



Lesson 5:

Conduction, Convection, Radiation

Investigating Heat Transfers

Overview

Heat moves from warmer matter to cooler matter in different ways. Students consider heat transfers that occur in everyday situations and investigate three specific ways that heat moves: conduction, convection, and radiation.

Teacher Background

Heat is thermal energy that is in transit. In the previous lessons students explored the idea that heat moves (transfers) and that heat moves from warmer matter to cooler matter. But how exactly is heat transferred from warmer matter to cooler matter? Conduction, convection, and radiation are the three ways that heat moves from one substance to another.

Have you ever grabbed the handle of a hot metal pan or walked barefoot across asphalt on a scorching summer day? Why do these objects feel hot to you? In both of these situations, heat is transferred to your body because it is in direct contact with matter that is at a higher temperature. You are at a lower temperature than the “hot” matter so heat moves from the hot matter to your “cooler” hand or foot. This form of heat transfer is called conduction. Conduction is the transfer of thermal energy between matter that is in direct contact.

Some materials conduct heat better than others. Why? When a metal pan is first placed on a stove and the stove is turned on for a few moments, a person can touch the pan without feeling any discomfort. But as the metal pan heats up, energy moves from the stove burner to the bottom of the pan, then from the bottom of the pan to the metal sides of the pan, and eventually moves up to the handle of the pan. Why does this happen? Energy from the stove burner causes the particles (atoms) making up the pan to move more rapidly. In some materials such as metals which are good conductors of heat, the rapidly moving particles readily cause neighboring particles in the same object to move faster. In turn, these particles cause their neighboring particles to move faster and so on up through the pan, causing a rise in temperature. This explains the experience of discomfort when touching the handle even though your hand is not directly touching the stove burner – conduction transferred heat to all parts of the pan making the handle hot. Conduction happens through the successive collisions

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of molecules. Different materials conduct heat differently depending on the way their particles are arranged; the closer the molecules are arranged, the more rapid the transfer. Both solids and liquids can transfer heat by conduction.

Imagine boiling a pot of water on the stove to cook some elbow pasta. Watching the water heating up you drop in one piece of elbow pasta. You notice the pasta rises to the top of the pan, gets pushed to the side, and then sinks to the bottom of the pan, rises again, and so on – moving around in circles from top to bottom in the pot of boiling water. As the water particles at the bottom of the pan heat up they not only move faster but they also spread apart. Because the water particles are spread out more they are said to be less dense than the cooler water at the top. The cooler water at the top sinks and the warmer, less dense water rises to the top. As the cooler water sinks it heats up and moves back to the top. The circular motion continues for as long as the water is being heated up. Convection is the transfer of heat by the actual movement of the warmed matter. The heat moves with the fluid. Observing the pasta lets us “see” the cycling movement of heat. Convection occurs in liquids and gases.

Matter must be present in order for heat to move by conduction or convection. Radiation is another method of heat transfer, one that does not rely upon any contact between the heat source and the heated object. For example, we feel heat from the Sun or a fire even though we are not touching them. Radiation can occur through objects and empty space. Radiation is the transfer of energy by electromagnetic waves. All objects possess thermal energy and emit some electromagnetic waves. Hotter objects are more energized than cooler ones. This method of heat transfer is one that middle school students may more fully appreciate after they have studied electromagnetic waves in high school. The focus should be on developing the concept of heat transfer by radiation using experiences familiar to students: the warmth of the Sun, a campfire, or an open oven door. In these contexts, students will recognize that matter is not necessary for this type of transference to occur. Some students may also be familiar with thermal images of buildings or animals or have seen infrared heat lamps at restaurants or pet stores. Learning more about thermal imaging and infrared heat would make an interesting extension for interested students.

In most situations, more than one method of heat transfer takes place. For example, in the boiling water and pasta convection example above, water becomes warmer due to the transfer of heat from the stove burner to the pot and then from the pot to the water (conduction). Developing the idea that heat transfers occur in a variety of ways should be emphasized rather than defining in absolute terms the differences between conduction, convection, and

radiation. Students should recognize that heat transfers, occurring in a variety of ways, can be used to explain everyday phenomenon. Keep in mind that even after instruction some students may not be able to discuss the heating or cooling of objects in terms of heat transference. This remains a very challenging and abstract idea for many middle school students. Some students may continue to hold on to their naive belief that heat moves from a colder object to a warmer object or that both “heat” and “cold” are transferred at the same time. Another noticeable idea that may be difficult for students to grasp is that things such as air, flour, or sugar can heat up. (*Benchmarks for Science Literacy*)



Key Ideas

- Energy can move from one place, object, or system to another.
- Substances heat or cool as a result of energy transfer.
- Energy transfers from warmer matter to cooler matter until both reach the same temperature.
- Heat transfers occur in three ways: by radiation, conduction, and convection.

Lesson Goals

Students will:

- explain how heat moves from one place to another including how cooler materials can become warmer and vice versa.
- describe how heat moves by conduction, convection, and radiation.
- give examples of heat transfers that occur in every day situations.

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Vocabulary

conduction: the transfer of heat through a material by direct contact.

convection: the transfer of heat in a fluid (gas or liquid) as a result of the movement of the fluid itself.

radiation: the transfer of heat via electromagnetic waves through space.

heat transfer: the transfer of thermal energy between substances due to a difference in their temperatures.

Preparation

- Affix each Heat Transfer Scene (Teacher Resource 5.1- the photos provided with this lesson) to the top of a piece of chart paper. Be sure there is enough room for students to write on the chart paper under each scene. Post chart paper around the room in areas that students can readily access.

Note: *Put in scenes in plastic protectors. This allows for easy removal of scenes for reuse with other classes.*

- Become familiar with the heat transfers present in the scenes. Consult the descriptions found in Teacher Resource 5.2.
- Preview and become familiar with the websites used in this lesson.
- Gather the materials required for the demonstrations and student activities. Prepare in advance the wax dots and the paper spiral (Teacher Resource 5.3). Have additional sets of these materials on hand in case demonstrations need to be repeated. Practice each demonstration and student activity.
- Review Student Handouts 5.1 and 5.2.

Safety

Use caution when using candles in the classroom. Have a fire extinguisher available. Tie loose clothing and hair away from face. Wear safety apron and goggles when conducting demonstrations. Do not allow students to touch the hot incandescent light bulb.

Materials

Item	Quantity
Teacher Resource 5.1: Heat Transfer Scenes	1 set per class
Chart paper	approx. 20 pieces
Markers	10
Scientists' Notebook	1 per student
Timer or access to clock with minute hand	1 per class
Student Handout 5.1: How Heat Travels Student Handout 5.2: How Heat Travels Content Organizer	1 per student
Access to internet	Individual, pairs, or whole class depending on availability
Wax dot demonstration: <ul style="list-style-type: none"> • Metal knitting needle • Wax shaped into pea sized dots • Candle and matches • Aluminum foil (to protect work surface) • Heat resistant apron • Safety goggles • Access to fire extinguisher 	1 set per class
Light bulb demonstration: <ul style="list-style-type: none"> • Incandescent light bulb (100 w) • Lamp 	1 set per class
Convection <ul style="list-style-type: none"> • Student Handout 5.3: Observing Convection • four 6 or 8-oz cups • food coloring • clear pie pan • water samples (room temperature, hot water, cold water) 	1 set per group
Hot air spiral demonstration <ul style="list-style-type: none"> • paper spiral cut out (Teacher Resource 5.3) • thread • candle and matches • heat resistant apron • safety goggles • fire extinguisher Note: Demonstration can be done by holding spiral over a lamp with an incandescent light bulb.	1 set per class

Time Required: 2-4 sessions

Session 1: Introduce heat scenes and discuss.

Session 2: Read and discuss article, websites, and graphic organizers.

Session 3: Further develop understanding of three transfers and demonstrations.

Session 4: Revisit scenes and share/discuss.

Connection to Maine Learning Results: Parameters for Essential Instruction (MLR), Benchmarks for Science Literacy (BSL), and National Science Education Standards (NSES)

- Describe how heat is transferred from one object to another by conduction, convection, and/or radiation. MLR D3(6-8) j
- Thermal energy is transferred through a material by the collisions of atoms within the material. Over time, the thermal energy tends to spread out through a material and from one material to another if they are in contact. Thermal energy can also be transferred by means of currents in air, water, or other fluids. In addition, some thermal energy in all materials is transformed into light energy and radiated into the environment by electromagnetic waves; that light energy can be transformed back into thermal energy when the electromagnetic waves strike another material. As a result, a material tends to cool down unless some other form of energy is converted to thermal energy in the material. BSL 4E/M3* (6-8)
- Heat moves in predictable ways, flowing from warmer objects to cooler ones until both reach the same temperature. NSES B (5-8)

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Teaching The Lesson

Engage



1 Introduce heat scenes.

Ask students: *What happens when you hold a chocolate bar in your hand?* Students will most likely say that it melts. Ask students to explain how this happens. Students should be able to explain that heat moves from your hand to the chocolate bar which raises the temperature of the chocolate, causing it to melt. A person's hand is at a higher temperature (98.6°F or 37°C) than the chocolate bar (70°F or 20°C room temperature) and heat moves when matter at different temperatures interact. Heat moves from warmer matter to cooler matter.

Explain to students that there are 10 photos displayed around the room. The photos are on chart paper and depict everyday situations involving heat transfers. Students, working in pairs, visit and observe each scene and consider how heat is moving in that picture. Post the following prompts:

- *What makes you think that heat is moving; is there any evidence that you see showing heat transfer?*
- *Where does the heat come from and where does it go?* (Hint: It may be helpful for students to remember which substances are at a higher temperatures and which are at lower temperatures.)
- *What questions do you have about this situation?*

Have each student pair find a scene to start their work. After discussing the scene with their partner, students are to write their ideas about the scene's heat transfers on the chart paper below the photo. Students may also pose a question about the scene if they are uncertain about a particular aspect of the scene or want to know more. Explain to students that they should not be concerned if they are not sure about how heat is being transferred in the picture. The idea is for students to think about and discuss each scene and record their ideas and questions.

Explain to students that after a given amount of time (approximately 2 minutes), they will be instructed to move to the next scene where they will observe the scene, read the comments already written on the paper by previous pair(s), and add their own ideas, comments, or question about the scene on the chart paper. Pairs will continue to rotate through the remaining scenes until all groups have visited each scene.

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Model the type of responses that may be given for a scene by using the introductory chocolate bar melting in your hand situation as an example. (Use a picture or ask students to imagine what a photograph of the melted chocolate bar would look like.) Students could note that the evidence of a heat transfer would be the liquefied or melted chocolate bar. Heat from the person's body is transferred to the chocolate bar, increasing its thermal energy (molecular movement) and the bar melts. An example of a question that students might pose: What role does a chocolate bar's wrapper play in heat transfers?

Note: *This introductory exercise is meant to reinforce prior understanding about heat, including the idea that heat flows from the warmer object (higher energy) to the cooler one (lower energy). It also sets the stage for this lesson which will introduce the different ways heat is transferred: conduction, convection, and radiation.*

As students are working, circulate among groups. Listen to students' conversations and read what they are adding below each scene. Ask guiding questions to any students who may appear "stuck" at a scene. Note any difficulties or questions students leave about various scenes in preparation for the debriefing that follows.

2 Discuss observations.

Review findings with the class by asking students which in scenes they thought the heat transfers were the easiest to identify and in which they thought were the most difficult. Discuss the heat transfers for a few of the scenes in detail and include the idea of heat sources. *What are sources of heat and where are they in the scenes?* A tip to help struggling students is to focus on the question, "Where does the heat come from and where is it going?" Once students are able to understand and believe that heat does in fact move, they can then consider directionality and how it moves.

3 Introduce the idea that heat travels in different ways.

Ask the class to look at the scenes around the room again. As the students are looking again at the photos, say something such as: *Notice how these photos show heat moving from object to object. Consider, is heat moving the same way in each of the photos. What do you think?* It may also be helpful to revisit the melted chocolate bar example introduced at the start of the lesson. Ask students: *In what other way could the chocolate bar be melted – other than the bar being in direct contact with a person's hand?* Students may suggest that the bar could be placed out in the Sun or warmed up over a campfire.

Encourage students to examine the scenes and help them identify similarities and differences in the way they think heat is being transferred in the situations. Students will most likely be able to

readily identify situations in which heat is being transferred by direct contact between two objects by (conduction) and via sunlight (radiation) even if they do not use those terms. Students may not suggest examples for convection as this is not as familiar to students as conduction or radiation. Do not spend too much time on this as students will have the opportunity to learn more about conduction, convection, and radiation momentarily.

Note: *Some students may be familiar with and offer the terms conduction, convection, and radiation. If students use the terms, ask them to elaborate, explaining their idea as much as they can at this point. Very often students will use vocabulary words when they do not truly understand their meaning. These concepts will be formally introduced in the activity that follows.*

Explore

4 Introduce the concepts conduction, convection, and radiation.

Provide each student with a copy of Student Handout 5.1: How Heat Travels (content summary) and Student Handout 5.2: How Heat Travels Content Organizer. Explain to students that there are three different ways that heat is transferred and they are called conduction, convection, and radiation. Note that they have seen evidence of these transfers in everyday situations but they may not have realized it. Explain to students that each of these transfers happens in different ways. These are described in the Student Handout 5.1 and in websites that students will visit. Explain to students that after they become familiar with each of type of transfer they will also take part in activities that will allow them to observe and discuss each type of transfer.

Call students' attention to the Student Handout 5.2 (content organizer). Explain to students that they are to use the graphic organizer to help them make sense of the different ways heat travels.

Review and discuss the information on Student Handout 5.1.

Allow students to visit the following websites either as a full class, in pairs, or as individuals depending on the availability of computers. If students are working in pairs or individually, point out that the sites have interactive components that they will need to click on to activate. Remind students to use the content organizer to record their findings as they visit each site.

BBC – Education School Bitesize: Energy transfer by conduction, convection, and radiation. Animated diagrams and text explain the different ways heat is transferred.

http://www.bbc.co.uk/scotland/education/bitesize/standard/physics/energy/heat_energy_rev2.shtml

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Teachers Domain: Heat Transfer

An interactive tutorial explaining convection, conduction, and radiation. http://www.teachersdomain.org/asset/lsp07_int_heat-transfer

Three Methods of Heat Transfer: Conduction, Convection, and Radiation

<http://www.vtaide.com/png/heat2.htm>

Convection, Conduction, and Radiation

<http://www.mansfieldct.org/schools/mms/staff/hand/conv-condrad.htm>

NOAA's National Weather Service – Jet Stream – Transfer of Energy

<http://www.srh.weather.gov/srh/jetstream/atmos/heat.htm>

[high level of content]

MSN Encarta

http://uk.encarta.msn.com/media_461530225_761567280_-1_1/Heat_Transfer.html

5 Observe conduction, convection, and radiation.

Conduct the following activities to illustrate heat transfer by conduction and then radiation. Let students know that some of the activities will be demonstrated by the teacher and some will be done by students in small groups or pairs. Instruct students to sketch and record their observations about each activity in their scientists' notebooks. Ask students to label the heat source and the direction heat travels for each example. Remind students to title each type of heat transfer.

Wax Dot Demonstration (Conduction)

- With forceps or tongs, hold one end of a metal knitting needle that has wax dots of equal sizes stuck to it in intervals.



- Heat the other end of the needle by putting it close to a candle.
- Ask students to record their observations of what happened in their scientists' notebooks and to describe their ideas about how the heat got from the source to the wax, causing it to melt.
- Ask students what kind of heat transfer this is an example of and why.

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Incandescent Light Bulb Demonstration – Review (Radiation)

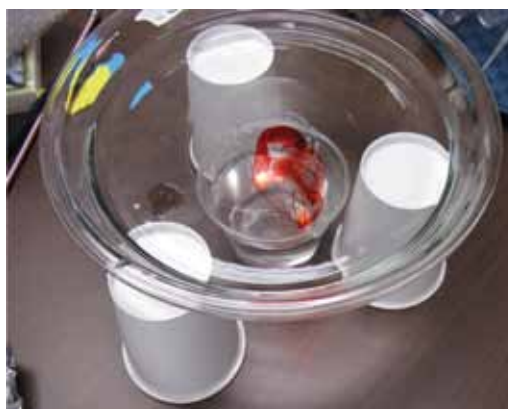
- Turn on the light bulb and let it glow for a few moments.
- Without touching the bulb, ask a volunteer to place his or her hands near the bulb and feel the heat from the bulb.

Safety: *Do not allow students to touch the bulb.*

- Ask students to record their observations of what happened in their scientists' notebooks and to describe how the heat got from the bulb to the volunteer's hands.
- Remind students to label the heat source and the direction heat travels (*Where is the heat coming from and where is it going?*).
- Ask students what kind of heat transfer this is an example of and why.

Observing Convection (Students)

- Distribute a copy of Student Handout 5.3: Observing Convection to each student.
- Review procedures, including safety and clean up directions. Determine student groups.
- Circulate among student groups as they work, asking questions and noting observations.
- Discuss findings at the conclusion of the exercise as a class.



Variations: Students could add rice, macaroni, or glitter to aid in observing “rolling” of material due to convection currents. Different groups of students could be assigned different water temperatures and compare differences in motion. Allow each group to “perfect” their demonstration then share with classmates.

Paper Spiral Demonstration (Convection):

- Hold the spiral using the thread over a lit candle.
- Remind students to label the heat source and the direction heat travels.
- Ask students to observe what happens (the spiral will spin) and to describe why the spiral that motion occurs.
- Ask students what kind of heat transfer this is an example of and why.

Direct students to add information to Student Handout 5.2 (content organizer) from the activities.



Reflect And Discuss

6 Revisit heat scenes.

Have student pairs adopt an energy scene from the opening photos exercise that they find particularly interesting given their new knowledge. (Alternately, scenes could be assigned to student pairs or small groups.) Provide each student pair a new piece of chart paper on which to write about their adopted scene. Give students the following task:

- Review the comments initially posted by the class about their scene. With their new knowledge, reflect on whether or not they agree or disagree with those comments and provide reasons.
- Below the scene on the new piece of chart paper, ask students to:
 1. identify the evidence that heat is being transferred;
 2. indicate the heat source;
 3. note the direction(s) heat is moving and;
 4. describe the type(s) (convection, conduction, or radiation) of transfers taking place.

Note: As indicated in the Teacher Resource 5.3, situations involve more than one method of heat transfer on some level and can be quite complex. The idea is for students to become familiar with these methods as opposed to memorizing the situations or terms as absolutes.

7 Debrief energy scenes.

Bring students together to share and discuss their scenes. After students have finished, consider displaying students' annotated energy scenes for others. As a follow up assignment, ask students to find interesting examples of conduction, convection, and radiation that have not yet been discussed in class. These could be sketched, described, and/or photographed, displayed on chart paper, and shared in a similar manner.

8 View Newton's Apple video clip on firefighting.

This online video explores the role of conduction, convection, and radiation as related to fire and fire safety. This could be shown to the class and/or assigned as follow up homework if students have internet access at home. Consider asking students to share this clip with their parents and other family members.

Newton's Apple Video on Firefighting:

<http://www.newtonsapple.tv/video.php?id=1162>

Extensions

Student may:

- figure out how popcorn could be made using all three methods of heat transfer: conduction, convection, and radiation. Visit three ways to cook popcorn:
<http://aspire.cosmicray.org/labs/atmosphere/popcorn.html>
- find out how astronauts “beat the heat” in outer space:
http://spaceplace.nasa.gov/en/kids/st8/thermal_loop/
- investigate how lava lamps work.
- prepare snacks for hungry a “Grunucus.” This game requires knowledge of heat transfers to prepare snacks properly:
<http://www.harcourtschool.com/activity/etgame/etgame.dcr>
- learn about heat transfer and ocean currents: <http://school.discoveryeducation.com/lessonplans/programs/oceans/>

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.

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Online References and Resources

Teach Engineering Lesson: How Hot Is It? Teacher Background on Convection , Conduction, and Radiation:
http://www.teachengineering.org/view_lesson.php?url=http://www.teachengineering.org/collection/cub_/lessons/cub_energy2/cub_energy2_lesson06.xml

Chikneyan, Zarui Sara. Lesson: *Three Methods of Heat Transfer*
http://sfos.calstatela.edu/Physics_592/Heat.pdf

Radiant vs. Convection, Flames vs. Coils and Other Hot Questions
Washington Post article describing convection, conduction, and radiation in ovens and cooktops:
<http://www.washingtonpost.com/wp-dyn/content/article/2007/03/27/AR2007032700665.html>

National Park Service: *Hot Springs and How They Work*.
<http://www.nps.gov/yell/naturescience/hotspring.htm>

Hot and Cold Cans: Descriptions of several hands-on activities that could be done as supplements or extension to this lesson.
<http://www.ciblearning.org/resource.exercise.cans.php>

Energy Transfers: How Does Heat Energy Move
<http://www.s-cool.co.uk/gcse/physics/energy-transfers/how-does-heat-energy-move.html>

Note: *Students may be confused at the following misleading text found on this site: "Convection cannot happen in solids, as the atoms aren't able to move around." Discuss with students how the author of this site may make this note clearer and avoid confusion.*

Heat Transfer Scenes Credits

Images used in accordance with Flickr.com's Creative Commons License

Ben's Breath by nordicshutter
<http://www.flickr.com/photos/juiceybrucey/2147951315/>

September 9, (cocoa) by romanlily
<http://www.flickr.com/photos/romanlily/1354377177/>

Soup spoon by mandydale
<http://www.flickr.com/photos/mandydale/264772724/>

near Geysir by jAnosmia
<http://www.flickr.com/photos/jenniferboyer/52475690/>

Chicks Cozy in the Latest April Storm 1 by Tim Somero
<http://www.flickr.com/photos/somerophoto/460100654/>

The Desert By Jesse The Traveler
<http://www.flickr.com/photos/jesseslife/237052581/>

happy little homemaker by Ryanwiz
<http://www.flickr.com/photos/ryanwiz/2266280449/sizes/m/>

Melting Ice cream by TDR1
<http://www.flickr.com/photos/tdr1/2896197164/>

fireplace by mhaithaca
<http://www.flickr.com/photos/mhaithaca/336279400/>

I love the sound of boiling water by chris.corwin
<http://www.flickr.com/photos/flickerbulb/37082767/>