Lesson 2: Molecules on the Move

Overview

Through direct observations and computer simulations students are introduced to the concept that heat is the transfer of thermal energy. Students will investigate the relationship between thermal energy and molecular motion.

Teacher Background

We are, in some ways, quite familiar with heat. Whether we realize it or not, heat plays a role in just about everything that happens: warming our food, heating our homes, keeping our hands warm on a chilly autumn day, warming the Earth, building mountains, and creating weather systems… the list goes on. Very simply put, heat is a form of energy, and energy makes things happen. We have all certainly felt heat and have observed its effects on matter. If asked to explain heat, however, many would find it challenging.

Let's use a familiar scenario to help us understand the fundamentals of heat. Picture this: An ice cube is placed in a bowl of very hot soup. The ice cube begins to melt. What is happening? Is heat involved? Is heat moving? Which way is it moving? In common terms we say that the bowl of soup is "hot" and the ice cube is "cold." But scientists would think of the ice-cube-in-a-bowl-of-soup scenario in terms of differences in thermal energies.

What is thermal energy and how is thermal energy related to heat? Thermal energy refers to the collective energies of the molecules that make up all matter. The ice cube and the soup are both made up of molecules. Like all molecules, the molecules that make up the ice cube and the soup are in constant motion and the energies of this molecular motion is what scientists refer to "thermal energy."

Temperature is a way of measuring a substance's thermal energy. Molecules move more rapidly at higher temperatures. Keep in mind that since thermal energy refers to the collective molecular energies, the amount of thermal energy a substance has is also dependent on the amount matter. This explains why a bathtub of warm water or an ocean of cold water has more thermal energy than a cup of boiling water even though the temperature reading is lower and the molecules are moving slower.

How is thermal energy related to heat? Strictly speaking, heat is thermal energy that is "in transit" or "on the move." Said another way, heat is thermal energy that is moving from one system to another or heat is moving thermal energy. Thermal energy is transferred when there are temperature differences and transfers from warmer substances to cooler ones. The transfer of heat stops when both substances reach the same temperature. In the ice-cube-in-the-soup scenario, the heat is moving from the soup to the ice cube.

What should middle school students know about heat? Connecting thermal energy to the motion of molecules is a grade-level expectation in middle and high school standards. However, development of this concept must occur over time in numerous contexts and through many experiences and discussions. Developing an understanding of heat requires students to synthesize a number of abstract concepts that are likely to be relatively new to adolescents. It is not intended that students discriminate between thermal energy and heat. The major emphasis of this instructional unit is on heat transfers, placing in the forefront the examination of where heat comes from and where it goes.

For teachers interested in taking their understanding of heat and thermal energy to a deeper level, the following online tutorial is recommended:

NSTA Science Objects: Energy: Thermal Energy, Heat, and Temperature at **http://www.nsta.org**.

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Key Ideas

- Matter is made up of particles (atoms or molecules) that are moving.
- The arrangement and motion of the particles of matter differs depending on temperature. At higher temperatures, particles have greater energy and are more spread out. At lower temperatures, particles have less energy and are more compact.
- Heat is a form of energy that is related to the random motion of molecules.
- Models are used by scientists to explain ideas.

Lesson Goals

Students will:

- describe the motion of particles (atoms or molecules) of matter at different temperatures and in different states.
- recognize the random motion of molecules as thermal energy. When that thermal energy is transferred from one object to another, the amount of energy transferred is called heat.
- be introduced to the idea that all matter has thermal energy.
- consider the benefits and limitations of models.

Vocabulary

heat: the flow of thermal energy from a warm area to a cooler one.

thermal energy: the collective energies of molecular motion of a substance. (The higher the temperature, the faster the atoms and molecules that make up the substance are moving and thus the more thermal energy the substance has. Thermal energy of a substance takes into account the amount of matter. The greater the amount of matter, the more thermal energy a substance has. This is why an iceberg contains more thermal energy than a cup of boiling water.) .

Preparation

- Practice the food coloring in hot and cold water demonstration. Make certain that the water is completely still before placing a drop of dark-colored food coloring into each container of water simultaneously. If the food coloring does not move through the samples of hot and cold water at noticeably different rates, use hotter hot water and colder cold water.
- Fold each index card in half to make freestanding labels for the "hot" and "cold" water samples used in the demonstration. Write "hot" and "cold" on each card.
- Preview and become familiar with how to navigate the websites used to introduce students to the different particle motions of different states of matter. Direct links to the website can be found on the *PowerSleuth* website under *Energy Heats Maine* Lesson 2. Consider organizing a classroom webpage such as **portaportal.com** for these and other *Energy Heats Maine* links of interest.

Safety

This investigation requires the use of hot water. Use caution when using hot water with students. Double check the temperature of the school's hot water to make certain that students would not be accidently burned if water contacts their skin.

Materials

Item	Quantity
10 oz or larger clear cups or containers that can hold hot water	2
Food coloring (a dark color)	1 bottle
Index cards (to label "hot" and "cold" water samples)	2
LCD projector and computer	1 per class
Student laptops (if available)	1 per 1-2 students
Scientist's Notebook	1 per student
Student Handout 2.1: *Molecules on the Move* (optional)	1 per student

Time Required: 2 sessions

Connection to *Benchmarks for Science Literacy (BSL)*

- Atoms and molecules are perpetually in motion. Increased temperature means greater average energy of motion, so most substances expand when heated. BSL 4D/M3ab (6-8)
- In solids, the atoms or molecules are closely locked in position and can only vibrate. In liquids, they have higher energy, are more loosely connected, and can slide past one another; some molecules may get enough energy to escape into a gas. In gases, the atoms or molecules have still more energy and are free of one another except during occasional collisions. Benchmarks 4D/M3cd (6-8)
- Models are very useful for communicating ideas about objects, events, and processes. When using a model to communicate about something, it is important to keep in mind how it is different from the thing being modeled. Benchmarks 11B/E4**(3-5)

Teaching The Lesson

Engage

1 Conduct food coloring in water demonstration.

Place two clear containers in a place visible to all students. Fill one container with hot water and another with the same amount of cold water. Label and take the temperature of the two water samples. Be certain that the "hot" or "cold" labels are placed as to not block students' view of the demonstration. Ask students to make a prediction of what they think will happen when a drop of food coloring is released into the different containers of water.

When the water is completely still, put a drop of dark-colored food coloring into the center of each container simultaneously. Ask students to observe and record in their scientists' notebooks what they see happening during the demonstration. Repeat the demonstration a second time if necessary. Students may be interested in timing how long it takes for the color to uniformly disperse.

> **Note:** *Alternatively, students could do this activity at their tables with a partner.* 5

2 Discuss students' observations.

Ask students to describe what happened during the demonstration. (Students should notice that the food coloring spread out faster in the hot water container than it did in the cold water container.) Ask students if they have any ideas about why this happened and what questions they have about the demonstration. Jot down students' ideas and questions on the board or on chart paper.

3 Elicit students' prior knowledge of molecular (particle) movement.

Explain to students that all substances (all matter), including water, are made up of tiny invisible particles (atoms and molecules). These particles are so small that they can't be seen even by using powerful light microscopes.

> **Note:** *Scanning tunneling microscopes (STM) have allowed scientists' to "see" atoms by locating the atoms position and making an outline of the atom. This type of microscope does not magnify objects in the same way that light microscopes do. For more information visit:* ***http://science.howstuffworks.com/atom10.htm***

Place a cup of water in a place that is visible to all students. Say something like: *Let's imagine that we* ***could*** *use some sort of tool that would allow us to see the tiny, tiny parts – the individual molecules - of water. What would these tiny parts of water look like?* Ask students to draw and describe their ideas in their scientists' notebooks. After a few moments, have students share their ideas with their neighbors.

Ask students to consider what they might see if they were able to see these tiny parts of water as the temperature changed. For example, ask students: *If I were to take the same water that you drew a picture of a moment ago and cooled it down so much that it eventually froze and then looked at it, do you think the parts of the frozen water would look the same or different as the liquid water?* Ask students to draw and describe their ideas about what frozen water (ice) would look like in their scientists' notebooks.

When students have completed this, ask students to do the same for water in its gas form (water vapor). When they are finished, have students share and discuss their ideas at their tables. Circulate around the room, taking note and listening to students' ideas.

> **Note:** *Upper elementary students may not be familiar with "atoms" and "molecules" unless they have had prior experiences with matter. Even if students have heard of the words, it is likely that their understanding may not be scientific. It is not the intent of this unit to develop an in depth understanding of matter and in particular, atoms and molecules. If students are unfamiliar with these terms, simply refer to these tiny parts of matter as particles rather than introduce unnecessary vocabulary prematurely. If students are familiar with the terms atoms and molecules use them.*
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> *It is also not expected that students have knowledge that the particles (atoms and molecules) that make substances up are constantly moving. Asking students to draw what they think they would see if they COULD see the particles that make up a familiar substance (water) serves to get students thinking about what they might look like. It is highly unlikely, unless students have had prior experiences with states of mater, that they will include molecular movement in their drawings and descriptions. Students without prior instruction may also lack an understanding or even an awareness of states of matter especially matter as a gas.*
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> *This brief exercise is meant to help students develop the idea that particles (atoms and molecules) that make up matter are in constant motion and help them link this idea to thermal energy and heat (the flow of thermal energy).*

Explore

4 View computer simulations of molecular movement of materials at different temperatures.

Discuss with students the idea that scientists often use models to represent ideas or processes for a number of reasons. (Refer to the drawings students made earlier as these are a type of model.) Ask students why they think scientists would make models of the smaller individual parts – the particles of substances? What might these models help scientists explore?

> **Note:** *If students are unaware of the use of models consider using a globe or other familiar example of a model. Most students understand that globes are used to represent the Earth. What they may not recognize is that it is a "model" and like all models it was designed to show certain aspects of the Earth and has strengths and weaknesses. Ask students to discuss the globe's strengths and weaknesses. (Strengths – Since we have the entire Earth in the classroom this model allows users to visualize the Earth in a semi-realistic way, allows users to communicate about the Earth using the same frame of reference. Weaknesses – size is obviously off, colors can't be accurate for each season of the year, etc.)*

Explain to students that they will be examining three computer models of some familiar substances. Make sure that students understand that these are models and that people cannot see directly the individual particles that make up substances. Students may wonder how people can make models of things they have never seen. Explain that models are often developed to show or represent ideas and effective models show ideas that are supported by evidence. Reiterate that models have their strengths and limitations in representing but in this situation models allow us to think about how molecules might be moving. 7

Using an LCD projector, display the web resource from the Miami Science Museum to the class: http://www.miamisci.org/af/sln/phases/index.html

> **Note:** *The representation shows the arrangement and motion of elements or molecules in gas, liquid, and solid phases. Even though the representation includes a thermometer, it does not explicitly discuss the energy levels of the molecules in each phase. It also does not clarify that molecules are not shaped or colored as depicted.*

Orient students to the simulation by reading the introductory caption on the top of the web page. Explain to students that we'll begin by putting water into the "molecule chamber" (click on water – nothing will appear in the box yet) and selecting a state to view. Point out the thermometer on the left hand side of the molecule chamber and ask students: *If we would like to "see" what the parts of water look like when water is a solid (ice), what temperature would I need to select on the thermometer?* Click on the base of the thermometer. The chamber should fill with blue particles. Ask students to describe what they see in the chamber and comment on how this is similar to or different from what they drew earlier in their scientists' notebooks. Students should notice the arrangement and motions of the molecules. (Solids have particles that vibrate in "place.")

Ask students, given the molecular motion they observed in solid water or ice, if they would like to predict what they think they will see when they look at liquid water? Click midway up the thermometer to view water in its liquid phase. Ask students: *What happens to the molecules as the temperature changes?* Students should notice that the arrangement and motion is different for water in its liquid state. (Liquids have particles that are loosely bound and slide past one another in a random motion.)

Follow a similar line of questioning and observations for water in the gas phase. Students should notice that the gas molecules can move around freely and interact – usually by bumping into one another – when they come close to one another. (Gases have particles that are further apart with more space between them and they move more rapidly than when in their liquid or solid phase. Students may think that there are more molecules in ice than water and more in water than in water vapor as opposed to molecules in the gas just being more spread out.)

Introduce students to two additional simulations described below. Depending on availability, students could view these sites in pairs on individually on laptops. As these simulations are introduced to students, orient them to the sites by pointing out key features and sharing navigation tips. Encourage students to jot down some notes about what they observe or read on these sites in their scientists' notebooks. Ask students to think about how increasing or decreasing the temperature affects the energy of the particles. (Optional: Provide each student with a copy of Student Handout 2.1: *Molecules on the Move* to focus their observations.)

- Harcourt School Publishers: http://www.harcourtschool.com/activity/states_of_matter/index.html

  Explain to students that in this model, the substance is not identified and point out the temperature gauge (the +/- bar to the right of the purple sample).

- Vision Learning: http://web.visionlearning.com/custom/chemistry/animations/CHE1.1-an-threestates.shtml

  This animation provides another model in a slightly more sophisticated way of the relative molecular motions of water in its various states. Students may ask why water particles in this model look like small Mickey Mouse heads. This model shows how the elements making up water, hydrogen and oxygen, are attached and arranged. This is added detail is one that students do not need to be concerned with at this point. Ask students to focus on the differences in the motions and arrangement of the particles in the models.

Reflect And Discuss

5 Revisit students' drawings.

Ask students to revisit and reflect upon the drawings they made earlier of water in each of the three states. Ask students to respond to the following prompt(s) in their scientists' notebooks:

- *How are your ideas about the movement of the molecules of water similar to the computer models?*
- *How are your ideas about the movement of the molecules of water different from the computer models?*
- *Make new pictures showing your new ideas of how the molecules of water move at each of the following temperatures: ice (0°C), water (20°C), and water vapor (100°C). Use words to describe your new models.*

6 Connect models to food coloring demonstration.

Remind students of the food coloring in hot/cold water demonstration from the beginning of the lesson. Pose the following to students: *Using what you know about the movement of water molecules at different temperatures, explain why the food coloring moved differently in the two samples.*

Allow students a few moments to discuss their ideas with a partner and then construct an explanation based on their observations. All students should write an explanation in their scientists' notebook. Students may wish to use pictures to help describe their thinking. Have a few student volunteers share their ideas.

> **Note:** *Students should include the following in their explanations: All matter has smaller parts that are constantly in motion. Substances at higher temperatures have more energy and therefore the molecules in them move around much more rapidly. When the food coloring is added to hot water, the particles of water bump into the food coloring particles at a faster rate and more frequently than when the food coloring is put into the colder water. This causes the food coloring to spread out much more rapidly in the hot water than in the cold water.*

7 Relate particle motion to heat and thermal energy.

Explain to students that all matter is made up of small particles and these particles are always moving. Emphasize the idea that all matter is made up of tiny moving particles by discussing a few examples: particles making up the table are moving even though we can't see movement in the table; particles making up icebergs are slowly jiggling; particles making up a cold liquid drink are moving; particles making up a glass window are also moving as is the air inside a basketball; the particles making up an apple are moving, etc. Explain that substances are made of smaller parts that are moving. It is this particle motion that moved the food coloring through the two containers of water. Students may think that the "release" of the food coloring made the particles move, so they may not be convinced. Consider leaving the sample undisturbed and discussing why the food coloring eventually spreads through the entire sample, long after the "push" or dropping in of color is not longer taking place.

Explain that scientists refer to the collective motion of particles in matter as thermal energy. The amount of thermal energy a substance has depends on its temperature and amount.

Dissect the word thermal by asking students if they have ever heard of the word thermal before. Ask students to suggest words that they've heard of that contain "therm" or "thermal." Students may suggest terms such as: thermos, thermal underwear, thermal pajamas, thermostat, thermometer, thermal blanket, thermal insulation, thermal pane windows, geothermal, thermo pack, thermodynamic, thermoregulation, isotherm, hypothermia, thermochemistry, endotherm, ectotherm, endothermic, exothermic, etc. Explain that the root of thermal is "therme"- a Greek word referring to heat. It may be fun to post their "therm" words on a white board or large sheet of paper so they can see as well as hear the root word.

Set the stage for upcoming lessons about heat by asking students why they think the word "thermal" was used to describe the collective energies of particles in a substance. Students will develop the idea in upcoming lessons that heat is thermal energy that flows.

> **Note:** *Physicists distinguish heat from thermal energy. Heat is thermal energy that is "in transit" – thermal energy that is moving from one system to another. Heat is moving energy. As noted earlier, thermal energy is transferred when there are temperature differences and transfers from warmer substances to cooler ones. The transfer of heat stops when both substances reach the same temperature. Teachers should not be overly concerned about students distinguishing between thermal energy and heat. The idea here is to help students recognize that there is a connection between*

thermal energy and heat and more importantly, that heat is related to the motion of particles. These ideas are addressed in upcoming lessons. Students' understandings about heat will develop over time.

8 Bring lesson to a close.

Challenge students to find additional words that contain the root "therme." Consider creating a "therme" board for students to post the words they come up with throughout the unit.

Extensions

Student may:

- explore Physics Central: Physics in your Glass: Racing Molecules www.physicscentral.com/experiment/physicsathome/glass.cfm. This site describes the molecular motion of water in its various states and explains the differential movement of food coloring though warm and cold water. Included is a "Try this" section that encourages users to try the food coloring experiment with vegetable oil, adding soap, and adding salt.
- investigate how thermometers work.
- build their own thermometer: http://www.pbs.org/wgbh/nova/teachers/activities/3501_zero.html

Connection to Maine Agencies

A Maine Energy Education Program (MEEP) representative and will come to interested schools, free of charge, to guide and support the concepts in lesson. For more information go to the MEEP website: http://www.meepnews.org/classroomactivities.

For schools in Aroostook County, a Maine Public Service (MPS) representative will come to interested schools, free of charge, to guide and support concepts developed in this lesson. A description of programs is available at www.mainepublicservice.com. Click on the education section of the site. To schedule a presentation contact Nancy Chandler at 207.760.2556 or nchandler@mainepublicservice.com.

Online References and Resources

- Berkheimer, G., Anderson, C., Blakeslee, T. et al. (1988) *Matter and Molecules.* East Lansing, MI: Institute for Research on Teaching, Michigan State University. http://ed-web3.educ.msu.edu/reports/matter-molecules/default.htm
- National Science Teachers Association. *Science Objects: Energy: Thermal Energy, Heat, and Temperature*. www.nsta.org