Demonstration: Intermolecular Forces & Physical Properties

FOR THE TEACHER

Summary
In this demonstration, students observe and compare the properties of surface tension, beading, evaporation, and miscibility for water and acetone.

Grade Level
High school

AP Chemistry Curriculum Framework
This demonstration supports the following units, topics and learning objectives:

- **Unit 3: Intermolecular Forces and Properties**
  - **Topic 3.1**: Intermolecular Forces
    - SAP-5.A: Explain the relationship between the chemical structures of molecules and the relative strength of their intermolecular forces when:
      a. The molecules are of the same chemical species.
      b. The molecules are of two different chemical species.
  - **Topic 3.8**: Representations of Solutions
    - SPQ-3.B: Using particulate models for mixtures:
      a. Represent interactions between components.
      b. Represent concentrations of components.
  - **Topic 3.10**: Solubility
    - SPQ-3.C: Explain the relationship between the solubility of ionic and molecular compounds in aqueous and nonaqueous solvents, and the intermolecular interactions between particles.

NGSS Alignment
This demonstration will help prepare your students to meet the performance expectations in the following standards:

- **HS-PS1-3**: Plan and conduct an investigation to gather evidence to compare the structure of substances at the bulk scale to infer the strength of electrical forces between particles.
- **Science & Engineering Practices**:
  - Planning and carrying out Investigations.
- **Crosscutting Concepts**:
  - Patterns: Different patterns may be observed at each of the scales at which a system is studied and can provide evidence for causality in explanations of phenomena.

Objectives
By the end of this demonstration, students should be able to

- Identify the intermolecular forces present in acetone and water.
- Explain the following phenomena in terms of intermolecular forces at the particle level:
  - The surface tension of water is greater than that of acetone.
  - Acetone evaporates more quickly than water.
  - The total volume of a mixture of acetone and water is less than the additive quantity of each.
  - Acetone is miscible in water but not in salt water.
  - The attraction of dyes to acetone or water.
Chemistry Topics
This demonstration supports students’ understanding of
- Intermolecular Forces
- Physical Properties
- Surface Area
- Beading
- Evaporation
- Miscibility

Time
Teacher Preparation: 20 minutes
Lesson: 45 - 60 minutes

Materials
Part 1: Beading and Evaporation
- Lab table top or another flat, dark surface
- 1 drop Water
- 1 drop 100% Acetone Fingernail Polish Remover
- 2 Disposable pipets

Part 2: Surface Tension
- ≈100 ml Water
- ≈100 ml 100% Acetone Fingernail Polish Remover
- 2 Disposable pipets
- 2 Petri dishes or small bowls
- 2 Paper clips

Part 3: Additive Volume and Miscibility
- 50 ml Water
- 50 ml 100% Acetone Fingernail Polish Remover
- 2 Disposable pipets
- 2, 50 ml graduated cylinders
  - Optional, but preferred: 2, 50 ml volumetric flasks
- 100 ml graduated cylinder
  - Optional, but preferred: 100 ml volumetric flask
- 250 ml beaker

Part 4: Miscibility
- 8 oz. Empty water bottle with cap
- 250 ml Beaker
- 200 ml Water
- ≈110 ml 100% Acetone Fingernail Polish Remover
- 24 grams Salt
- Blue and red food coloring

Safety
- Acetone SDS
  Acetone is a flammable liquid. There should be no heat source, sparks, open flames, or hot surfaces nearby.
  Students should wear proper safety gear during chemistry demonstrations. Safety goggles and lab apron are required.
Teacher Notes

- Students should know about intermolecular forces: London dispersion, dipole-dipole, hydrogen bonding, and ion-dipole interactions.
- Acetone is a polar substance that is soluble in water because hydrogen bonding occurs between oxygen and the hydrogen atoms of water. Because of its structure, it is also soluble in non-polar substances, such as benzene.
- Acetone is not soluble in a sodium chloride solution. When sodium chloride dissolves in water, the sodium and chloride ions are strongly attracted to the water molecules, forming ion-dipole attractions, which are stronger than the hydrogen-bonds between water and acetone.
- The molecules in the blue dye are more polar than those in the red dye, which is why the salt water will be blue and the acetone will be red when the mixture separates.
- You can purchase 100% Acetone Fingernail Polish Remover at most drug stores.

Before class begins, set up the following demonstration stations:
- **Part 1: Beading and Evaporation:** You can use your lab bench or any dark surface. Have a pipet with water and another with acetone ready to use.
- **Part 2: Surface tension:** Add ≈100 ml of water to a petri dish or small bowl and ≈100 ml of acetone to another. You will also need two small paper clips. Note: You may want to have a strip of paper towel available to help you float the paper clip on the water.
- **Part 3: Additive Volume and Miscibility:** Add 50 ml of water to a 50 ml graduated cylinder. Add 50 ml of acetone to a second 50 ml graduated cylinder. Have a 100 ml graduated cylinder and a 250 ml beaker ready to use. Note: If you have 50 ml and 100 ml volumetric flasks available they will give a more drastic result.
- **Part 4: Miscibility:** Add 24 grams of table salt to 200 ml of water in a 250 ml beaker. Stir to dissolve salt. Note: If you have a magnetic stirrer/hot plate it will make this process much faster. Have the acetone, water bottle, and food coloring ready to use.

Demonstration Procedure:

- **Introduction:** The purpose of the demonstration is to observe and compare the properties of surface tension, beading, evaporation, and miscibility for water and acetone. Use the molecular representations on the activity sheet to have students identify the intermolecular forces present in each. Ask students to define each type of intermolecular force and then draw a particle diagram to show the interaction between water molecules and acetone molecules.

- **Part 1: Beading and Evaporation:** Ask students to describe the phenomena of beading and evaporation and then predict which substance will have greater beading and which will have a higher rate of evaporation. Place a single drop of each substance on a dark, hard surface. Make observations. Ask students to explain why water has greater beading and acetone has a higher rate of evaporation in terms of intermolecular forces. Move through the remaining stations and then revisit this at the end of the demonstration. The pictures on the right were taken at the beginning and one hour later.

- **Part 2: Surface tension:** Ask students to describe the phenomenon of surface tension and then predict which substance will have greater surface tension. Gently place one paper clip on the surface of the water so that it is floating. Attempt to do the same thing with the other paper clip and acetone. Put your finger in the water to break the surface tension and the paper clip sinks. Ask students to explain why water has greater surface tension in terms of intermolecular forces. Note: If you lay the paperclip over a strip of paper towel and gently lower it into the water it will make it easier to get it to float.
Part 3: Additive Volume and Miscibility: Ask students to predict the total volume of liquid when you add exactly 50 ml of water to exactly 50 ml of acetone. Add the water to the acetone and you will find a total volume of 98 ml. Pour the contents of the graduated cylinder into a 250 ml beaker and stir. Note that the two are miscible. Ask students to explain these two phenomena in terms of intermolecular forces.

Part 4: Miscibility: Review the process of dissolving salt in water and ask students to draw a particle diagram of several water molecules with the sodium and chloride ions. Ask students to predict which attraction is stronger, ion-dipole or hydrogen bonding, and ask them to also predict if the acetone will be miscible with salt water. Pour salt water in the bottle until it is half full. Pour in acetone to fill the bottle. Ask student to explain why the two do not mix in terms of intermolecular forces. Also ask them why the acetone is on the top (density).

Add one drop of blue food coloring to the bottle. It will gently drop down to the acetone/water interface and spread out. Add one drop of red food coloring to the bottle. It will do the same. Put the cap on the bottle, shake it well, and put it on the table. The mixture will be purple and will then begin to separate, the red dye traveling up with the acetone and the blue dye remaining on the bottom with the water. Ask students about the relative polarity of the molecules in the red and blue dyes.
FOR THE STUDENT
Lesson

Intermolecular Forces

Introduction
1. Write a brief definition of each type of intermolecular force:
   a. London dispersion forces:
   b. Dipole-dipole interactions:
   c. Hydrogen-bonding:
   d. Ion-dipole interactions:

2. Identify the intermolecular forces present in acetone and water. Explain.

3. Draw a particle diagram to show the interaction between water molecules and acetone molecules.

   Acetone  Water

Part 1: Beading and Evaporation
4. Define the following phenomena:
   a. Beading:
   b. Evaporation:
5. Which substance had greater beading? Explain in terms of intermolecular forces.

6. Which substance evaporated most easily? Explain in terms of intermolecular forces.

**Part 2: Surface tension**
7. Define surface tension:

8. Which substance had greater surface tension? Explain in terms of intermolecular forces.

**Part 3: Additive Volume and Miscibility**
9. Explain what happened with the total volume of the water and acetone in terms of intermolecular forces.

**Part 4: Miscibility**
10. Draw a particle diagram of several water molecules with the sodium and chloride ions.

11. Explain why the acetone is miscible in water, but not in salt water.

12. Which intermolecular force is stronger, ion-dipole or hydrogen bonding? Use your observations to support your answer.

13. Which dye is more polar? Use your observations to support your answer.