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Mass Is Conserved — Volume Is Not!

Chemical Demonstration Kit

Introduction

Many students have heard that matter is neither created nor destroyed. This principle of the conservation of matter relates to mass but not to volume. Show students that adding 50 mL + 50 mL does not always add up to 100 mL!

Concepts

- Conservation of mass
- Hydrogen bonding
- Intermolecular forces
- Neutralization

Activity Overview

Using three different demonstrations, students will observe that volumes are not always conserved. Water and anhydrous ethyl alcohol take up less volume together than when they are separated. Hydrochloric acid and sodium hydroxide solution will have a greater volume than the sum of the two reactants individually.

Materials (for each demonstration)

Ethyl alcohol, anhydrous, C_2H_5OH, 500 mL*
Hydrochloric acid, HCl, 2 M, 500 mL*
Sodium hydroxide solution, NaOH, 2 M, 500 mL*
**Materials included in kit.*

Water, deionized or distilled (DI)
Graduated cylinders, 50-mL, 2
Graduated cylinder, 100-mL
Volumetric flask, 100-mL (optional)

Safety Precautions

Sodium hydroxide solution is corrosive to all body tissue, especially to the eyes. Hydrochloric acid is toxic by ingestion or inhalation and severely corrosive to all body tissues. Ethyl alcohol is a flammable solvent and dangerous fire risk. The addition of denaturant to ethyl alcohol makes it poisonous. Do not ingest. Wear chemical splash goggles, chemical-resistant gloves, and a chemical-resistant apron. Wash hands thoroughly with soap and water before leaving the laboratory. Please review current Material Safety Data Sheets for additional safety, handling, and disposal information.

Procedure

Water and Water

1. Carefully measure out exactly 50.0 mL of deionized or distilled water in a 50-mL graduated cylinder.
2. Carefully measure out exactly 50.0 mL of DI water into another 50-mL graduated cylinder.
3. Ask students to predict the final volume of water after the two volumes of liquid are combined.
4. Pour the water from both graduated cylinders into a 100-mL graduated cylinder or volumetric flask.
5. Relate the total volume to the class and compare predictions—the volume should be 100.0 mL.
6. Clean and dry all glassware.

Water and Ethyl Alcohol

7. Carefully measure out exactly 50.0 mL of deionized or distilled water in a 50-mL graduated cylinder.
8. Carefully measure out exactly 50.0 mL of anhydrous ethyl alcohol into another 50-mL graduated cylinder.

9. Ask students to predict the final volume of solution after both liquids are poured into the same container.
10. Pour the liquids from both graduated cylinders into a 100-mL graduated cylinder.
11. Relate the total volume to the class and compare predictions—the volume will be less than 100.0 mL.
12. Clean and dry all glassware.

Hydrochloric Acid and Sodium Hydroxide

13. Carefully measure out exactly 50.0 mL of 2 M hydrochloric acid in a 50-mL graduated cylinder.
14. Carefully measure out exactly 50.0 mL of 2 M sodium hydroxide solution into another 50-mL graduated cylinder.
15. Ask students to predict the final volume of solution after both liquids are poured into the same container.
16. Pour the solutions from both graduated cylinders into a 100-mL graduated cylinder.
17. Relate the total volume to the class and compare predictions—the volume will be greater than 100.0 mL.

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. Excess hydrochloric acid may be neutralized with base such as the leftover sodium hydroxide solution and rinsed down the drain with excess water according to Flinn Suggested Disposal Method #24b. Leftover sodium hydroxide solution may be neutralized with acid such as the leftover hydroxide solution and then rinsed down the drain with excess water according to Flinn Suggested Disposal Method #10. Excess anhydrous ethyl alcohol may be stored for future use.

Tips

- This kit contains enough chemicals to perform the demonstration as written seven times: 500 mL of anhydrous ethyl alcohol, 500 mL of 2 M hydrochloric acid, and 500 mL of 2 M sodium hydroxide solution.
- The deionized water and ethyl alcohol demonstration is even more interesting when done in a 24″ glass demonstration tube (Flinn Catalog No. GP9146). Fill the tube with equal volumes of deionized water and anhydrous ethyl alcohol, stopper the ends and begin to mix the solvents by turning the tube. An air bubble will soon appear out of nowhere. Adding equal volumes to a volumetric flask also works well—100-mL through 1000-mL size.
- The reaction between hydrochloric acid and sodium hydroxide is exothermic. To get a more accurate measurement of the volume, measure the solution at room temperature—the original starting temperature. The final volume will still be greater than the sum of the two.
- These demonstrations can be used when teaching intermolecular forces, hydrogen bonding, and acid–base neutralization.
- An extension of this demonstration is to show conservation of mass and to weigh all amounts before and after addition of the solutions. Data and calculations should show mass is conserved.

Discussion

In a chemical reaction mass is conserved. What does this mean? The mass of the reactants will always equal the mass of the products. What about volume?

When 50 mL of water is added to 50 mL of water or when 50 mL of ethyl alcohol is added to 50 mL of ethyl alcohol, the final volume will always be 100 mL, as expected. In this demonstration, when the water is added to the alcohol, the final volume is about 10% less than the original volume of the two liquids before mixing. The "vanishing volume" is due to differences in packing of the solvent molecules in the mixture versus the pure substances. Molecules of ethyl alcohol actually pack together more closely with water molecules than with other alcohol molecules due to hydrogen bonding. The solvent molecules form a highly-laced, three-dimensional network held together by strong hydrogen bonds (see Figure 1 on page 3). The hydrogen bonds are represented by dashed lines. Each alcohol molecule is able to form as many as three hydrogen bonds with neighboring water or alcohol molecules. The result is an intricate lattice or network of molecules strongly attracted to one another.

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Looking at the Molecules

Hydrogen bonding is an especially strong form of dipole–dipole interaction. A dipole–dipole interaction is the attraction between the positive end of one polar molecule and the negative end of another polar molecule. In hydrogen bonding, a hydrogen atom serves as a bridge between two electronegative atoms (nitrogen, oxygen or fluorine).

Hydrogen bonding plays a major role in the properties of water and alcohols. Hydrogen bonding between water molecules leads to a very high boiling point when compared to other similar liquids. The effect of hydrogen bonding can also be clearly seen when boiling points for alcohols are compared to nonpolar ethers having the same molecular weight. Consider butyl alcohol and ethyl ether. Both have the same formula ($C_4H_{10}O$), the same molecular weight (74 g/mole), and the same size. Butyl alcohol, however, boils at 118 °C, while diethyl ether boils at 35 °C. The 80 °C difference in boiling points is due to hydrogen bonding between alcohol molecules.

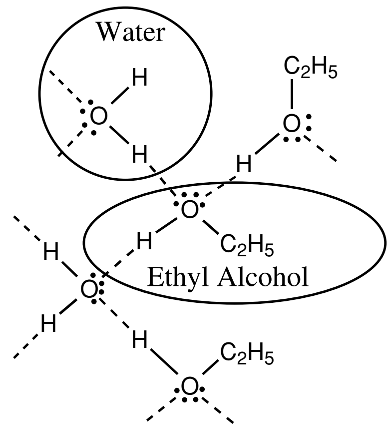

Figure 1. Hydrogen bonding between alcohol and water.

Neutralization

When the hydrochloric acid is added to the sodium hydroxide the final volume is greater than the original volume of the two liquids. The "additional volume" is also due to the differences in packing of the solvent molecules in the mixture versus the original solutions. The densities of the solutions illustrate this point. In this demonstration, 2 M solutions of both NaOH and HCl are used—equal concentrations. The acid and base react as follows:

$$HCl(aq) + NaOH(aq) \rightarrow H_2O(l) + NaCl(aq)$$

The solution volume, molarity, and density are known. From this information the mass total and mass of each component can be calculated. See Table 1. Volumes are calculated using 500.00 mL sample sizes and 2.000 M solutions.

Solution	Volume	Density	Mass	Total Mass of Solution	Mass of Solution Components
2 M NaOH	500.00 mL	1.0805 g/mL	540.25 g	1056.90 g	40.00 g NaOH + 500.25 g H_2O
2 M HCl	500.00 mL	1.0333 g/mL	516.65 g		36.45 g HCl + 480.20 g H_2O
NaCl	? mL	1.0378 g/mL	unknown	1056.91 g	58.44 g NaCl + 500.25 g H_2O + 480.20 g H_2O + 18.02 g H_2O

Table 1

After the 2 M NaOH and 2 M HCl solutions are added together, one mole of NaCl(aq) and one mole of H_2O are formed. Using the balanced equation, this results in a solution in which the total mass consists of 58.44 g of NaCl (one mole NaCl), the water from the 2 M NaOH solution, the water from the HCl solution, and the mole of water formed. Note that the total mass is conserved (see Table 1), but what is the volume of the 500.00 mL 2 M NaOH + 500.00 mL 2 M HCl solution? Laboratory data shows the volume of the final solution is 1018 mL. How does this compare to a mathematical estimation?

To calculate an approximate volume for the final solution, the density of a 1 M NaCl solution is used, 1056.9 g/1.0385 g/mL = 1020.6 mL. Since the final volume is actually 1018 mL, instead of using the density of a 1 M NaCl solution, the density of a 1 mole NaCl/0.1018L (0.9823 M) solution should be used for a more accurate calculation. It is experimentally found that the density for a 0.9823 M NaCl solution is 1.0378 g/mL. So the final volume of the NaCl solution is 1056.9 g/1.0378 g/mL = 1018 mL.

Connecting to the National Standards

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

Unifying Concepts and Processes: Grades K–12
- Systems, order, and organization
- Evidence, models, and explanation
- Constancy, change, and measurement
- Form and function

Content Standards: Grades 5–8
- Content Standard A: Science as Inquiry
- Content Standard B: Physical Science, properties and changes of properties in matter

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Content Standards: Grades 9–12

Content Standard A: Science as Inquiry

Content Standard B: Physical Science, structure of atoms, structure and properties of matter, chemical reactions, interactions of energy and matter

Sample Data Table

Demo	Solutions		Final Volume (mL) Prediction	Final Volume (mL) Actual
Demo 1	*50.00* mL of water	*50.00* mL of water	*100.0 mL*	*100.0 mL*
Demo 2	*50.00* mL of water	*50.00* mL of ethyl alcohol	*100.0 mL*	*91.6 mL*
Demo 3	*50.00* mL of hydrochloric acid	*50.00* mL of sodium hydroxide	*100.0 mL*	*101.8 mL*

Answers to Worksheet Questions

1. Calculate the final mass for each demonstration using the following reference densities.

   Water—0.9982 g/mL
   Ethyl alcohol—0.789 g/mL
   2 M hydrochloric acid solution—1.0333 g/mL
   2 M Sodium hydroxide solution—1.0805 g/mL
   1 M Sodium chloride solution—1.0385 g/mL
   0.9823 M Sodium chloride solution—1.0378

Demo	Solutions		Final Mass (g)
Demo 1	*49.91* g of water	*49.91* g of water	*99.82* g of water
Demo 2	*49.91* g of water	*39.45* g of ethyl alcohol	*89.36* g of solution
Demo 3	*51.67* g of hydrochloric acid	*54.03* g of sodium hydroxide	*105.7* g of solution

2. Explain how accurately your final volume predictions matched the actual final volume.

   (Student answers will vary but the answers should relate to their predictions.) Combining water with water did have a final volume as predicted. The addition of ethyl alcohol to water had a lower volume than predicted, and the neutralization of hydrochloric acid and sodium hydrochloric acid had a higher volume than predicted.

3. Explain the reasoning for the final volume after combining ethyl alcohol and water. Draw an example.

   Intermolecular forces, specifically the dipole–dipole interaction of hydrogen bonding, pulled the water and ethyl alcohol molecules closer together which resulted in a lower than expected final volume.

4. Write the balanced equation for the neutralization of hydrochloric acid and sodium hydroxide.

   $HCl(aq) + NaOH(aq) \rightarrow NaCl(aq) + HOH(l)$

5. Using the balanced equation and the density information, show the mathematical calculation for the final volume of solution in demonstration 3.

   $\text{Final mass} \times \text{density} = \text{final volume}$

   $$105.7\ g \times \frac{1\ mL}{1.0378\ g} = 101.8\ mL$$

Reference

Shakhashiri, B. Z. *Chemical Demonstrations: A Handbook for Teachers in Chemistry;* University of Wisconsin: Madison; 1983; Vol. 1, p 77.

The *Mass Is Conserved—Volume Is Not!—Chemical Demonstration Kit* is available from Flinn Scientific, Inc.

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Name: ______________________________

Mass iIs Conserved — Volume Is Not! Worksheet

Data Table

Demo	Solutions		Final Volume (mL) Prediction	Final Volume (mL) Actual
Demo 1	________ mL of water	________ mL of water		
Demo 2	________ mL of water	________ mL of ethyl alcohol		
Demo 3	________ mL of hydrochloric acid	________ mL of sodium hydroxide		

Questions

1. Calculate the final mass for each demonstration using the following densities.

   Water—0.9982 g/mL
   Ethyl alcohol—0.789 g/mL
   2 M hydrochloric acid solution—1.0333 g/mL
   2 M Sodium hydroxide solution—1.0805 g/mL
   1 M Sodium chloride solution—1.0385 g/mL
   0.9823 M Sodium chloride solution—1.0378

Demo	Solutions		Final Mass (g)
Demo 1	________ g of water	________ g of water	________ g of water
Demo 2	________ g of water	________ g of ethyl alcohol	________ g of solution
Demo 3	________ g of hydrochloric acid	________ g of sodium hydroxide	________ g of solution

2. Explain how accurately your final volume predictions matched the actual final volume.

3. Explain the reasoning for the final volume after combining ethyl alcohol and water. Draw an example.

4. Write the balanced equation for the neutralization of hydrochloric acid and sodium hydroxide.

5. Using the balanced equation and the density information, show the mathematical calculation for the final volume of solution in demonstration 3.

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