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Publication No. 91249

Volumes Don't Always Add Up

Hydrogen Bonding

Introduction

When equal volumes of water and ethyl alcohol are mixed, the total volume is less than that of the two liquids before mixing. What happened to the vanishing volume?

Concepts

- Intermolecular forces—hydrogen bonding
- Polar molecules

Materials

Ethyl alcohol, anhydrous, C_2H_5OH, 500 mL
Water, distilled or deionized, 500 mL
Food coloring, yellow and blue
Volumetric flasks, 500 mL, 2
Volumetric flasks, 1 L, 1

Safety Precautions

Ethyl alcohol is a dangerous fire risk; it is flammable. The addition of denaturant (methyl alcohol) makes ethyl alcohol poisonous. Do not ingest. Wear chemical splash goggles and chemical-resistant gloves. Please review current Material Safety Data Sheets for additional safety, handling, and disposal information.

Procedure

1. Carefully measure out exactly 500 mL of water in a 500-mL volumetric flask. Add yellow food coloring to the water.
2. Carefully measure out exactly 500 mL of anhydrous ethyl alcohol into a second 500-mL volumetric flask. Add blue food coloring to the alcohol.
3. Pour the alcohol into the 1-L volumetric flask.
4. Carefully pour the water into the 1-L volumetric flask.
5. Observe that the final volume of liquid in the cylinder is less than 1000 mL or 1 L.

Disposal

Please consult your current *Flinn Scientific Catalog/Reference Manual* for general guidelines and specific procedures governing the disposal of laboratory waste. The resulting solution may be flushed down the drain with excess water according to Flinn Suggested Disposal Method #26b.

Tips

- This demonstration is even more spectacular if done in a 24″ glass demonstration tube (Flinn # 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 of water and ethyl alcohol to a volumetric flask also works well.
- Anhydrous ethyl alcohol does not contain any water. Do not use 95% alcohol that contains 5% water.
- Add the yellow food coloring to the water and not the alcohol; it is not alcohol soluble.

Discussion

When 500 mL of water is added to 500 mL of water or when 500 mL of alcohol is added to 500 mL of alcohol, the final volume will always be 1000 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. 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, 3-dimensional network held together by strong hydrogen bonds (Figure 1). 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.

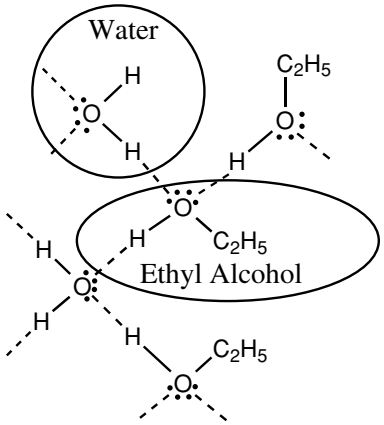

Figure 1. Hydrogen bonding between alcohol and water.

Looking at the Molecules

Hydrogen bonding is an especially strong form of dipole–dipole interaction. A dipole-dipole interaction is the attraction of the positive end of one polar molecule for 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 the hydrogen bonding in the butyl alcohol.

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
Constancy, change, and measurement
Content Standards: Grades 9–12
Content Standard B: Physical Science, structure of atoms, structure and properties of matter

Flinn Scientific—Teaching Chemistry™ eLearning Video Series

A video of the *Volumes Don't Always Add Up* activity, presented by George Gross, is available in *Hydrogen Bonding,* part of the Flinn Scientific—Teaching Chemistry eLearning Video Series.

Materials for *Volumes Don't Always Add Up* are available from Flinn Scientific, Inc.

Catalog No.	Description
E0012	Ethyl alcohol, C_2H_5OH, 500 mL
V0003	Food coloring, 4 color set
GP4040	Volumetric Flask, 500-mL
GP4045	Volumetric Flask, 1000-mL

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