Rates of Diffusion

Diffusion of Gases

Introduction

The temperature of a gas is a measure of the average kinetic energy of the gas particles. The kinetic energy of any object depends on the mass of the object and its velocity. Imagine two vehicles—a large truck and a compact car—traveling down the highway at the same time. In order for these vehicles to have the same kinetic energy, the compact car must travel much faster than the large truck. The same analogy will be used in this demonstration to compare the motion of gas particles in different gases at the same temperature.

Concepts

- Diffusion
- Kinetic-molecular theory

Materials

Ammonium hydroxide, concentrated 14.8 M, NH_4OH, 4 mL

Hydrochloric acid, concentrated, 12 M, HCl, 2 mL

Phenolphthalein solution, 1%, 4 mL

Thymol blue solution, 0.04%, 2 mL

Beral-type pipets, 2

Bunsen burner

Cotton balls, 12

Distilled water and wash bottle

Glass diffusion tubes, 18-mm wide by 30-cm long, 2

Forceps

Medicine droppers, glass, 2

Ring stands and clamps, 2

Rubber stoppers, size 2, 4

Safety Precautions

Concentrated ammonium hydroxide and hydrochloric acid are toxic, corrosive, and will cause severe burns. Their vapors are extremely irritating, especially to the eyes and respiratory tract. Dispense these reagents in an operating hood and exercise caution. Do not handle the soaked cotton balls with bare hands. Use forceps and wear chemical-resistant gloves. Phenolphthalein indicator solution contains alcohol and is flammable. Wear chemical splash goggles, chemical-resistant gloves, and a chemical-resistant apron. Please review current Material Safety Data Sheets for additional safety, handling, and disposal information.

Procedure

Part A. Diffusion of Ammonia Gas

1. Set up a ring stand and clamp a glass diffusion tube in place horizontally (see Figure 1).
2. Using a Beral-type pipet, add about 1 mL of phenolphthalein indicator solution to a cotton ball. Set the cotton ball aside to allow the alcohol solvent to evaporate.
3. Hold the "indicator" cotton ball with a pair of forceps and add 10–20 drops of water. Immediately place the cotton ball into one end of the glass diffusion tube and seal the end of the tube with a rubber stopper.
4. Using a glass medicine dropper, add 10–20 drops of concentrated ammonium hydroxide solution to a clean cotton ball. Using forceps, immediately place the cotton ball into the other end of the diffusion tube and seal the end of the tube with a rubber stopper.

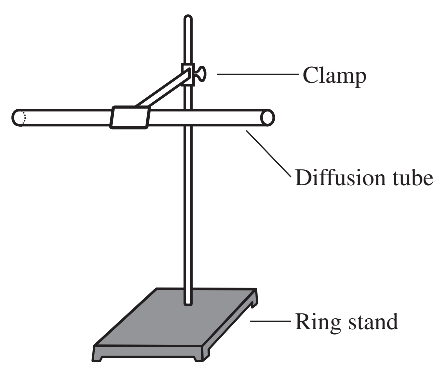

Figure 1.

5. Observe how long it takes for ammonia gas to diffuse through the tube and reach the phenolphthalein-soaked cotton ball. *(The front end of the cotton ball will begin to turn pink within about 90 seconds. It takes 3–5 minutes for the entire cotton ball to turn bright pink due to the reaction of ammonia with water to form a basic solution.)*

Part B. Effect of Temperature on the Rate of Diffusion

6. Set up two glass diffusion tubes in the horizontal position and obtain a Bunsen burner.
7. Prepare two phenolphthalein–water-soaked cotton balls as described in steps 2 and 3. Stopper one indicator ball in place in one end of each glass diffusion tube.
8. Repeat step 4 to prepare two ammonia-soaked cotton balls and stopper the soaked balls in place in the other end of each diffusion tube.
9. *Gently* heat one diffusion tube using the soft flame of a Bunsen burner. *Do not overheat—the diffusion tube is made of soft, flint glass.*
10. Compare how long it takes for ammonia gas to reach the phenolphthalein-soaked cotton ball in each tube. *(The indicator ball in the heated tube will turn bright pink within about 45 seconds, twice as fast as in the unheated tube. The rate of diffusion increases as the temperature increases.)*

Part C. Comparing the Rate of Diffusion for Ammonia and Hydrochloric Acid

11. Set up two glass diffusion tubes in the horizontal position.
12. Prepare two thymol blue–soaked cotton balls by adding about 20 drops of water, followed by 10–20 drops of thymol blue indicator solution, to each ball. The indicator balls will be dark gold in color. *Note:* Thymol blue is red at pH <1, blue at pH >9, and yellow-gold in the pH range 2.8–8.0.
13. Stopper one indicator ball in place in one end of each glass diffusion tube.
14. Using a clean, glass medicine dropper for each solution, add 12 drops of concentrated ammonium hydroxide solution to one cotton ball and 10 drops of concentrated hydrochloric acid to a second cotton ball. *Note:* Adding unequal amounts of the two solutions compensates for the fact that the ammonium hydroxide solution is more concentrated than the hydrochloric acid solution.
15. Using forceps, immediately place one cotton ball into the opposite end of each glass diffusion tube. Stopper the tubes.
16. Compare how long it takes for ammonia versus hydrochloric acid to diffuse the length of the tube in each case. *(Within about 90 seconds, the indicator cotton ball in the* NH_3 *tube will turn blue. It will take about 5 minutes for the indicator cotton ball in the HCl tube to turn red.)*

Part D. Gas-Phase Reaction of Ammonia and Hydrochloric Acid

17. Set up a clean glass diffusion tube in the horizontal position.
18. Repeat step 14 to prepare ammonia- and hydrochloric acid-soaked cotton balls and stopper one ball in place in each end of the diffusion tube.
19. Observe any changes along the length of the glass tube. *(In less than one minute, a white ring of solid* NH_4Cl *will be visible about two-thirds of the way down from the* NH_3 *source in the diffusion tube. The reaction takes place closer to the HCl source rather than in the middle of the tube because the lighter* NH_3 *gas molecules travel farther than the heavier HCl gas molecules in the same length of time.)*

Disposal

Please consult your current *Flinn Scientific Catalog/Reference Manual* for general guidelines and specific procedures, and review all federal, state and local regulations that may apply, before proceeding. The cotton balls should be placed in a fume hood to thoroughly degas and then may be placed in the trash according to Flinn Suggested Disposal Method #26a.

Tips

- Handle the soaked cotton balls in Parts A–D with great care to prevent skin contact and avoid cross-contamination. Always wear clean gloves and hold the cotton balls with forceps.
- The phenolphthalein-soaked indicator balls must be wet with water in order to observe the color change due to ammonia gas. Ammonia gas is extremely soluble in water.

- The concentrations of ammonium hydroxide and hydrochloric acid in Part C will affect the time needed for the indicator color changes to be observed.

Discussion

Gas diffusion refers to the mixing of different gases throughout an enclosed space due to the random molecular motion of the gas particles. When ammonia molecules are introduced into the diffusion tube, they will mix with the existing oxygen, nitrogen, and other gas particles in the tube. The ammonia molecules will collide with other gas molecules and the side of the tube and slowly diffuse down the tube until they dissolve in the water solvent in the phenolphthalein-soaked cotton balls. The resulting chemical (acid–base) reaction with the phenolphthalein indicator causes a color change from colorless to pink.

The rate of diffusion of a gas is determined by the root mean square speed of the gas molecules. If two different gas molecules have the same average kinetic energy but have different masses, then the lighter molecules will move faster. This is shown in Parts C and D, where ammonia molecules (17-g/mole) diffuse faster than hydrochloric acid molecules (molar mass 36.5-g/mole).

The kinetic-molecular theory (KMT) assumes that the particles in a gas are in constant motion and therefore predicts that a gas will eventually fill its container. The KMT also predicts that if two gases are added to a container, they will quickly mix and form a homogeneous solution. The mixing of gases is called diffusion.

Connecting to the National Standards

This laboratory activity relates to the following National Science Education Standards (1996):

Unifying Concepts and Processes: Grades K–12
Evidence, models, and explanation

Content Standards: Grades 5–8
Content Standard B: Physical Science, properties and changes of properties in matter, understanding of motions and forces

Content Standards: Grades 9–12
Content Standard B: Physical Science, structure and properties of matter, motions and forces

Answers to Worksheet

Sample Data Table

Part A.	**Procedure –** *A cotton ball soaked in phenolphthalein solution was placed in one end of a glass diffusion tube. A cotton ball soaked in ammonium hydroxide was placed in the other end.*
	Observations – *After about 90 seconds, the front of the phenolphthalein cotton ball began to turn pink. After several minutes the entire ball had turned pink.*
Part B.	**Procedure –** *Two glass diffusion tubes were set up just like in Part A. One tube was heated over a Bunsen burner.*
	Observations – *The phenolphthalein cotton ball in the heated tube turned pink in about 45 seconds, while in the unheated tube it took 90 seconds.*
Part C.	**Procedure –** *Two glass diffusion tubes were set up, one with a ammonium hydroxide-soaked cotton ball and one with a hydrochloric acid-soaked cotton ball. The indicator used in each was thymol blue.*
	Observations – *The ammonia took about 90 seconds to turn the indicator cotton ball blue. It took the hydrochloric acid about 5 minutes to turn the indicator ball red.*
Part D.	**Procedure –** *A glass diffusion tube was set up with an ammonia-soaked cotton ball in one end and a hydrochloric acid-soaked cotton ball in the other.*
	Observations – *After about a minute, a white ring of solid formed in the tube, about a two thirds of the way from the ammonia, and therefore closer to the hydrochloric acid.*

Discussion Questions

1. What is gas diffusion?

   Gas diffusion refers to the mixing of different gases throughout an enclosed space due to the random molecular motion of the gas particles.

2. Ammonia and hydrochloric acid gas molecules have the same kinetic energy. Why, then, do you think the hydrochloric acid diffused at a slower rate?

   If two different gas molecules have the same kinetic energy but different masses, the lighter molecules will move faster. The hydrochloric acid molecules moved at a slower rate than ammonia because hydrochloric acid has a higher molar mass, and lighter molecules move faster than heavier molecules.

3. Ammonia molecules move at a different rate than hydrochloric acid molecules because ammonia molecules have a lower mass (17-g/mole) than hydrochloric acid (36.5-g/mole). Propose a way that you could get hydrochloric acid gas and ammonia gas to move at the same rate.

   If you heated the hydrochloric acid at the right temperature, you could speed up the diffusion of HCl molecules to the same rate that ammonia diffuses at in room temperature.

Flinn Scientific—Teaching Chemistry™ eLearning Video Series

A video of the *Rates of Diffusion* activity, presented by Peg Convery, is available in *Diffusion of Gases*, part of the Flinn Scientific—Teaching Chemistry eLearning Video Series.

Materials for *Rates of Diffusion* are available from Flinn Scientific, Inc.

Materials required to perform this activity are available in the *Diffusion of Gases—A Kinetic Energy Demonstration* available from Flinn Scientific. Materials may also be purchased separately.

Catalog No.	Description
AP6630	Diffusion of Gases—A Kinetic Energy Demonstration
A0174	Ammonium Hydroxide, 14.8 M, 100 mL
H0031	Hydrochloric Acid, 12 M, 100 mL
P0019	Phenolphthalein Indicator Solution, 1%, 100 mL
T0079	Thymolphthalein Indicator Solution, 0.04%, 100 mL

Consult your *Flinn Scientific Catalog/Reference Manual* for current prices.

Rates of Diffusion Worksheet

Data Table

Part A.	**Procedure –**	
	Observations –	
Part B.	**Procedure –**	
	Observations –	
Part C.	**Procedure –**	
	Observations –	
Part D.	**Procedure –**	
	Observations –	

Discussion Questions

1. What is gas diffusion?

2. Ammonia and hydrochloric acid gas molecules have the same kinetic energy. Why, then, do you think the hydrochloric acid diffused at a slower rate?

3. Ammonia molecules move at a different rate than hydrochloric acid molecules because ammonia molecules have a lower mass (17-g/mole) than hydrochloric acid (36.5-g/mole). Propose a way that you could get hydrochloric acid gas and ammonia gas to move at the same rate.