Bouncing Ball Distillation

Evaporation and Boiling

FLINN SCIENTIFIC CHEM FAX!

Introduction

When molecules are the size of balls, phase changes such as melting and evaporation can be very "moving" events! A tubful of rubber balls is a perfect demonstration device for comparing the energy and motion of molecules in the solid, liquid, and gas phases. It's time to put the "kinetic" back into the kinetic–molecular theory!

Concepts

- Melting and freezing
- Evaporation and condensation
- Kinetic–molecular theory

Materials

Clear plastic container

Rubber balls, assorted colors, 14 total

Safety Precautions

Make sure that you are aware of your surroundings when shaking the tub. The flying rubber balls could cause damage. Wearing safety glasses or goggles is a good idea.

Procedure

1. Explain to students that each rubber ball represents a molecule in this demonstration.
2. Place all the rubber balls inside the plastic tub. Hold up the tub to show the students that the balls are touching but not moving. *(The molecules are in the solid state, resting in fixed positions.)*
3. Add some energy to the rubber balls by gently shaking the tub sideways. The balls will still be touching one another, but they will have more motion and become more "fluid." *(At first, as the "molecules" gain energy, they begin to rotate and vibrate. When sufficient energy has been added, the molecules will begin to move apart and "break loose" from their resting positions. This represents the liquid state.)*
4. What happens if you stop shaking the tub? Slow down the shaking until all the rubber balls are again stationary. *[If energy is not continually added, the "molecules" in the liquid state will lose energy as they collide with the container walls and will slow down and "solidify" (freeze) again.]*
5. Shake the tub once again, but with even more energy and vigor—the balls will begin to fly out of the tub! The tub may have to be tilted a little to assist the "evaporation" process—remember, evaporation requires a lot of energy. *(This represents evaporation. The "molecules" leave the liquid state and enter the vapor phase.)*
6. Ask students to pick up the rubber balls that have "evaporated" and to toss them back into the tub. What a chance to throw something at the teacher—this may be a good time to put on safety glasses! Catch the rubber balls in the tub—this represents "condensation." *(If the students throw the balls too hard, the "molecules" will have too much energy and will not condense. Have students toss the balls gently at the box. Catch the balls by moving the box down slightly in order to absorb the energy as the balls land. The process of evaporating a liquid and then condensing the resulting vapor is called distillation.)*

Disposal

None required—save all materials for future use.

Tip

- Use your imagination to come up with other applications for this truly "kinetic" demonstration of the kinetic–molecular theory. For example, you may want to illustrate that when the rubber balls are in the "solid" state, they exist in a closest-packed arrangement or crystal lattice. To do this, place the balls in a dishpan or small roasting pan. Tilt the container and point out the geometric arrangements of the balls in the bottom of the pan. Gently shake the pan to shift the balls into a closest-packed arrangement.

Publication No. 95023
061616

Discussion

The kinetic–molecular theory may be summarized in one simple phrase—molecules in motion. This activity provides a visual demonstration of this important concept. Visualizing molecules in motion helps students understand and compare the kinetic and potential energy of molecules in the solid, liquid, and gas phases. This model can be used to explain on a molecular level what happens when a solid melts or a liquid boils and also to predict the energy changes that accompany these phase changes.

The energy changes that occur when a solid melts or a liquid freezes can best be understood by imagining what solids and liquids look like at the level of molecules or ions. Solids and liquids differ in how ordered or rigid their structures are and in the range of motion that the molecules are allowed. Molecules in a crystalline solid are packed together in an ordered three-dimensional pattern, called the crystal lattice, where they are "held in place" by attractive forces between the molecules. The motion of molecules in the solid state is limited to vibrations (stretching and rocking motions)—the molecules are not free to move away from their fixed positions. The forces between molecules in the liquid state are less well understood. Molecules in the liquid state are free to move and are not locked in position. Attractive forces between molecules, however, tend to keep the molecules close together, so that their motion is perhaps best described as coordinated rather than independent.

A solid and its liquid are in equilibrium at the melting point, the temperature at which a crystalline solid becomes a liquid. When a solid is heated (energy is added), the temperature of the solid will increase until it reaches the melting point. Temperature is related to the average kinetic energy of the molecules. As the temperature increases, the average kinetic energy increases and the molecules in the solid state begin to vibrate more rapidly. At the melting point, the vibrations become so rapid that the molecules begin to "break free" from their fixed positions and melting occurs.

The properties of liquids also reflect the motion of molecules in the liquid phase and the existence of attractive forces between molecules. According to the kinetic–molecular theory, the molecules in a liquid are in constant, random motion. The molecules are close enough together, however, that attractive forces between neighboring molecules influence their motion and give liquids their characteristic properties. Comparing the properties of different liquids allows us to compare the strength of attractive forces between molecules. The vapor pressure of a liquid reflects the ability of molecules in the liquid phase to break the attractive forces between them and "escape" into the vapor phase. Liquids with weak attractive forces between molecules have high vapor pressures are considered volatile—they will evaporate readily from an open container at room temperature. The kinetic–molecular theory also explains how the vapor pressure of a liquid increases as the temperature increases. Increasing the temperature increases the average kinetic energy of the molecules. At higher temperatures, a larger number of molecules will be moving fast enough and have sufficient kinetic energy to overcome the forces of attraction in the liquid and enter the vapor phase. The number of molecules in the vapor phase above the liquid, and hence the vapor pressure, increases with increasing temperature.

Connecting to the National Standards

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

Unifying Concepts and Process: Grades K–12
Systems, order, and organization
Evidence, models, and exploration

Content Standards: Grades 5–8
Content Standard A: Science as Inquiry
Content Standard B: Physical Science, properties and changes of properties in matter, understanding of motions and forces, transfer of energy.

Content Standards: Grades 9–12
Content Standard A: Science as Inquiry
Content Standard B: Physical Science, structure and properties of matter, motions and forces, conservation of energy and increase in disorder, interactions of energy and matter.

Answers to Worksheet Questions

1. What do the rubber balls used in this demonstration represent?

   Each rubber ball represents a molecule.

2. Using the rubber balls in the tub as a model, describe the arrangement and motion of molecules in the solid state.

   Molecules in the solid state are very close together (generally described as a closest-packed arrangement). The molecules occupy fixed positions—they cannot change positions relative to one another. The molecules, however, are "moving." They "rock" back and forth and can "roll" around. The motion of molecules in the solid phase is therefore limited to rotational and vibrational motion.

3. Based on the motion of the bouncing balls when the tub was shaken, explain what happens to the motion of molecules in the solid state when energy is added. What does this process represent?

   When the tub was shaken, the balls began to move around more. The balls started "bouncing" around in the tub so that they were not in the same place anymore, but the balls remained within the tub. This process corresponds to a solid melting and becoming liquid. The balls bouncing around within the tub represent the liquid phase. When a solid is heated and energy is added, the molecules gain kinetic energy and the temperature increases. When the kinetic energy is high enough, the molecules will begin to move around while maintaining the same general volume. This is what happens when a solid melts. The molecules in a liquid are in constant, random motion.

4. What happened to the balls when the tub was shaken rapidly and violently? What does this process represent?

   The balls began to bounce high enough that they "escaped" from the tub and started flying around the room. This process represents evaporation—molecules leaving the liquid phase and entering the vapor phase. Evaporation occurs when molecules have sufficient kinetic energy to "break free" from the "ties that bind them" (intermolecular attractive forces). The molecules in the gas phase are very far apart!

5. The kinetic–molecular theory (KMT) describes how close together the molecules are in a solid, liquid, and gas, their relative motion, and the attractive forces between molecules. Use the KMT to explain the following properties of liquids and solids:

   a. A liquid flows and takes the shape of its container.

   The molecules in a liquid slide freely and randomly over each other.

   b. Solids are generally incompressible.

   The molecules in a solid are physically as close together as possible (tightly packed).

   c. Liquids have a definite volume.

   The molecules in a liquid are close together and there are attractive forces between the molecules.

   d. A solid absorbs heat from its surroundings as it melts.

   Relatively strong attractive forces exist between the molecules in the solid state—these forces must be partially broken when the solid changes to a liquid.

Acknowledgment

Special thanks to Doug De La Matter, retired chemistry teacher from Madawaska Valley District High School, Barry's Bay, Ontario, for providing Flinn Scientific with the idea for this activity.

Flinn Scientific—Teaching Chemistry™ eLearning Video Series

A video of the *Bouncing Ball Distillation* activity, presented by Irene Cesa, is available in *Evaporation and Boiling*, part of the Flinn Scientific—Teaching Chemistry eLearning Video Series.

Materials for *Bouncing Ball Distillation* are available from Flinn Scientific, Inc.

Materials required to perform this activity are available in the *"Bouncing Ball" Distillation Kit* available from Flinn Scientific.

Catalog No.	Description
AP6888	"Bouncing Ball" Distillation

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

Bouncing Ball Distillation Worksheet

1. What do the rubber balls used in this demonstration represent?

2. Using the rubber balls in the tub as a model, describe the arrangement and motion of molecules in the solid state.

3. Based on the motion of the bouncing balls when the tub was shaken, explain what happens to the motion of molecules in the solid state when energy is added. What does this process represent?

4. What happened to the balls when the tub was shaken rapidly and violently? What does this process represent?

5. The kinetic–molecular theory (KMT) describes how close together the molecules are in a solid, liquid, and gas, their relative motion, and the attractive forces between molecules. Use the KMT to explain the following properties of liquids and solids:

   a. A liquid flows and takes the shape of its container.

   b. Solids are generally incompressible.

   c. Liquids have a definite volume.

   d. A solid absorbs heat from its surroundings as it melts.