Diffusion of Gases

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PURPOSE OF THE EXPERIMENT

Determine the relative rates of diffusion of ammonia and hydrogen chloride gases.

BACKGROUND INFORMATION

The molecules of a gas are in rapid random motion. This continuous rapid movement causes gaseous molecules to occupy any volume available to them. We call the spontaneous motion that leads to uniform distribution of a gas throughout a container **diffusion**.

The lighter the gas, that is, the lower the molar mass of the gas, the more rapidly its molecules move. Oxygen (O_2) has a molar mass of 32.00 g mol^{-1}. At 0 °C the average velocity of O_2 molecules is about 1,000 mi hr^{-1}. The molar mass of hydrogen (H_2) is 2.016 g mol^{-1}. The average velocity of H_2 molecules at 0 °C is about 4,000 mi hr^{-1}. The gas molecules that have a greater average velocity will diffuse more rapidly than those that have a lower average velocity. We refer to the speed at which gas molecules move as the **rate of diffusion**. We can determine this rate by dividing the distance which a gas has moved by the time required to move that distance. This relation is shown in Equation 1.

$$\frac{1}{\text{rate of diffusion, cm s}^{-1}} = \frac{\text{time, s}}{\text{distance, cm}} \qquad \text{(Eq. 1)}$$

$$\frac{\text{s}}{\text{cm}}(\text{distance, cm}) = \text{time, s} \qquad \text{(Eq. 2)}$$

Inspection of this relation suggests that we can determine the time required for a gas to diffuse a given distance by multiplying the reciprocal of the rate of diffusion of the gas by the distance the gas diffuses.

In 1829, Thomas Graham formulated what we now call Graham's law of diffusion. **Graham's law** states that, at constant temperature and pressure, the relative rates of diffusion of two gases are inversely proportional to the

ratio of the square root of their molar masses. Mathematically, Graham's law may be written as Equation 3

$$\frac{R_1}{R_2} = \sqrt{\frac{M_2}{M_1}} \qquad \text{(Eq. 3)}$$

where R_1 and R_2 are the rates of diffusion of two gases of molar masses M_1 and M_2. For O_2 and H_2 gases,

$$\frac{R_{H_2}}{R_{O_2}} = \sqrt{\frac{32.0}{2.0}} = 4.0$$

The rate of diffusion of H_2 gas is four times greater than that of O_2 gas.

In this experiment, you will use a concentrated ammonium hydroxide solution (NH_4OH) as your source of ammonia gas (NH_3). You will use a concentrated hydrochloric acid solution (HCl) as a source of hydrogen chloride gas (HCl).

EDURE

Section _____ Date _____

Post-Laboratory Questions

(Use the spaces provided for answers and additional paper if necessary.)

1. A student tried an experiment to determine what would happen when an HCl-saturated cotton ball was placed in one end of a glass tube and a NH_3-saturated cotton ball in the other end of the same tube. The molar mass of HCl is 36.46 g mol^{-1} and of NH_3 is 17.03 g mol^{-1}.

(1) If the distance between the two cotton balls was 10 cm, where, with respect to the two cotton balls, would the two gases meet?

(2) What experimental evidence would the student have that the two gases met?

2. The instructions for the experiment described in this module involve specific experimental conditions.

(1) Explain briefly why new corks are necessary if a second determination for either NH_3 or HCl is done.

(2) Based on what you understand about the experimental sources of NH_3 and of HCl(g), explain why it is important to dry the glass tube before making any measurements with either gas.

3. The rates of diffusion of NH_3 and of HCl were measured in a glass tube that was filled with air. The major components of air are nitrogen (N_2) and O_2. Explain briefly why either NH_3 or HCl was able to diffuse in a tube that was already filled with a gas.

(2) If the pineapple odor reached the student 9.0 m from the front door in 36 s, what was the rate of diffusion, in cm s^{-1}, of ethyl butyrate?

(3) What was the diffusion rate of ethyl formate?

(4) How long did it take the student to smell the rum odor?

2. Explain briefly why two students working next to each other on a laboratory bench must be careful that one of them does not do the experiment with HCl at the same time that the other student does the experiment with NH_3.

3. A student was studying chemistry at home when someone walked in the front door carrying two open bottles. One bottle contained ethyl formate ($C_3H_6O_2$), which has a molar mass of 74.08 g mol^{-1} and an odor of rum extract. The other bottle contained ethyl butyrate ($C_6H_{12}O_2$), which has a molar mass of 116.2 g mol^{-1} and the odor of pineapple extract.

(1) Which odor would the student smell first? Briefly explain your reasoning.