Heat Transfer

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CHAPTER 1 Heat Transfer

Objectives

The student will:

- Explain the relationship between heat and energy transfer.
- Describe how energy is transported through the processes of conduction, convection, and radiation.

Vocabulary

- **conduction**: The transfer of heat through matter by communication of kinetic energy from particle to particle (molecular collision), with no net displacement of the particles.
- **convection**: The transfer of heat from one place to another by the movement of fluids, also known as convective heat transfer.
- **heat**: The sum of all the kinetic energies of all the molecules in an object or substance.
- **radiation**: Energy emitted in the form of electromagnetic waves and covers the entire electromagnetic spectrum, extending from the radio-wave portion of the spectrum through the infrared, visible, ultraviolet, x-ray, and gamma-ray portions.

Introduction

Energy can be transferred as **heat** in three ways: through **conduction**, **convection**, and **radiation**.

Heat Conduction

Conduction occurs when a temperature difference exists, causing the molecules of an object to transmit energy throughout the object. We usually associate conduction with solids. The atomic structure of a solid is more rigid than a liquid or gas, and thus better able to communicate atomic vibrations caused by heating. Conduction is the transfer of kinetic energy from one molecule to another by molecular collision. Conduction occurs, for example, when a metal spoon is put into a hot cup of tea and the handle of the spoon gets hot.

We mentioned above that some of the food energy we consume is used to maintain a constant body temperature. What happens on a hot day when our body temperature is the same as the outside temperature? No energy will be transferred, since the temperatures are equal and therefore we'll feel uncomfortably warm since we won't be able to shed our heat. In contrast, when it is very cold, the temperature difference between our body and the outside temperature can be considerable and thus energy is transferred (rather quickly, if we're not dressed warmly) from our body to the outside environment. We interpret this rapid transfer of energy as feeling cold.

On a cold day, an object made of metal typically feels colder to the touch than wood, because energy leaves your hand more quickly when touching metal than wood. We say that metal has a higher conduction rate than wood. For example, for the same temperature difference, the conduction rate of copper is over 3,000 times greater than that of wood. Energy will flow from your hand 3,000 times more quickly if you hold a piece of copper, compared to holding a piece of wood of the same temperature. This means, of course, that you don't want to grab the handle of a copper (or any metal) pot when it's being heated on your stove. Heat conduction assures that the energy from the flame under the pot is conducted to the handle of the pot and to your hand should you touch it. Ouch!

The relationship between the rate of heat flow (heat conduction) $\frac{\Delta E}{\Delta t}$ and the temperature difference ΔT is

$\frac{\Delta E}{\Delta t} = kA\frac{\Delta T}{t}$. The rate of heat flow $\frac{\Delta E}{\Delta t}$, is measured in $\frac{J}{s}$, k is the thermal conductivity that depends upon the properties of the object, A is the cross-section of the object, and t is distance over which the heat is conducted between the two temperatures $\Delta T = T_2 - T_1$.

Note: Typically when we discuss heat flow, the letter E is replaced with the letter Q. We will use Q in the section on specific heat below.

http://demonstrations.wolfram.com/ExperimentOnHeatConduction/

The Direction of Heat Flow

There is a misconception regarding heat flow that we should dispel at this point. Under normally occurring conditions, heat flows only from a hot environment to a cold environment, never in reverse. An open door on a very cold day does not let the cold in. It permits the heat to flow more readily to the outside.

On a cold day, even in a warm room, if you put your hand on a window pane inside your home, it will feel cold. The room temperature may be comfortable, but heat is flowing from the inside of the room to the outside through the glass pane. The air close to the glass pane inside the room has a lower temperature than the average temperature of the room because of its proximity to the outside. Conversely, the layer of air on the outside of the window pane has a higher temperature than the air farther from the window. On windy days, this effect is considerably lessened.

Illustrative Example 1

The temperature very near a glass window pane on the inside of a house is measured as 13°C and the temperature on the outside near the window is measured as 10°C. The window has dimensions 1.25 m by 0.90 m. The thickness t of the window is *4* mm, and its thermal conductivity k is 0.80 $\frac{\text{J}}{\text{s}\cdot\text{m}}{}^{\circ}$C. Find the rate at which energy is transferred from the inside of the room to the outside environment.

Answer:

Remembering that the area $A = (1.25\text{m})(0.90\text{m})$, and substituting the givens into the equation $\frac{\Delta E}{\Delta t} = kA\frac{\Delta T}{t}$ we have:

$$\frac{\Delta E}{\Delta t} = \left(0.80\frac{\text{J}}{\text{s}\cdot\text{m}\cdot{}^{\circ}\text{C}}\right)(1.25\text{m})(0.90\text{m})\left(\frac{13^{\circ}\text{C} - 11^{\circ}\text{C}}{0.004\text{m}}\right) = 450\ \frac{\text{J}}{\text{s}}$$

This amount of energy transfer is equivalent to seven-and-one-half incandescent 60-W light bulbs. And this is through only one window! Installing energy-efficient windows in your home saves a good amount of money and helps the environment since most people still use fossil fuels to heat their homes.

Convection

Convection typically arises from the movement of gases or liquids over large distances. Convection takes place throughout the Earth's atmosphere all the time. Heated air is less dense than cooler air, so it rises. As the air rises, it cools down and becomes denser. The air then falls back to the ground where it is heated again, and the process repeats. A convection cell, which is a circulating pattern of moving energy, is created. The **Figure** 1.1 shows how the convection cell reverses direction from day to night due to the ground giving off the heat in the evening that it absorbed during daylight hours.

Imagine the air that is heated by the asphalt and the concrete within a city rising, cooling, falling back, and being reheated by the asphalt and concrete, over and over again.

Many atmospheric conditions are the result of convection.

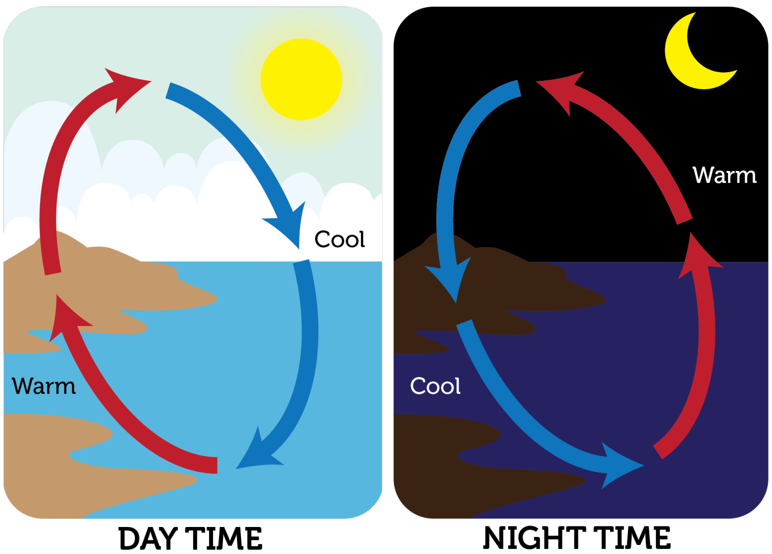


FIGURE 1.1
Convection cell reverses direction at night.

In hot climates, convection is used to cool homes. Ducts within the house provide pathways for the warm air to circulate. As the sun goes down and the temperature drops outside, the warmer air in the house flows through the ventilation ducts and to the cooler environment outside.

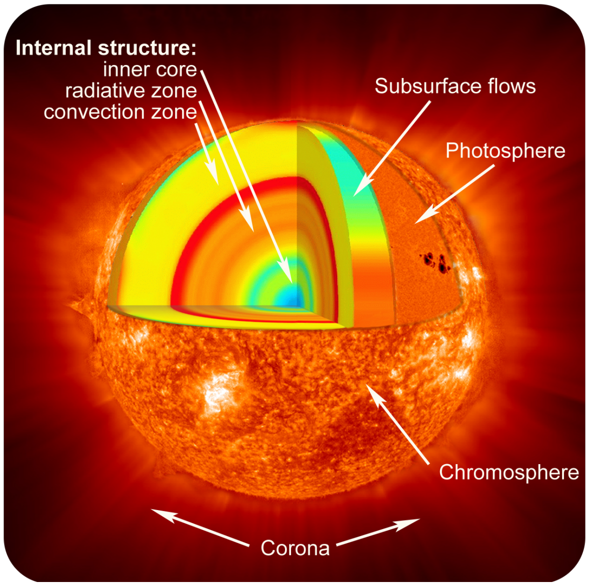
Convection is not restricted to earthly phenomena. The interior region of the sun is in a constant state of convection, which is seen in photographs showing what astronomers call "granulation." The granulation represents an innumerable amount of convection cells "boiling" to the sun's surface. See **Figure** 1.2 for a diagram of the sun's interior and a photograph of the convection cells (granulation).

Radiation

Both conduction and convection rely upon moving matter. Radiation does not. Radiation is energy transferred by electromagnetic waves (or photons). We will say more about radiation when we discuss the electromagnetic spectrum.

Energy transferred by radiation from the sun travels millions of kilometers through the vacuum of space before reaching the Earth. Some of this energy is visible radiation (sunlight, for example), while other energy is invisible. Heat radiation is an example of invisible radiation. It belongs to a part of the electromagnetic spectrum below the threshold of human sight. Just as there are sounds we cannot hear, there is light we cannot see.

When you sit next to a campfire or a fireplace and feel all warm and cozy, thank radiation! If the only heating we could experience was through convection, we would not be warmed. We would benefit very little from a convection cell up a chimney or directly above a campfire. It is the flow of radiation from the fire that warms us.



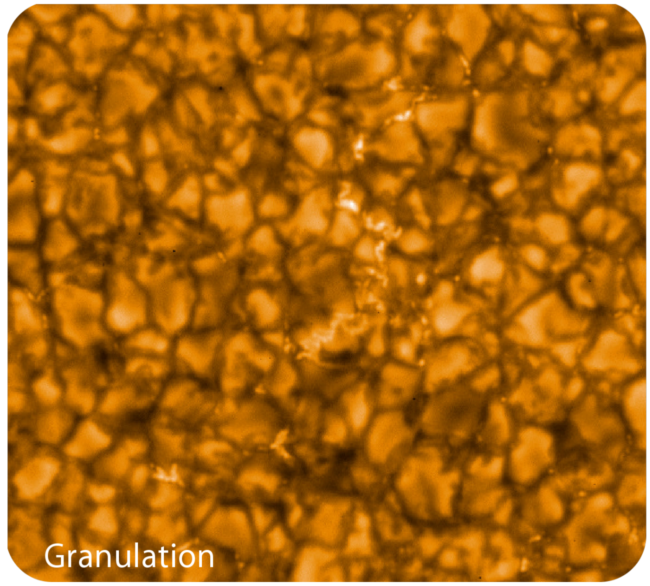


FIGURE 1.2
See Convection zone above

Check Your Understanding

What form of energy transfer is the most likely cause of sunburn?

a. conduction

b. convection

c. radiation

Answer: The answer is C. If it's a hot day and you touch any metal on a car, you might suffer a burn. This happens through conduction. If you feel a warm breeze, this is through convection. But sunburn is caused by ultraviolet radiation from the sun. As with infrared radiation, ultraviolet radiation is also invisible. It is, however, just above the threshold of human vision. And just as some animals can hear higher frequency sounds than we can (dogs, for example), other animals can see higher frequencies of light than we can (bees can see ultraviolet light).

http://www.youtube.com/watch?v=nm8RCkeUCqk

References

1. Christopher Auyeung. CK-12 Foundation .
2. Diagram: Courtesy of NASA; Granulation: Courtesy of Hinode JAXA/NASA/PPARC. Diagram: http://www.nasa.gov/mission_pages/hinode/solar_020.html; Granulation: http://www.nasa.gov/mission_pages/hinode/solar_013.html . Public Domain