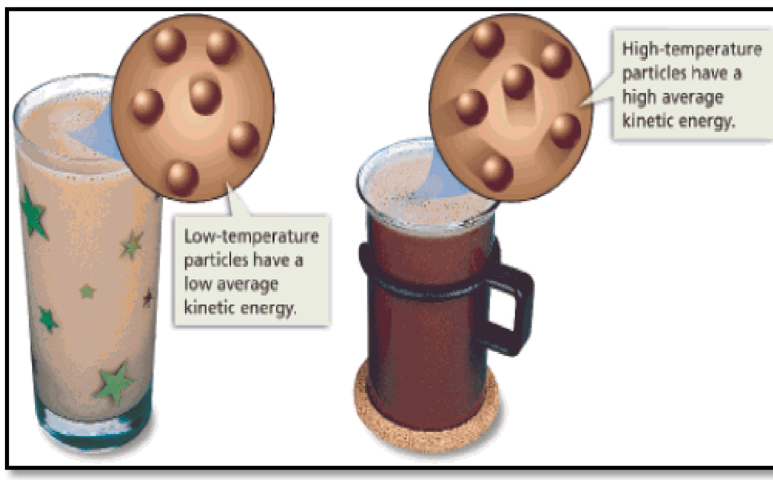
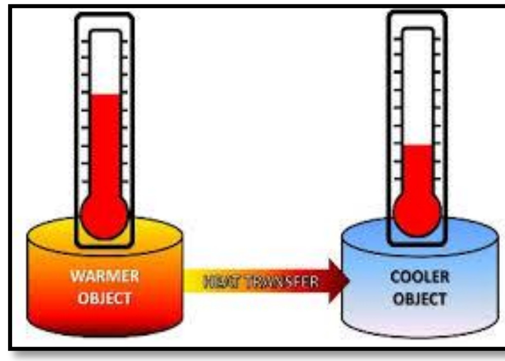
TEACHER BACKGROUND:
SPECIFICS OF HEAT TRANSFER

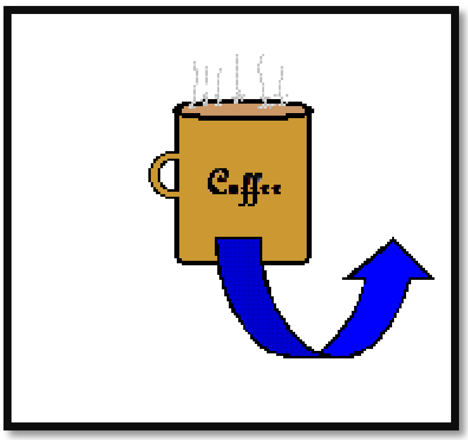
All matter consists of particles, which ***vibrate*** (wiggle about a fixed position), ***translate*** (move from one location to another) and even ***rotate*** (revolve about an imaginary axis). An object ... or a particle ... that is moving has ***kinetic energy***. A warm cup of water on a countertop may appear to be as still as can be; yet the particles that are contained within it have kinetic energy. At the particle level, there are atoms and molecules that are vibrating, rotating and moving through the space of its container. Stick a thermometer in the cup of water and you will see the evidence that the water possesses kinetic energy. The water's ***temperature***, as reflected by the thermometer's reading, is ***a measure of the average amount of kinetic energy possessed by the water molecules.***



When the temperature of an object increases, the particles that compose the object begin to move faster. They either vibrate more rapidly, rotate with greater frequency or move through space with a greater speed. Increasing the temperature causes an increase in the particle speed. So as a sample of water in a pot is heated, its molecules begin to move with greater speed and a higher thermometer reading reflects this greater speed. Similarly, if a sample of water is placed in the freezer, its molecules begin to move slower (with a lower speed) and are reflected by a lower thermometer reading. The higher the temperature of an object, the greater the tendency of that object to transfer heat. The lower the temperature of an object is, the greater the tendency of that object to be on the receiving end of the heat transfer.

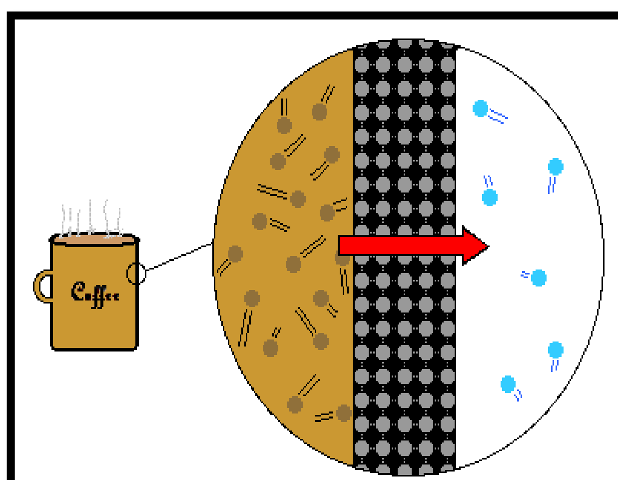
Heat is the flow of energy from a higher temperature object to a lower temperature object. It is the temperature difference between the two neighboring objects that causes this heat transfer. The heat transfer continues until the two objects have reached ***thermal equilibrium*** and are at the same temperature. Heat can move from one point to another in three basic ways: by ***conduction***, by ***radiation***, or by ***convection***.





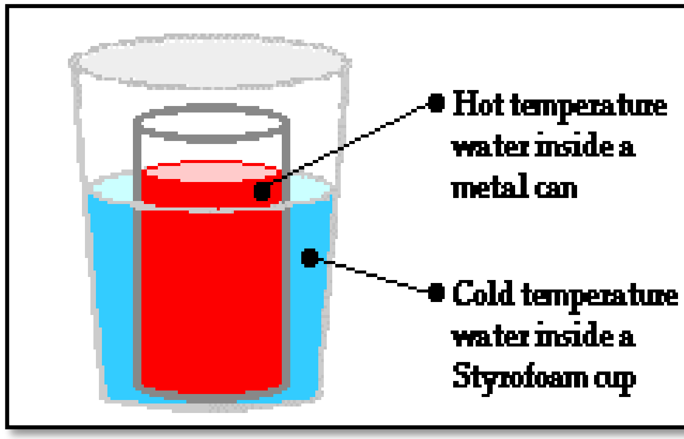
Imagine a very hot mug of coffee with a spoon in it resting on the countertop of a kitchen. That cup of coffee has a temperature very high temperature and the surroundings (countertop, air in the kitchen, etc.) have a temperature that is much lower. The cup of coffee will gradually cool down over time. At 80°C, you wouldn't even think about drinking the coffee; even the coffee mug will likely be too hot to touch. Over time, both the coffee mug and the coffee will cool down, reach a drinkable temperature and eventually reach room temperature.

The coffee and the mug are transferring heat to the surroundings. This transfer of heat occurs from the hot coffee and hot mug to the surrounding air. The fact that the coffee lowers its temperature is a sign that the average kinetic energy of its particles is decreasing. The coffee is losing energy. The mug is also lowering its temperature; the average kinetic energy of its particles is also decreasing. The mug is also losing energy. The energy that is



lost by the coffee and the mug is being transferred to the colder surroundings. This transfer of energy from the coffee and the mug to the surrounding air and countertop is ***heat***.

In a new scenario, a metal can containing hot water is placed in a Styrofoam cup containing cold water. Heat is transferred from the hot water to the cold water until both samples have the same temperature. The transfer of heat from the hot water through the metal can to the cold water is referred to as ***conduction***.

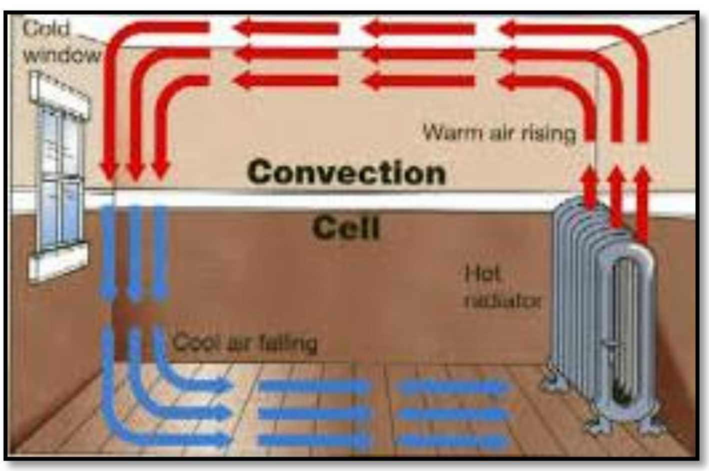


Conduction involves the transfer of heat from one location to another. There is nothing physical or material moving from the hot water to the cold water; only energy is transferred from the hot water to the cold water. Other than the loss of energy, there is nothing else escaping from the hot water and other than a gain of energy, there is nothing entering the cold water. Conduction by particle-to-particle interaction is very common in ceramic materials such as a coffee mug. Although slightly more complex, it works the same in metal objects. A good example is the high temperatures attained by the metal handle of a skillet when placed upon a stovetop. The burners on the stove transfer heat to the metal skillet. If the handle of the skillet is metallic, it also attains a high temperature, certainly high enough to cause a bad burn. The transfer of heat from the skillet to the skillet handle occurs by conduction.

Liquids and gases are ***fluids***; their particles are not fixed in place; they move around the bulk of the sample of matter. The model used for explaining heat transfer through the bulk of liquids and gases involves ***convection-the process of heat transfer from one location to the next by the movement of fluids.*** The moving fluid carries energy with it. The fluid flows from a high temperature location to a low temperature location.

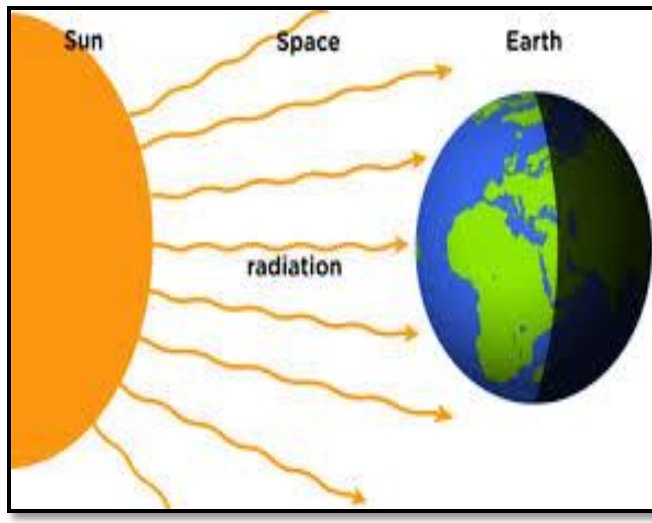
Consider the heat transfer through the water that is being heated in a pot on a stove; the source of the heat is the stove burner. The stove burner heats the metal pot that holds the water. As the metal becomes hot, it begins to conduct heat to the water. The water at the boundary with the metal pan becomes hot. Fluids expand when heated and become less dense. So as the water at the bottom of the pot becomes hot, its density decreases. Differences in water density

between the bottom of the pot and the top of the pot results in the gradual formation of ***convection currents***. Hot water **(red arrow)** begins to rise to the top of the pot displacing the colder water (blue arrow) that was originally there. The colder water that was present at the top of the pot moves towards the bottom of the pot where it is heated and begins to rise. These circulation currents slowly develop over time, providing the pathway for heated water to transfer energy from the bottom of the pot to the surface.

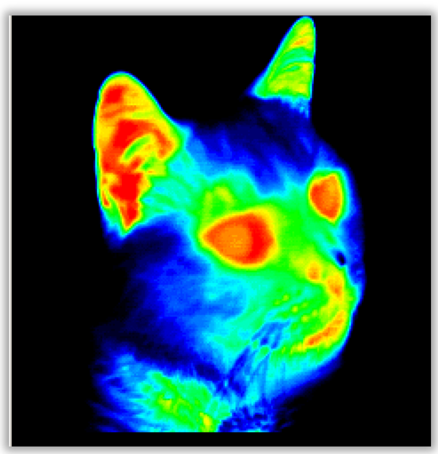


Convection also explains how a heater on the floor of a cold room warms up the air in the room. Air present near the coils of the heater warm up. As the air warms up, it expands, becomes less dense and begins to rise. As the hot air rises, it pushes some of the cold air near the top of the room out of the way. The cold air moves towards the bottom of the room to replace the hot air that has risen. As the colder air approaches the heater at the bottom of the room, it becomes warmed by the heater and begins to rise and convection currents are slowly formed.

The two examples of convection discussed here - heating water in a pot and heating air in a room - are examples of ***natural convection***. The driving force of the circulation of fluid is natural - differences in density between two locations as the result of fluid being heated at some source. Natural convection is common in nature. Earth's oceans and atmosphere are heated by natural convection. The opposite of natural convection, ***forced convection,*** involves fluid being forced from one location to another by fans, pumps and other devices. Many home heating systems involve force air heating. Air is heated at a furnace and blown by fans through ductwork and released into rooms at vent locations.



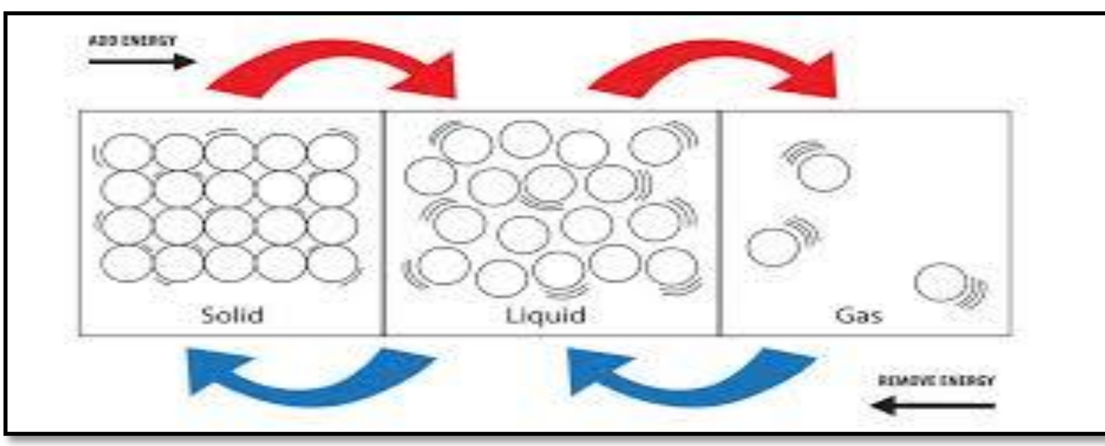
Radiation, (the final method of heat transfer), ***is the transfer of heat by means of electromagnetic waves.*** If something *radiates,* it protrudes or spreads outward from a point of origin. The transfer of heat by radiation involves the carrying of energy from an origin to the space surrounding it. The energy is carried by electromagnetic waves and does not involve the movement or the interaction of matter. Thermal radiation can occur through matter or through a region of space devoid of matter (a vacuum). In fact, the heat received on Earth from the sun is the result of electromagnetic waves traveling through the space between the Earth and the Sun.



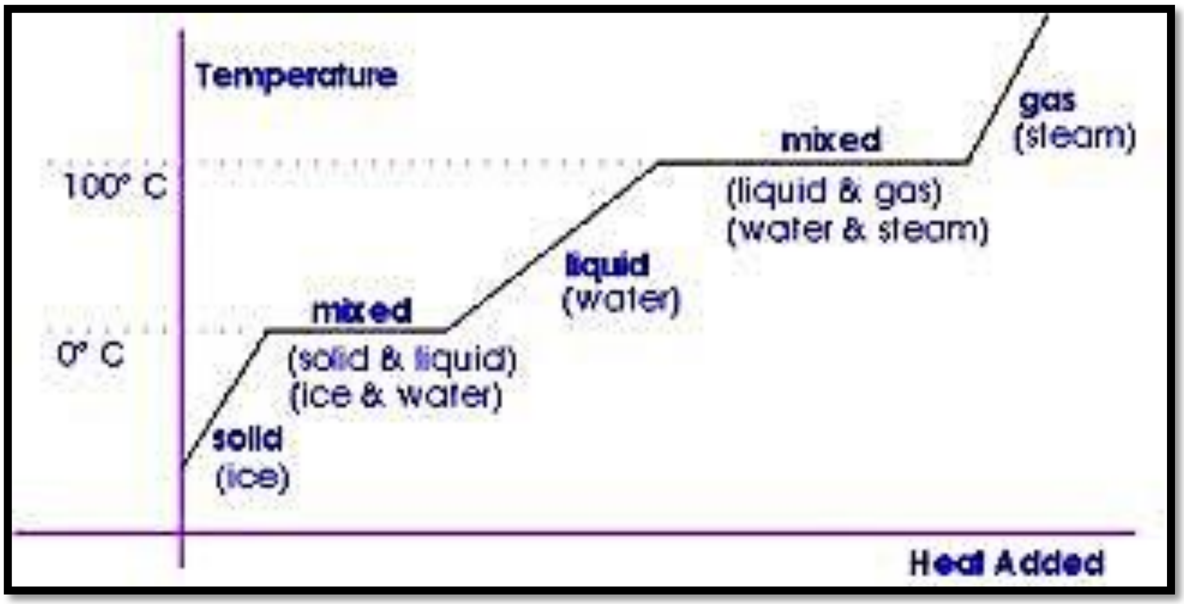
All objects radiate energy in the form of electromagnetic waves. The hotter the object, the more it radiates. The sun obviously radiates more energy than a hot mug of coffee. The temperature also affects the wavelength and frequency of the radiated waves. Objects at typical room temperature radiate energy as ***infrared waves***. Infrared energy is invisible to the human eye, but an infrared camera is capable of detecting it. Thermal photographs or videos of the radiation surrounding a person or animal or a hot mug of coffee or the Earth illustrate this method of heat transfer. The camera detects the radiation emitted by objects and represents it by means of a color photograph. The hotter colors represent areas of objects are emitting thermal radiation at a more intense rate.

Heat affects substances in different ways. First, it ***changes the temperature*** of an object. If heat is transferred from an object to the surroundings, then the object can cool down and the surroundings can warm up. When heat is transferred to an object by its surroundings, then the object can warm up and the surroundings can cool down. Heat, once absorbed as energy, contributes to the overall internal energy of the object. One form of this internal energy is kinetic energy; the particles begin to move faster, resulting in greater kinetic energy. This more vigorous motion of particles is reflected by a temperature increase. The reverse logic applies as well. Energy, once released as heat, results in a decrease in the overall internal energy of the object.

The second thing that heat does is that it contributes to ***changes in state*** of a substance. The addition of heat to a sample of matter can cause solids to turn to liquids and liquids to turn to gases. Similarly, the removal of heat from a sample of matter can cause gases to turn to liquids and liquids to turn to solids. Each of these transitions between states occur at specific temperatures - commonly referred to as melting point temperature, freezing point temperature, boiling point temperature and condensation point temperature.



For example, suppose that a sample of water is placed in a styrofoam cup with a digital thermometer. The water is then placed in the freezer (temperature = -20°C) and frozen. The thermometer can be connected to a computer with software that is capable of collecting temperature-time data. After the water has frozen and remained in the freezer for several hours, it is removed and placed in a beaker on a hot plate. The hot plate is turned on, gets hot, and begins transferring energy in the form of heat to the beaker and the water.



The sloped sections in the graph above represent heat causing a temperature change in the substance that absorbs it. The two plateau sections represent heat causing a change of state in the substance that absorbs it. At the particle level the temperature changes are the result of the added energy causing the particles of water to move more vigorously. Either the particles of solid vibrate more vigorously about their fixed positions or the particles of liquid and gas move about their container more rapidly. Either way, the addition of heat is causing an increase in the average kinetic energy of the particles in the sample of water. The changes of state are the result of the added energy causing changes in the strength of the inter-particle attractions. The attractions that hold water in the solid or in the liquid state are being overcome.