What Flows When Heat Flo

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Heat energy is hard to understand. You cannot see it, you cannot measure it directly, and it is not a material. In fact, you can only infer heat energy indirectly from its ability to heat or cool things. No wonder everyone—including the eminent scientists Lavoisier and Laplace—had it so wrong for so long. They thought that something called "phlogiston" flowed like a gas from hot substances where it was dense, to cold ones where it was less dense.[1]

But no one ever found phlogiston. Scientists concluded that if it existed, it had no mass, or maybe a negative mass. They got it confused with fire, oxidation, and other sources of heat. It's no wonder students have problems understanding heat. The following lesson can help your students to unlock the mystery.

Overview

This computer-based lesson uses the Molecular Workbench (MW) software to make heat visible and to provide a playground where students can interact with heat and temperature, pose questions, run experiments, and see what happens. MW is a computational model that simulates how atoms and molecules interact. Understanding atomic interactions is essential for understanding heat flow, so experimentation with MW gives students a unique way to figure out what's happening on their own.

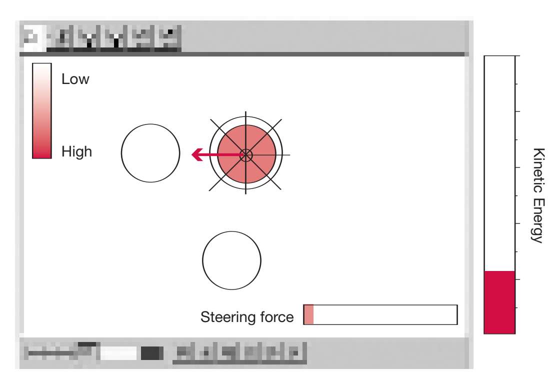

Figure 1. This model starts with three atoms at rest. The student can steer the one atom with arrow keys. As it speeds up, it turns red. The challenge is to get the steered atom white and the other atoms red.

Kinetic energy is made visible in MW by coloring atoms. When still, atoms are white, but as they speed up, they become pink and then red. Students learn that kinetic energy is associated with speed and that it can be transferred through collisions. From there, it's a short step to see that atoms will share some of their kinetic energy with any other atoms they contact and that the average kinetic energy is temperature.

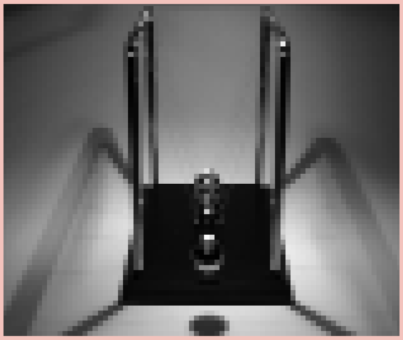

Figure 2. Newton's Cradle.

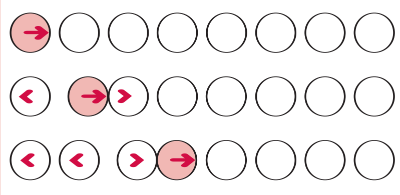

Figure 3. A series of snapshots of the MW simulation of Newton's Cradle.

Step One: Why Are Those Atoms Red?

Go to the Molecular Workbench database of activities at: <u>*http://molo.concord.org/*</u>

Jump to Activity #292, "What is Heat Flow?"

This activity consists of a series of pages, each containing a model. On the first page is an activity (see Figure 1) designed to familiarize students with the Molecular Workbench software, and the association between kinetic energy and the color of the atom. Using the keyboard's arrow keys to apply force, the user can "steer" an atom. One warm-up challenge consists of turning the white atom red and then white again as fast as possible.

Note

① For more information, see *http://en.wikipedia.org/wiki/Caloric_theory*

ws?

Step Two: Newton's Cradle

This model mimics that familiar pendulum toy called the Newton's Cradle (Figure 2). Four atoms in a row are hit by another atom. All the atoms are red if they have kinetic energy. The model—like the desktop toy—dramatically illustrates how kinetic energy moves from one atom to the next, down the line to quite distant atoms (Figure 3).

In real substances, of course, atoms are not in perfect lines, so the energy does not flow quite so rapidly, but the idea is the same.

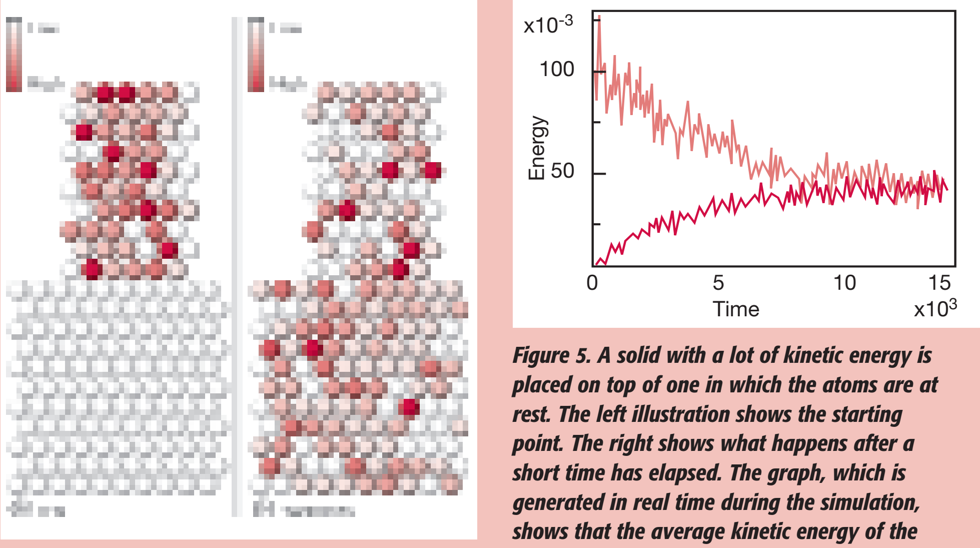

Figure 5. A solid with a lot of kinetic energy is placed on top of one in which the atoms are at rest. The left illustration shows the starting point. The right shows what happens after a short time has elapsed. The graph, which is generated in real time during the simulation, shows that the average kinetic energy of the two kinds of atoms converge to a single value.

Step Three: Heating by Hitting

In this step, students are challenged to give kinetic energy to the last atom on the lower left (Figure 4), starting with everything at rest. This is an important step—and a natural progression from Newton's Cradle—because it introduces a solid crystal and shows that kinetic energy can spread among its atoms.

The obvious way to achieve the goal is to steer the big atom to the right at maximum speed. After two hits, the nearby atoms have a lot of kinetic energy, and the kinetic energy begins to spread down throughout the solid. As you run the MW model, you can see the red atoms ripple outward from the point of impact. Ask your students to explain in detail why the red color seems to hop from one atom to another at random.

Step Four: Heat Flow Experiments

Students are now prepared to understand energy flow from one object to another. The final step uses a model of two substances, one with lots of kinetic energy and one with none. The model has the two in contact and gives the results shown in Figure 5. This might represent a hot cup placed on a counter. Have students experiment with ways to increase and decrease the rate of energy flow by changing the starting positions of the atoms. Can the heat flow be stopped?

These experiments show that kinetic energy will transfer from atom to atom until all atoms have the same average kinetic energy. Since heat flows until temperatures are equalized, this justifies thinking of temperature as the average kinetic energy, and heat flow as the transfer of kinetic energy at the atomic level. This is a profound result with many implications in chemistry, biology, and technical fields.

Closing Thoughts

The Molecular Workbench allows students to explain and connect a wide range of concepts. In this short activity, students use guided inquiry to learn about kinetic energy and atomic collisions. They learn two foundational concepts: temperature is average kinetic energy and heat flow is simply the spread of kinetic energy. No equations or numbers are required; a purely conceptual approach can get the ideas across better than pages of equations and numbers.

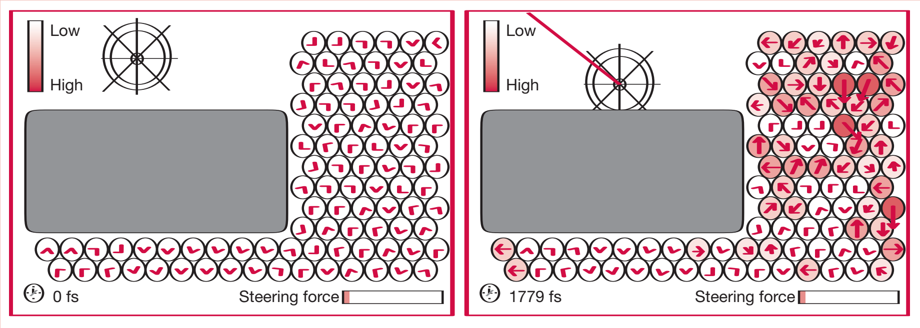

Figure 4. The starting condition (left) and after the big atom has hit the solid crystalline atoms twice (right). The atoms are held together by mutual attraction. The arrowheads in each atom indicate velocity. On the right, the leftmost atoms have been given some kinetic energy as indicated by the slight shading and their velocity vectors.

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