)

Boyle's Law Example

- A 1.50 L sample of methane gas exerts a pressure of 1650 mm Hg. Calculate the new pressure if the volume changes to 7.00 L.

  Given: V_1 = 1.50 L P_1 = 1650 mm Hg V_2 = 7.00 L

  Find: P_2

  Equation: $P_1V_1 = P_2V_2$

  Solution: (1650 mm Hg)(1.5 L) = (P_2)(7.00 L)

  Answer: P_2 = 354 mm Hg

Charles' Law

- The volume of a gas is directly proportional to temperature, all other factors remaining constant.
- $V_1/T_1 = V_2/T_2$

  V_1 - First Volume (L, ml, cm^3, m^3, ft^3)

  T_1 - First Temperature (K)

  V_2 - Second Volume (L, ml, cm^3, m^3, ft^3)

  T_2 - Second Temperature (K)

Charles' Law Example

- A balloon filled with krypton has a volume of 555 ml at 21°C. If the balloon is cooled and the volume decreases to 475 ml, what is the new temperature?
- Given: V_1 = 555 ml T_1 = 21°C V_2 = 475 ml
- Find: T_2
- Convert from Celsius to Kelvin: 21 °C + 273 °C = 294 K
- Equation: $V_1/T_1 = V_2/T_2$
- Solution: 555 ml/294 K = 475 ml/T_2
- Answer: T_2 = 252 K = -21°C

Gay-Lussac's Law

- The pressure of a gas is directly proportional to temperature, all other factors remaining constant.
- $P_1/T_1 = P_2/T_2$

  P_1 - First Pressure (Atm, inHg, mm Hg, Kpa, PSI, Torr)

  T_1 - First Temperature (K)

  P_2 - Second Pressure (Atm, inHg, mm Hg, Kpa, PSI, Torr)

  T_2 - Second Temperature (K)

Gay-Lussac's Law Example

- A copper sphere has a volume of 555 ml and is filled with air at 25.0^{o}C. The sphere is immersed in dry ice and the pressure of the gas drops from 761 torr to 495 torr. What is the new temperature of the air inside the sphere?

Gay-Lussac's Law Example

- Given: V_1 = 555 ml T_1 = 25.0^{o}C P_1 = 761 torr
  V_2 = 555 ml P_2 = 495 torr
- Find: T_2
- Convert from Celsius to Kelvin: 25.0 ^{o}C + 273 ^{o}C = 298 K
- Equations: $P_1/T_1 = P_2/T_2$
- Solution: 761 torr/298 k = 495 torr/T_2
- Answer: T_2 = 194 K = -79^{o}C

The Combined Gas Law

- The three individual gas laws can be combined into one general gas law:
- $P_1V_1/T_1 = P_2V_2/T_2$

Combined Gas Law Example

- An oxygen sample occupies 50.0 ml at 27.0°C and 765 mm Hg. What is the final temperature if the gas is cooled in such a way that the final volume is 35.5 ml and the final pressure is 455 mm Hg?

Combined Gas Law Example

- Given: $V_1 = 50.0$ ml $T_1 = 27.0^oC$ $P_1 = 765$ mm Hg
  $V_2 = 35.5$ ml $P_2 = 455$ mm Hg
- Find: T_2
- Convert from Celsius to Kelvin: $27.0\ ^oC + 273\ ^oC = 300$ K
- Equation: $P_1V_1/T_1 = P_2V_2/T_2$
- Solution:

  (765 mm Hg)(50.0 ml)/300 K = (455 mm Hg)(35.5 ml)/T_2
- Answer: $T_2 = 127$ K or -146^oC

The Ideal Gas Law

- According to the combined gas law, PV/T is constant for a sample of gas.
- This constant depends on the amount of gas present, or the number of moles.
- All four factors can be combined resulting in what is called the ideal gas law: $PV = nRT$

The Ideal Gas Law

- In this equation:

  P - Pressure

  V - Volume

  T - Temperature

  n - Number of Moles of the Gas

  R - The Ideal Gas Constant: 0.0821 atm·L/mol·K

Ideal Gas Law Example

- How many moles of hydrogen gas occupy a volume of 0.500 L at STP?
  - Given: $V = 0.500$ L $P = 1.00$ atm $T = 273$ K
    $R = 0.0821$ atm·L/mol·K
  - Find: n
  - Equation: $PV = nRT$
  - Solution:

    $n = PV/RT$

    $n = (1.00 \text{ atm})(.500 \text{ L})/(.0821 \text{ atm·L/mol·K})(273 \text{ K})$

    Answer: $n = 0.0223$ mol

Properties of Ideal Gases

- Gases are made up of very tiny particles.
- Gas particles travel at a high average rate of speed in straight lines and in random directions.
- Gas molecules have no attraction for one another.
- Gas molecules undergo elastic collisions.
- The average kinetic energy of the gas molecules is proportional to the Kelvin temperature.

Vapor Pressure

- Water vapor is a gas and exerts a pressure like any other gas.
- When a container holds a mixture of several different kinds of gases, each contributes to the pressure
- The total pressure of the gas is equal to the sum of the partial pressures of each of the gases.
- When a gas is collected over water, the gas contains water vapor, the pressure of which must be subtracted from the total pressure to find the pressure of the dry gas.