TEACHER BACKGROUND INFORMATION
THERMAL ENERGY

In general, when an object performs work on another object, it does not transfer all of its energy to that object. Some of the energy is lost as heat due to friction, but nonetheless energy was not created nor destroyed. Since frictional loss on the form of heat always occurs, it is important to understand the subject of heat in some detail.

Thermal energy, temperature and heat are all related, but they describe very different quantities. It is important to note right away, that temperature and heat are not the same thing.

TEMPERATURE

Temperature is a measure of how hot or how cold an object is compared to a reference point. On the Celsius scale, the reference point is the normal boiling and freezing points of water. One of the definitions of temperature is the following: ***Temperature*** is the average kinetic energy of molecular motion. Molecular motion is the motion of all particles in a substance (atoms, molecules, ions, etc...), not just molecules, but to simplify things we will use the term molecules. The important thing to remember about the definition is that temperature is the average energy of molecular motion; the total amount of energy would be thermal energy. For example, a hot cup of cocoa has a higher temperature than cold chocolate milk. On average, the particles are moving faster in the hot cocoa than in the cold chocolate milk. If the chocolate milk is heated, the particles will move faster and the temperature will rise.

Note: The common expression "You have a temperature" is incorrect. All objects have a temperature. What should be said is the following: "You have a higher temperature than you normally have!"

THERMAL ENERGY

Different objects at the same temperature can have different energies. Thermal energy is the total energy of all the molecules in an object. The ***thermal energy*** of an object depends on three things:

- the number of molecules in the object
- the temperature of the object (average molecular motion)
- the arrangement of the object's molecules (states of matter).

The more molecules an object has at a given temperature, the more thermal energy it has. For example, a large bucket of water at 25^{o}C has more thermal energy than a small glass of water at 25^{o}C. Now if the temperature is different but the amount of molecules is the same, the object with the higher temperature has more energy. For example, an 8 oz. glass of boiling water has more thermal energy than an 8 oz. glass of cold water.

Thermal energies differ between solids, liquids and gases (See section on matter and heat).

KINETIC ENERGY AND MATTER

According to the ***kinetic theory of matter***, matter is made up of tiny particles called molecules, and these molecules are in constant state of motion. In the matter unit, we discussed the arrangement of particles in solids, liquids and gases without discussing their motion in detail. Now that we know more about motion and energy, it is important to revisit the states of matter.

A ***gas*** has no fixed shape or volume; the electromagnetic (cohesive) forces between the molecules are so weak that they do not stay together. Thus, a gas fills any container. Within the container the gas molecules move randomly in all directions, from top to bottom to all sides. Gas pressure results from collisions between molecules, as well as collisions against the wall of the container. The collisions among gas molecules are assumed to be perfectly elastic, with both kinetic energy and momentum being conserved. Apart from the exchange of kinetic energy (work) during collisions, there are no cohesive forces acting between gas molecules, or between them and the wall.

In a ***liquid***, the molecules are much closer together than in a gas so compression is more difficult (definite volume). Although the cohesive forces (electromagnetic) between the molecules are not strong enough to hold them in fixed positions, they are strong enough to keep the molecules fairly close together. Thus, a liquid maintains its volume but takes the shape of its container. Since liquids and gases both have the ability to flow, they are referred to as fluids.

In a ***solid***, the molecules are arranged in an orderly, fixed array and are attracted to one another by relatively strong cohesive forces (electromagnetic). Solids have fixed shapes and sizes and are incompressible (definite volume). The molecules cannot move very far but vibrate about nearly fixed positions. An increase in temperature causes the molecules of a solid to vibrate faster around these positions.

HEAT

Heat is thermal energy being transferred from a warmer object to a cooler object. According to this definition, matter does not *contain* heat. Matter contains ***thermal energy***. Heat is thermal energy in transit. After heat has been transferred to an object, it ceases to be heat and becomes thermal energy. The amount of heat transferred from one object to another can be measured. The science of heat measurements is known as ***calorimetry***.

TRANSFER OF HEAT

Heat moves spontaneously ***from hot regions to cold regions*** in three ways: by ***conduction***, by ***convection***, and by ***radiation***.

It is important to know how heat is transferred at the molecular level before discussing its large-scale transfers. The molecular transfer of heat is best explained using an example such as water being heated in a beaker on a hot plate. The high-speed molecules of the hot plate strike the molecules of the beaker and transfer some of their energy through collisions and raise the temperature of the beaker. The faster-moving molecules of the beaker then collide with the cooler water molecules and increase their kinetic energy so that the temperature of the water increases as well. In this way, thermal energy (in the form of heat) was transferred from the hot plate to the water.

Note: NOT all of the energy transferred goes into increasing the translational motion of the water molecules. The molecules move from one place to another. Some of the energy increases the rotational (atoms spinning around in molecule) motion and vibrational (atoms vibrating back and forth in molecule) motion of the molecules.

On a large-scale, heat is spontaneously transferred from hot regions to cold regions by:

- **Conduction**: In the process of conduction, heat is transferred from one molecule to another without the movement of matter. With an increase in temperature, the molecules vibrate faster and transmit energy through collisions with adjacent molecules in the material. Think back to the water beaker on a hot plate, but add a spoon to this scenario. The fast-moving particles collide with the slow-moving particles, transferring heat from the hot plate to the water, and from the water to the spoon. If you were to touch the spoon, heat would be transferred to your fingers.

Metals are better conductors than nonmetals (e.g. wood), but metals differ in their conductivity (remember the conductometer!). Air and gases are quite poor conductors (insulators) of heat. The poor conductivity of air has been used to create energy efficient windows. They are made of two layers of glass, separated by an air space. This allows houses in cold climates to keep hot air from going outside; and houses in warm climates, to keep hot air from coming inside (where it's cooler).

- **Convection**: Fluids (liquids and gases) transfer heat by convection, a process that causes mixing of the warmer regions with the cooler regions of the liquid or gas. Going back to the example of the beaker of water on a hot plate, the bottom-most layer of water is heated by conduction and the fast moving particles move apart, so the water expands. The increase in volume (expansion) lowers the density of the warm water at the bottom, feeling less pressure from gravity, the warm water moves up and the cooler, denser water moves down to replace it. With convection, the particles in the material move, carrying thermal energy with them.

In the presence of gravity, convection involves the flow of hot material up (less dense) and cold material down (more dense). Large-scale motions on and within the Earth are caused by convection: flow of air in the atmosphere, water in the ocean, and rock and metal within the mantle and core.

The main difference between convection and conduction is that convection involves the movement of matter and conduction does not.

- **Radiation:** is the transfer of energy by electromagnetic waves. You can feel the radiation from a fireplace all the way across a room. Radiation is also what takes place in a microwave. In a microwave oven, microwaves (electromagnetic radiation), pass through plastic and ceramic dishes but are absorbed by water molecules in food. The radiation causes the water molecules to vibrate faster and increase the temperature of the food. This is why old popcorn needs to be soaked in water in order to pop again!

Radiation only cooks the outer layers of the food. Heat is then conducted to the interior, cooking the food throughout.

Unlike conduction and convection, radiation *does not require matter* to transfer thermal energy. All of the sun's energy that reaches Earth travels through millions of kilometers of empty space. With radiation, electromagnetic waves radiate away from a hot region.

CHANGES OF STATE OF MATTER

The state of matter depends on the amount of thermal energy it has. The more the thermal energy matter has, the faster its molecules move. Matter can physically change from one state to another when thermal energy is absorbed or released. Figure 1 shows that as thermal energy increases, matter changes from a solid to liquid and then to a gas. The opposite happens if thermal energy is removed from it. The flat regions of the graph show thermal energy being added but temperature remaining the same. Under these conditions, matter is changing state. During a change of state, the addition or loss of thermal energy is not used to move the particles faster, rather it is used to change the arrangement of molecules (overcoming cohesive forces between molecules). Since temperature is a measure of average kinetic energy of molecular motion, temperature does not change when the state of matter changes.

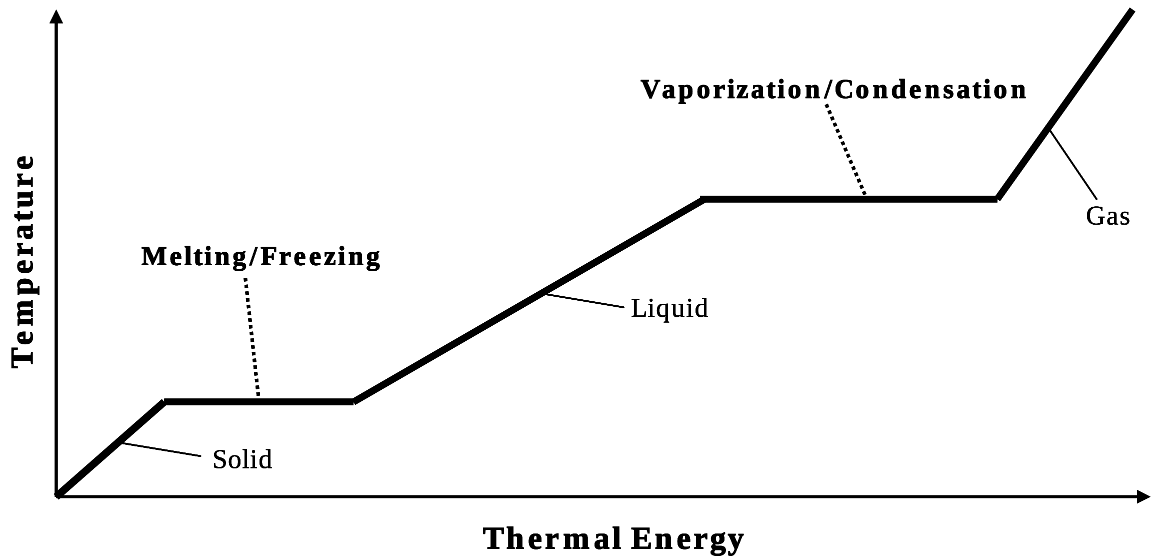

Figure 1 – Thermal energy and temperature change as matter changes from one state to another. Notice- the areas where phase change occurs have a constant temperature.

- **Solid-Liquid Changes of State**:

Melting occurs when a solid absorbs thermal energy. As the thermal energy of the solid increases, the molecules vibrate faster and faster about their normal positions. The vibrations become so strong that the molecules break out of their fixed positions and start rolling over one another. During melting, the temperature does not change. Instead, work must be done to overcome the cohesive forces (electromagnetic) between the molecules.

Freezing occurs when a liquid releases thermal energy. As the thermal energy of the liquid decreases, the molecules slow down. Eventually the molecules slow down so much that they can no longer slide past each other and they stay in fixed positions. During freezing, the temperature does not change. Instead, the molecules can no longer overcome the cohesive forces (electromagnetic) between them. This process releases energy, and requires energy to be reversed (melting).

- **Liquid-Gas Changes of State**:

Vaporization occurs when a liquid absorbs thermal energy. As the thermal energy of the liquid increases, the molecules vibrate and move faster and faster. During vaporization (boiling), the temperature does not change; instead the molecules are overcoming the cohesive forces between them. Without the attractive forces, the molecules are no longer confined to the limited volume of the liquid, so they move out in all directions as a gas. The work done against these cohesive forces raises the potential energy of the molecules.

Condensation occurs when a gas releases thermal energy. As the thermal energy of the gas decreases, the molecules slow down. Eventually the molecules slow down so much that they are clumped together because they don’t have enough energy to overcome the cohesive forces between them. During condensation, the temperature does not change. Instead, the energy goes into arranging the molecules as a liquid. This process absorbs energy.

THERMAL EXPANSION

As thermal energy of matter increases, its particles spread out and the substance expands, or increases in volume. With a few exceptions (e.g. water), this is true for all matter, even when matter is not changing state. The expanding of matter when it is heated is known as **thermal expansion**.

When matter is cooled and releases thermal energy, the molecules slow down and move closer together. In nearly all cases, as matter is cooled, it contracts, or decreases in volume.

MATTER AND ENERGY

Albert Einstein's theory of relativity states that energy *can* sometimes be created by destroying matter. Just as one form of energy can be transformed from one form to another, Einstein discovered that matter can be transformed to energy. Looking at Einstein's famous formula shows that energy and matter (anything that has mass) are related:

$E = mC^2$ E is energy, m is mass, and C is the speed of light

The law of conservation of energy had to be adjusted because in some situations, energy alone is not conserved. Since matter can be transformed to energy, scientists say matter and energy together are always conserved.

You experience matter being converted to energy everyday in your car. The matter you put into your car is gasoline and when you fill up your tank it has a mass of about 30 kg (same as 30 liters). When gasoline undergoes a chemical change, some of the gasoline is converted to exhaust and some of it into energy. Matter was not conserved during the chemical reaction because the exhaust does not have the same mass as the gasoline (30 kg), so some of that matter had to be converted into energy.