Overview

Students tend to be very familiar with the different phases of matter, although they may not formally realize it. If you were to ask students to name a few examples of a solid, a liquid, or a gas, they could probably do this with ease, but the relationship between the different phases and the transformation from one to another is not as easy to comprehend. In this activity, we are exploring these questions: What happens to molecules when they get more energy? When they give it away?

Theory

By examining what is happening at an atomic-scale, we can gain a better understanding of phase changes. For our first exploration, let’s consider a common material that people are familiar with: water. A molecule of water will travel in a straight line until it hits something, either the side of the container or another molecule. Then it bounces off and moves in another direction. The speed with which each molecule travels is determined by how much energy it has, and so this energy determines what phase that the material is in: solid, liquid or gas.

Water in the solid form has a defined shape, as molecules move very little — they have very little energy. Liquid water, on the other hand, will fill the container it is in, up to a certain level. The molecules are moving faster than they were in the solid phase, and they bounce off the walls of the container and other water molecules. In the gas phase, the molecules completely fill the entire container, moving quickly, continuing to bounce off the sides of the container and other water molecules. How can a material, like water, transition between these states of matter? How can it change phase from a solid to a liquid, or a liquid to a gas? The answer is energy. Once a certain energy threshold is exceeded, matter can transition to a state of matter in which its constituent molecules are (on average) moving significantly faster, which correlates to a phase characterized by significantly less bonding between molecules (e.g., evaporation: liquid → gas). Similarly, if matter “loses” enough energy to its environment, it can transition to a phase in which its molecules are (on average) moving significantly slower, which correlates to a phase characterized by significantly more bonding among molecules (e.g., freezing: liquid → solid).

Water is commonly found in all three phases because the points at which it can change from one phase to another are within the normal day-to-day temperature experience here on Earth. Water freezes (becomes a solid) at 0°C and boils (becomes a gas) at 100°C. We are not used to experiencing many other materials in all three phases. For example, nitrogen gas is very common (78% of the atmosphere is nitrogen in the gas phase), and we sometimes can see liquid nitrogen, but solid nitrogen is something most people will never see — nitrogen freezes at -210°C!

What causes the transition from solid to liquid to gas can be difficult to grasp. In this activity we will ask students to step into the shoes of a molecule undertaking this journey with a fun, kinesthetic atomic model.

Doing the activity

Depending on the level and background of your class, you might want to start out with some leading questions: What is matter? What is a molecule? What are the three phases of matter? (solid, liquid, and gas). Ask students to name some examples of each. Ask them to name a few examples of things they never see in the liquid form, the solid form, the gas form, and then ask them to speculate why they’ve never seen these forms before. Some examples to suggest are oxygen, nitrogen, or helium.
as a solid. Have they seen copper or iron as liquid or gas? Leave this question open and ask students to keep it in mind while they participate in this kinesthetic activity that will demonstrate how and why phase changes occur.

If you use a rope, select four students to hold the rope taut between them to form a square or rectangle. Explain to the class that the rope acts as the sides of your container and choose one side to be the “bottom.” Have the rest of the students step inside the roped-off area and explain to them that they will be acting the part of water molecules, and will be changing from one phase to another based on your instructions.

There are two rules that students will follow at each stage. Rule 1: They are always pulled towards the “bottom” of the container by gravity. Rule 2: Students always hold their hands clasped in front of them with elbows out to the sides. Instruct them to maintain this position throughout the activity.

**Solid**

Start with the students being a solid: an ice cube. The rule here is that, in the solid form, they must always be elbow-to-elbow with at least one other student, but otherwise they are allowed to move. Based-on this rule, the students should form a cluster in the roped-off area against the bottom of the container. Ask the students to talk about themselves as molecules and ask these questions: Are they moving fast or slow? Do they have an abundance of energy or not so much? What needs to happen for them to “melt” and become liquid water? Most students will answer “heat” — the ice needs to be heated up. Heating the ice gives each individual molecule more energy, which allows it to move more quickly. Have the four students holding the rope gently shake it; this simulates putting energy into the container.

**Liquid**

Now the students inside can “melt” and become liquid. As a liquid, the rule they must follow is this: They must be touching another student with their elbow, but they do not have to be elbow-to-elbow. They will notice that now they can move slowly around the bottom of the container. As they are moving around, ask them again to talk about themselves as molecules. Are they moving faster or slower than they were as a solid? How much energy do they have? What needs to happen for them to move from the liquid phase to the gas phase? Again, most students will answer “heat”. Have the students holding the rope shake it quickly, simulating a large amount of energy going into the system.

**Gas**

Now the students acting as molecules can “evaporate” and become a gas. The rule in this phase changes yet again — now students may not touch another student with their elbows. If, as they are moving around, they bump into each other, they will bounce apart and will not maintain contact. In this situation, they can move quickly around the container, bouncing off the walls and each other.

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**Necessary materials:**

- one long rope, or four shorter ones (you may be able to borrow these from a PE teacher; see below for alternatives)*
- a large open area in the classroom or the playground

*You will need to designate an area within which your “molecules” are contained; this is one function of the rope. The second function of the rope is a visual representation of energy transfer. If you can’t access a rope, you may still be able to designate an “container” for the “molecules” using desks, ball game markings on the playground or gym, or orange cones (PE teachers will often have these). You will also need a way to signify increases and decreases in energy. This could be achieved by playing music and raising or lowering its volume, or by having the students clap their hands faster or slower depending on how much energy they, as molecules, have.
Again, ask them to talk about themselves as molecules. Are they moving faster or slower than they were as a liquid? How much energy do they have?

It’s important to now run the activity backwards: have the students holding the rope shake it slower, simulating the removal of energy from the system. The students inside now condense into a liquid. Have the students holding the rope shake it just a little. The students now freeze into a solid. This is a natural way to bring them back together and refocus them for a closing discussion as well.

For a follow-up discussion, ask students to revisit the question posed at the beginning of the activity: Why do we never see some materials in certain phases? (Reference some of the examples they provided.) What would it take to have liquid copper or solid helium?

**Summing up**

This activity is a great way to explore phase changes on a molecular level. After participating in this activity, students will have experienced the basic microscopic characteristics of the different phases, and will have an understanding of how energy dictates these changes. Phase change ideas are central to the understanding of many scientific disciplines.

**For more information**

Little Shop of Physics: [https://www.lsop.colostate.edu](https://www.lsop.colostate.edu)

Colorado State University College of Natural Sciences: [https://www.natsci.colostate.edu](https://www.natsci.colostate.edu)