ChemActivity **33**

The Ideal Gas Law

(How Do Gases Behave?)

Information

- T (K) = Kelvin or Absolute temperature = T(°C) + 273.15
  T (K) is always > 0.

- Boyle's Law (1660): The volume of a sample of a gas varies inversely with pressure, if the temperature is held constant.

$$V = k_B \frac{1}{P} \qquad \text{at constant } n \text{ and } T$$

  where n is the number of moles of gas.

- Charles' Law (1887): The volume of a gas varies linearly with temperature, if the pressure is held constant.

$$V = k_C T \qquad \text{at constant } n \text{ and } P$$

- Avogadro's Hypothesis (1812): Samples of different gases which contain the same number of molecules—of any complexity, size, or shape—occupy the same volume at the same temperature and pressure.

$$V = k_A n \qquad \text{at constant } T \text{ and } P$$

Model 1: The Ideal Gas Law Equation.

$$P V = n R T$$

where R is a constant called the **ideal gas constant.**

The numerical value of the ideal gas constant is calculated from the fact that one mole of gas occupies 22.414 L at a pressure of one atmosphere and a temperature of 0 °C (273.15 K).

$$R = \frac{PV}{nT} = \frac{(1 \text{ atm})\,(22.414 \text{ L})}{(1 \text{ mole})\,(273.15 \text{ K})} = 0.08206 \frac{\text{L atm}}{\text{K mol}}$$

Critical Thinking Questions

1. How does the volume of a gas (at constant n and P) change as the temperature is raised?

2. How does the volume of a gas (at constant n and T) change as the pressure is increased?

3. How does the volume of a gas (at constant T and P) change as the number of molecules is increased?

4. For each case, rearrange the Ideal Gas Law Equation to show that it is consistent with the given law or hypothesis and obtain an expression for the corresponding constant.

   a) Boyle's Law, k_B

   b) Charles' Law, k_C

   c) Avogadro's Hypothesis, k_A

Information

In a mixture of gases the total pressure, P_T, is the sum of the pressures of the individual gases, P_i.

$$P_T = \sum_i P_i \tag{1}$$

The partial pressure of each gas in the mixture is given by

$$P_i = n_i \frac{RT}{V} \tag{2}$$

Exercises

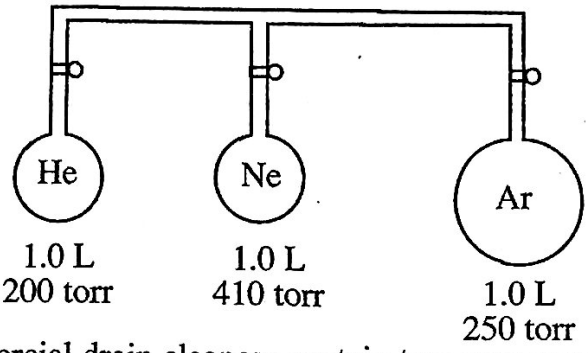
1. Calculate the volume of 20.5 g of NH_3 at 0.658 atm and 25 °C.
2. Calculate the volume of 359 g of CH_3CH_3 at 0.658 atm and 75 °C.
3. Calculate the volume of 525 g of O_2 at 25.7 torr (760 torr = 1 atm) and 25 °C.
4. A spherical space colony proposed by Gerald O'Neill (Princeton University) has a diameter of 1.00 km. How many grams of N_2 are needed to fill the interior of the colony at one atmosphere and 20 °C (room temperature)?
5. A 2.00 L container is placed in a constant temperature bath and is filled with 3.05 g of CH_3CH_3. The pressure stabilizes at 800 torr. What is the temperature of the constant temperature bath?
6. The density of a gas is typically given as: density $= d = \frac{\text{grams}}{\text{liter}}$. Use this definition of density and the ideal gas law to derive an equation that has only the density on the left-hand side and the other variables (P, T, MW) on the right-hand side.
7. Calculate the density of NH_3 at 850 torr and 100 °C.

9. A 2.00 L container holds 4.00 moles of O_2 and 2.70 moles of He at 293 K. What is the partial pressure of O_2? Of He? What is the total pressure?
10. The density of air at 1.000 atm and 25 °C is 1.186 g/L.
    a) Calculate the average molecular mass of air.
    b) From this value, and assuming that air contains only molecular nitrogen and molecular oxygen gases, calculate the mass % of N_2 and O_2 in air.

Problems

1. Consider the three flasks in the figure below. Assume that the connecting tubes have no volume and the temperature is held constant.

   a) Calculate the partial pressure of each gas when all stopcocks are open.
   b) Calculate the total pressure when all stopcocks are open.



2. Some commercial drain cleaners contain two components: sodium(I) hydroxide and aluminum powder. When the mixture is poured down a clogged drain, the following reaction occurs:

$$2\,NaOH(aq) + 2\,Al(s) + 6\,H_2O(\ell) \longrightarrow 2\,NaAl(OH)_4(aq) + 3\,H_2(g)$$

   The heat generated in this reaction helps melt away grease and the dihydrogen gas released stirs up the solids clogging the drain. Calculate the volume of H_2 formed at 20 °C and 750 torr if 3.12 g of Al is treated with excess NaOH.

3. A certain gaseous hydrocarbon is found to be 88.8% C and 11.2% H by mass. The compound has a density of 2.12 g/L at 31 °C and 742 torr. a) What is the empirical formula of the compound? b) What is the molecular weight of the compound? c) What is the molecular formula of the compound? d) Draw a possible structural formula for the compound.