Modeling Changes of State in a Dishpan

INTRODUCTION:
This demonstration gives students a concrete visual reference for many ideas related to changes of state and other physical properties.

CHEMICAL CONCEPTS:
absolute zero, changes of state, freezing point depression, evaporation, vapor pressure, distillation, inter-molecular forces, AND isotopes

MATERIALS:
12 polished styrene balls (styrofoam with a smooth surface), or other balls similar in size to tennis balls, but much lighter.
6 tennis balls of one colour
6 tennis balls of a different colour
a "RubberMaid© " type flexible pan (about 28 cm x 38 cm) with 10 cm high sides.
a clear polyethene box (25 cm x 40 cm) with 20 cm high sides.

PROCEDURE:

Place about 12 balls in the dishpan, or rectangular box with low sides.

Arrange them into a regular cubic lattice (in a single layer). Tilt the pan so students can see the geometric arrangement of the layer.

With no motion, they represent atoms in a crystal at absolute zero.

Tilt the box slightly and tap the side with your hand*. "The atoms begin to vibrate as the crystal warms up*". Gentle tapping causes rearrangement of the balls into a hexagonal close-packed lattice ... a "*phase transition to a denser form*".

Tap more strongly and the balls on top will slide down to the bottom as the "*crystal melts into a liquid*".

Continue to increase the strength of the tapping as you tilt the box into a more horizontal position. "*The liquid is heating up*". Occasionally, a ball will bounce out of the box as "*evaporation*" begins. [Later, you can relate this to vapour pressure].

Finally, with a flip of the wrists, "*boil*" the balls out into the classroom. The class will never forget that "*molecules in a gas are flying around*". Students near the front feel under a lot of pressure!

Now, they will want to throw them back. But they can't throw the balls too fast because they will just hit the bottom of the pan and bounce out again. "*We have to slow down gas molecules before they will condense into a liquid again*".

VARIATIONS AND EXTENSIONS:

1. Put some bigger, coloured ones into the "crystal" at the beginning to show the effect of a solute on melting point (the balls slide down to the bottom with much less tapping... "easier to melt!")

2. With two different types of balls, the firmer ones tend to bounce out first... allowing you to **model distillation**. Use the clear box with higher sides so students can see the action of the balls inside the box as well as the ones bouncing out.

Tennis balls are about the same size as some Styrofoam balls.

The Styrofoam ones "evaporate" first, every time.

Occasionally, a tennis ball will bounce out early. *"What happens when we hurry a distillation by heating too fast? We get poor separation of components!"*

Substituting a box with higher sides can be a model for a longer distillation column.

3. Use a hypodermic syringe and a heavy gauge needle [**Care!**] to half-fill some tennis balls with water before the demonstration. Place them in the "distillation box" along with normal air-filled tennis balls. The normal ones will bounce out first. Can atoms look the same but have different masses? "Isotope so!"

(HINT: If the balls are completely water-filled, they bounce almost as well as a normal one. Here we want the water to slosh around inside the half-filled ball to absorb some of the momentum of collision.)

SAFETY PRECAUTIONS:

Wear safety glasses!

After all, you are "*boiling a liquid*" close to your face!

I find that a lab coat and face shield are good props for the "condensation" demonstration when the students throw balls back to (at) you. If no one dares to throw one fast, insist on it!

DISPOSAL: Keep the balls from year to year. Tennis balls come in watertight plastic sleeves. I have found that (without using any disinfectant) the injected ones will last all year and would last longer if they were refrigerated between demonstrations. After the summer holiday they discolor and don't smell very good!

Another Demo Idea! When you are through with them, use a sturdy knife to cut the balls in half. Wash the halves and use then as pop-up toys to demonstrate activation energy! (Push the half-ball almost inside-out, then set on a table and wait… after a few minutes, it will resume its original shape with a snap and will jump up off the table.

DISCUSSION:

This model is very close to the kinetic theory model and so is very reliable as a framework for discussion.

Students can predict that if the molecules were "sticky", it would take more shaking before they boiled. (Hydrogen bonding elevates boiling temperature of water).

They understand that heavy "super-balls" might bounce out with less shaking than lighter, softer balls (boiling point is not always related to mass of the molecule), but with similar molecules, we would expect that the lighter ones would boil more easily than heavier ones… (Methane is a gas, octane is a liquid at room temperature, etc.)

I have found that this demonstration dramatically improves students' understanding of the factors involved in distillation… care in heating, the function of the distilling column, the role of differences in boiling temperature, why the boiling temperature rises during distillation etc. etc.