TOPIC V
ENERGY IN EARTH PROCESSES

The steam and boiling water that erupt from the Old Faithful geyser in Yellowstone National Park are heated by geothermal energy.

CHAPTER 8

You will know something about energy in earth processes if you can:

1. Describe the properties of electromagnetic energy.
2. Explain how energy is transferred.
3. Explain the difference between heat and temperature.
4. Explain how energy is conserved.
5. Describe the various ways in which energy can be transformed from one kind to another.

As we have already noted, little, if anything, happens in this world without energy. We are going to run into energy every time we start to examine an earth process. So it will help to get a clearer idea of what we mean by energy, what its properties are, its different forms, where it comes from and where it goes, and so on. This chapter is about energy and its relation to the earth.

ENERGY

Energy is defined as the capacity to do work. This statement basically means that energy is needed to make something move against a resisting force. Energy cannot be observed or measured unless a change is occurring. Even then, only a *change* in energy is observed. During these changes, one body or system usually loses energy while another gains energy.

Kinds of Energy. Energy appears in many different forms during processes of change, but it always represents a capacity for doing work. *Electrical energy,* for example, is the energy in an electric current; this energy can be used to run a motor.

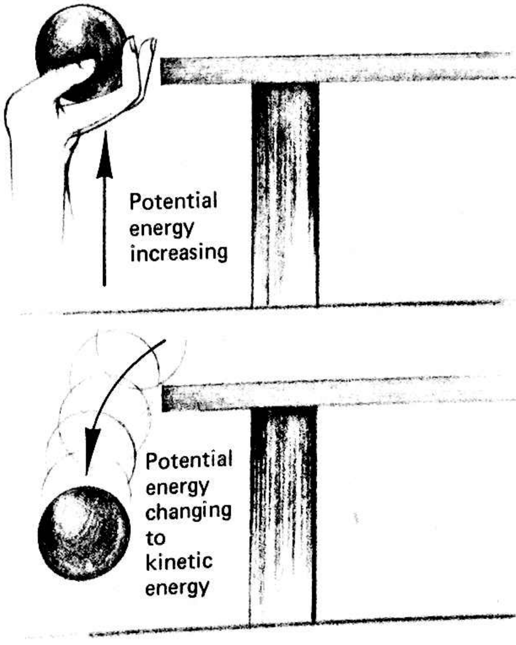
An important form of energy is the energy of a moving body. This is called *kinetic energy.* The kinetic energy of a hammer, for example, can drive a nail into wood. The kinetic energy of the random motion of molecules of matter is often called *heat energy,* or *thermal energy.*

Another important concept is that of *potential energy.* This is the energy that a body has because of its position or state. As objects are lifted against gravity, they acquire more potential energy. This energy can be released when the objects fall (see Figure 8-1). Water at the top of a dam has more potential energy than the same amount of water at the base of the dam. If water flows down over a water wheel or through a turbine, the change in its potential energy can be used to do work. When a body falls freely, some of its potential energy changes to kinetic energy.

Electromagnetic Energy. *Electromagnetic energy* is a form of energy that can travel through empty space. It can then interact with matter, be changed to other forms, and do work. Visible light is one kind of electromagnetic energy. X rays, ultraviolet rays, infrared rays, and radio waves are other examples.

Everything in the world—even you—gives off electromagnetic energy. The amount of energy given off by an object varies with its temperature. The hotter the object, the more electromagnetic energy it gives off. The colder the object, the less energy it gives off.

Figure 8-1. Potential and kinetic energy. When the ball is lifted against gravity, its potential energy is increased. When the ball drops, some of this potential energy is transformed to kinetic energy.



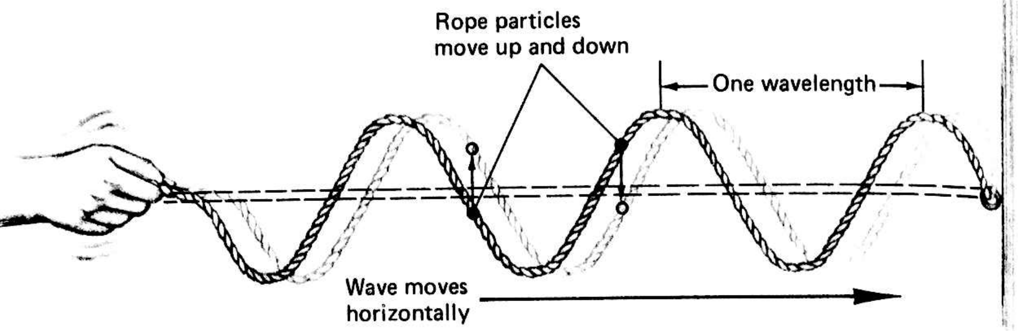


Figure 8-2. A transverse wave in a rope at two moments a short time apart. As the particles of the rope move up and down, the form of the wave moves to the right. In an electromagnetic wave, there are no moving particles. Instead, there are varying electric and magnetic forces at right angles to the direction of propagation of the waves.

The source of electromagnetic energy is the kinetic energy of moving atoms, molecules, and other particles of matter. As the temperature decreases, the movements of these particles, and hence their kinetic energy, become less. The less the kinetic energy of the particles, the less the electromagnetic energy that is given off. At *absolute zero,* which is theoretically the lowest temperature possible, the particles of matter would have no kinetic energy, and no electromagnetic energy would be given off.

All forms of electromagnetic energy travel in *transverse waves.* This means that the waves vibrate at right angles to the direction in which they are moving (see Figure 8-2). You can see what we mean by a transverse wave if you tie one end of a rope to a solid object and shake the loose end of the rope up and down. The particles of the rope move up and down while the wave passes along the length of the rope. The direction of travel of an electromagnetic wave is often shown by a straight-line arrow called a *ray.*

Since electromagnetic waves travel through empty space, there is nothing actually vibrating in such a wave. Instead, there are electric and magnetic forces that vary in a regular manner as the wave passes. These electric and magnetic forces are directed at right angles to the direction of the wave. Electromagnetic waves are often called *electromagnetic radiation,* or simply *radiation.*

Speed of Electromagnetic Waves. All electromagnetic waves travel through space at a constant speed of approximately 3 × 10^8 m/sec. This is often called the "speed of light."

The Electromagnetic Spectrum. As we have mentioned, there are many different types of electromagnetic energy, or radiation. The various forms of electromagnetic energy are distinguished from one another by differences in their *wavelengths.* The wavelength is the distance between the *crest,* or peak, of one wave, and the crest of the next wave (see Figure 8-2). The shorter this distance, the shorter the wavelength.

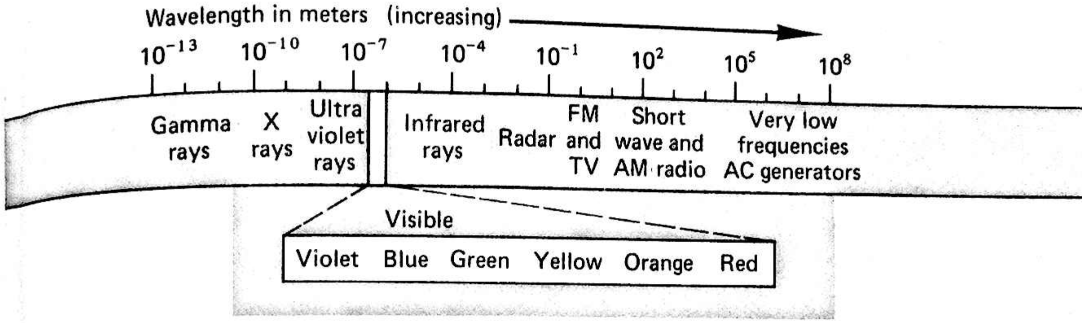


Figure 8-3. The electromagnetic spectrum. Wavelengths are indicated on a logarithmic scale, in which each mark indicates a wavelength 10 times as great as the preceding one. There is no zero point on such a scale.

Figure 8-3 shows the different forms of electromagnetic energy arranged in order of increasing wavelength. The entire range of electromagnetic radiations is called the *electromagnetic spectrum.* You may be familiar with the word "spectrum" as it applies to the colors of the rainbow, from red at one end to violet at the other. This is the spectrum of visible light. You can see from Figure 8-3 that visible light accounts for only a small portion of the much wider spectrum that includes all electromagnetic radiation.

We have already noted that the total amount of electromagnetic energy given off by a body depends on its temperature. The distribution of this energy among the various wavelengths also varies with the temperature of the radiating body. Cool objects give off relatively little electromagnetic energy, and their radiation is mostly of longer wavelengths. As the temperature of an object increases, the amount of electromagnetic energy given off increases, and more and more of the radiation is of shorter wavelengths, and less and less of longer wavelengths.

Interaction of Electromagnetic Radiation with the Environment. When electromagnetic waves come into contact with matter, the waves interact with the particles of the material. There are four possible results of this interaction: (1) The waves can be *refracted,* which means that their direction is changed as they pass through the material. (We say that the waves have been "bent.") (2) The waves can be *reflected,* which means that they are bounced back. Reflected waves do not pass through the material. (3) The waves can be *scattered,* which means that they are reflected and/or refracted in various directions. (4) The waves can be *absorbed,* which means that their energy is taken into the material.

What happens to electromagnetic waves when they interact with matter depends both on the types of radiation (wavelengths) involved and the nature of the material. In most cases, all four of the possible interactions occur in varying degrees.

Electromagnetic energy may also pass through matter without interacting with it. In this case we say that the energy has been *transmitted.*

SUMMARY

1. Kinetic energy is the energy of a moving body. Potential energy is the energy of the position or state of the body.
2. All objects at temperatures above absolute zero give off electromagnetic energy.
3. Electromagnetic energy travels in transverse waves of electric and magnetic forces.
4. The speed of electromagnetic waves through empty space (also called the speed of light) has a constant value of approximately 3×10^8 m/sec.
5. The various forms of electromagnetic energy are distinguished from one another by differences in their wavelengths.
6. All the various forms of electromagnetic energy make up the electromagnetic spectrum.
7. When electromagnetic radiation interacts with matter it may be refracted, reflected, scattered, or absorbed.

ENERGY TRANSFER

We have previously stated that all earth processes involve a transfer of energy. Let's examine some of the ways in which energy is transferred from one place to another or from one body to another.

Radiation. As you have just learned from the preceding section, energy can be transferred across empty space in the form of electromagnetic waves. This method of energy transfer is called *radiation*. (The term "radiation" is used rather loosely. Sometimes it means the energy itself; sometimes it means the process of *giving off* electromagnetic energy; and sometimes—as we are using it now—it means the transfer of energy by electromagnetic waves.)

Atomic reactions inside the sun are continuously releasing enormous amounts of energy. This energy *radiates* from the sun in all directions, traveling in the form of electromagnetic waves at the speed of light, 3×10^8 m/sec. Only a small fraction of the sun's total radiation is intercepted by the earth. However, this energy that reaches us by radiation from the sun is the earth's major source of energy.

Electromagnetic energy can be transferred by radiation here on earth, as well as in space. When you turn on an electric light, the light reaches your eyes by radiation. Heat from a campfire is energy reaching you primarily by radiation (see Figure 8-4).

Conduction. Did you ever wonder why the metal handle of a frying pan gets so hot even though it's not in the flame? How did the heat get from the fire out to the end of the handle? You'd probably say that it traveled through the metal. And you would be right! This form of energy transfer is called *conduction*. Conduction is a method of energy transfer in which heat energy is passed from atom to atom or from molecule to molecule through collisions.

Let's see what actually happens to our frying pan when the stove is turned on. One point you should remember is that when matter is heated, its molecules and atoms move faster and faster, because they are gaining energy. So when a burner is turned on, the areas of the pan directly over the flames or in contact with the electric coils immediately begin to heat up. The molecules in these areas move faster and faster. These fast-moving molecules collide with neighboring molecules and transmit some of their energy to them. The neighboring molecules then collide with still other molecules, and so on. In this way heat is transmitted throughout the pan.

Figure 8-4. Transfer of heat. Heat from the fire is being transferred in several different ways in this picture. Can you identify them?

Heat energy can be transferrred by conduction through solids, liquids, or gases. However, the solid form of any material usually conducts heat more effectively than the liquid or gaseous forms. The main reason for this is that the atoms or molecules of a solid are held together by strong forces of attraction. In a liquid or gas, the particles move more freely. Therefore, the motion of each particle in a solid has a greater effect on its neighbors than the motion of particles in liquids and gases.

Convection. Did you ever stand on a stool in the kitchen while the oven was on? Did you notice that the air felt much warmer near the ceiling than it did near the floor? You'd probably find the same thing if you measured the air temperature near the floor and near the ceiling of your classroom. Why does this happen? It happens because of the process called *convection*. Of the methods of energy transfer, convection is probably the least direct, and therefore may seem to be most complex. Let's analyze it in some detail.

The air around a stove or radiator is warmed by conduction. The warm air expands, and in expanding, becomes less dense. This less dense, warm air is forced upward by the surrounding cooler, denser air, which moves in underneath it.

When the warm air reaches the ceiling, it spreads out horizontally and begins to give up its heat to the cooler

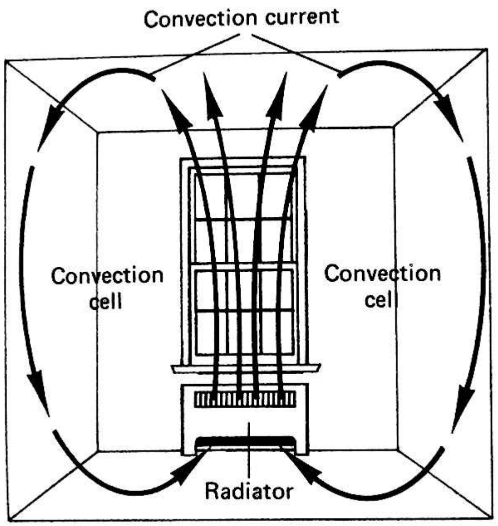


Figure 8-5. Heating a room by convection. The air around the radiator is heated by conduction. The heat is then carried around the room by circulatory movements of the air—convection currents.

ceiling and the surrounding air. As the air loses heat, its temperature drops. Its density increases. After a time, the cooled-off, and now more dense air sinks once more toward the floor. The rising of the heated air and sinking of the cooler air results in a circulatory motion of the air as a whole (see Figure 8-5).

If you think a moment about what is happening, you will see that the circulatory movement of the air is transferring heat energy from one place to another. The heat is entering the air near the source and is being carried upward by the moving air. This kind of circulatory movement can occur in any fluid—either a gas or a liquid. Convection can be defined as the transfer of heat by circulatory movements of a fluid, caused by differences in temperature and density in different regions of the fluid. The moving masses of fluid are called *convection cells,* or *convection currents.* It is the convection currents that actually do the job of transferring heat.

Rooms heated by "radiators" are actually heated by convection. The air around the radiator is warmed, and the heat is distributed around the room by convection currents in the air.

Heat is transferred through the atmosphere and the hydrosphere of the earth by convection currents. It is believed that convection may also occur in the earth's *mantle,* which is the rock layer beneath the lithosphere, or outer crust.

SUMMARY

1. Radiation is a method of energy transfer in which electromagnetic energy travels across empty space in the form of transverse waves.
2. Conduction is the transfer of heat energy from atom to atom or molecule to molecule through contact when the atoms or molecules collide.
3. Convection is the transfer of heat by movements in gases and liquids. These movements are caused by differences in density within the gas or liquid.
4. In convection, heat is transferred from one place to another by a circulatory motion called a convection cell, or convection current.

HEAT AND TEMPERATURE

We have been using the terms "heat" and "heat energy" without being very careful to explain just what they mean. Because heat is such an important concept in earth science, it will help to state more clearly just what we mean by it. At the same time we will find out what we mean by temperature, how it differs from heat, and how the two terms are related.

Temperature. All matter is made up of particles that are in a state of continuous, random motion. Because the particles are in motion, they have kinetic energy. At any moment, the kinetic energies of the individual particles vary widely. *Temperature* is a measure of the *average* kinetic energy of the particles of a substance. The higher the average kinetic energy, the higher the temperature. The lower the average kinetic energy, the lower the temperature. The particles of all objects at the same temperature have the same average kinetic energy.

Heat. What happens when you put a hot object into a container of cold water? The hot object cools off, and the water warms up. Why? Some of the kinetic energy from the particles of the hot object is transferred to the particles of the cold water. As a result, the average kinetic energy of the particles of the hot object decreases. In other words, its temperature drops. At the same time, the average kinetic energy of the particles of water increases. In other words, the temperature of the water rises. This transfer of energy continues until the particles of the object and the water have the same average kinetic energy, that is, until the object and the water have the same temperature.

Whenever two bodies of matter have different temperatures, energy will flow from the hotter one to the colder one. This energy that flows from one body to another because they have different temperatures is called *heat.* A gas flame is hotter than a pot of water; heat flows from the flame to the pot. The sun is hotter than the earth; heat flows from the sun to the earth.

We have already seen that there are three basic processes by which heat energy can be transferred—radiation, conduction, and convection. But whatever the transfer process is, the energy flow is always from hot to cold—from higher temperature to lower temperature.

Sources and Sinks. A body or region from which heat energy is flowing is sometimes called a heat *source.* A body or region into which heat is flowing is sometimes called a heat *sink.* The concept of sources and sinks is a useful one.

SUMMARY

1. Temperature is a measurement of the average kinetic energy of the particles of a substance.
2. Heat is energy that is transferred from a hotter object to a cooler object because of a difference in temperature.
3. Heat energy flows from a region called a source to a region called a sink.

CONSERVING QUANTITIES OF HEAT

Heat, Mass, and Temperature Change. As we have just seen, an increase in temperature of a body requires an increase in the average kinetic energy of its particles. This means that energy must be added to a body to raise its temperature. In fact, to raise its temperature 2°C will require twice as much total energy as to raise it only 1°C. It is also fairly easy to see that to raise the temperature of 2 grams of a substance by 1°C will require twice as much energy as to raise only 1 gram by 1°C. The reason for this is that 2 grams have twice as many particles as 1 gram. Thus the total amount of heat energy needed to raise the temperature of an object is proportional to both the mass of the object and the desired temperature change.

Measuring Amounts of Heat. Amounts of heat can be measured by making use of the ideas of the preceding paragraph. The unit of heat energy is the *calorie*. You're probably familiar with the term already because it is commonly used to express the energy content of foods. One calorie is the amount of heat needed to raise the temperature of one gram of liquid water by one degree Celsius.

It takes 1 calorie to raise the temperature of 1 g of liquid water by 1°C. How many calories does it take to raise the temperature of 2 g of water by 1°C? If you said 2 calories, you were correct. It takes twice as much heat to raise the temperature of 2 g of a substance by 1°C as it does for 1 g of the same substance.

How many calories would it take to raise the temperature of 1 g of water by 2°C? If you said 2 calories, you were correct again. It takes twice as much heat to raise the temperature of 1 g of a substance by 2°C as it does to raise it by 1°C.

For a given substance, the amount of heat involved in a temperature change is directly proportional to the amount of the temperature change and to the mass of the substance.

Specific Heat. You know that 1 calorie of heat will raise the temperature of 1 g of liquid water by 1°C. But how does the same amount of heat affect 1 gram of other substances? Will their temperatures also be raised 1°C by 1 calorie?

Suppose we take a piece of lead, a piece of iron, and a piece of rock, all with the same mass and all at the same starting temperature. We put them in separate containers, and we heat the three different materials from the same source and for the same period of time. At the end of the heating time you would probably find that the lead was much warmer than either the rock or the iron. In fact, all three substances would probably be at different temperatures.

Different substances heat up at different rates. The amount of heat needed to raise the temperature of a substance by a given number of degrees is a characteristic of the substance.

The amount of heat needed to raise the temperature of one gram of a substance one degree Celsius is called the *specific heat* of that substance. The specific heat of water is 1 cal/g/°C. It takes 1 calorie to raise the temperature of 1 g of water 1°C. If you have a substance that has a specific heat of 0.3 cal/g/°C, you would have to add 0.3 calorie to raise the temperature of 1 g of that substance 1°C.

Substance	Specific heat in cal./g./°C.
Water	1.0
Ice	.5
Water vapor	.5
Dry air	.24
Basalt	.20
Granite	.19
Iron	.11
Copper	.09
Lead	.03

Table 8-1. Specific heats of some common substances.

Liquid water has the highest specific heat of all naturally occurring substances. This means that all other natural substances heat up (and cool off) more rapidly than water. Table 8-1 gives the specific heats of some common substances.

Heat Calculations. If you want to calculate the amount of heat gained or lost by a substance during a temperature change, you must know the specific heat of the substance. You must also know the mass of the substance, and the number of degrees the temperature changed. The heat lost or gained (in calories) can be calculated using the formula given in the example below.

Conservation of Energy. Many observations and experiments have led scientists to an important law concerning energy. This law states that in any transfer of energy, the total amount of energy remains the same. That is, the energy lost by a source equals the energy gained by a sink. This is called the *law of conservation of energy*.

Let's conduct an experiment in which we will transfer heat from a heat source to a heat sink. We will then calculate how much heat left the source and how much entered the sink, and see if our results agree with the law of conservation of energy.

The experiment involves two containers connected by an aluminum

EXAMPLE OF HEAT CALCULATION

The temperature of a piece of metal is raised from 20°C to 100°C. Its mass is 30 g and its specific heat is 0.1 calorie/g/°C. How much heat in calories was added to the metal?

Number of calories = temperature change x mass x specific heat

The temperature changed from 20°C to 100°C.

The temperature change was: 100°C − 20°C = 80°C

The mass of the object: 30 grams

Specific heat of the material: 0.1 calorie/gram/°C

The number of calories transferred =

temperature change x mass x specific heat:

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80°C x 30g x 0.1 calorie/gram/°C = 240 calories

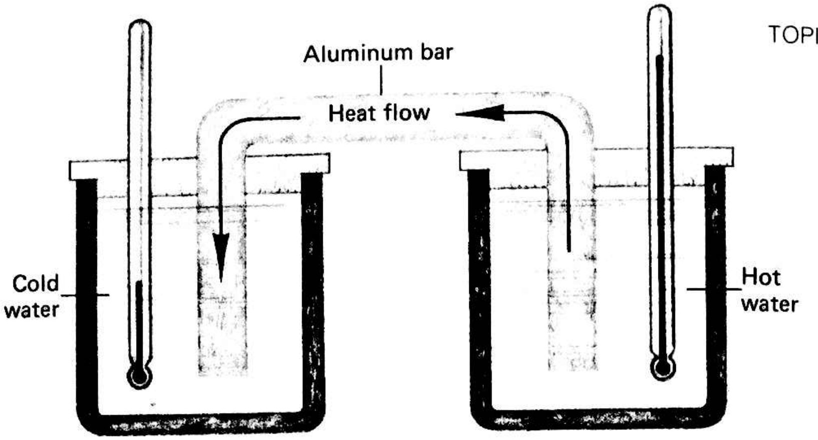


Figure 8-6. Conservation of energy. In this experiment we can observe the flow of heat from a source—the warmer water—to a sink—the cooler water.

bar, as shown in Figure 8-6. The containers are made of Styrofoam or some other material that is a poor conductor of heat (a good insulator). One container is filled with hot water; the other, with cold water. Each container has a thermometer fitted through an insulating cover. To simplify matters, we will make the mass of water the same in each container.

Since the water in one container is at a higher temperature than the water in the other, and since there is a way for heat to flow from one container to the other (by conduction through the aluminum bar), we know that heat will do so. (The rule of nature says that if a way exists, heat will always flow from a hotter body to a colder one.)

We record the masses of water and the two temperatures at the start of the experiment. We then read the temperatures every minute. Knowing the mass of water in each container and the observed temperature changes, we can then calculate the heat loss and heat gain at every stage of the experiment. When we do this in a practical case, we find that the amount of heat gained by the cool water is almost—but not quite—as much as the amount of heat lost by the hot water. Theoretically, the two quantities of heat should be equal. The heat lost by a source should equal the heat gained by a sink. What has happened to the "missing" energy?

You probably know the answer. Some heat did leave the hot water through the walls of the container and was lost to the surroundings. Some heat also left the aluminum bar by conduction and convection of the air. The law of conservation of energy applies only to what is called a *closed system.* A closed system is one in which energy can neither enter nor leave. The two containers and their metal connector did not form a closed system.

If we cover the metal bar with Styrofoam or some other heat-insulating material and repeat the experiment, we will get a better agreement with the theoretical result. We have brought the system closer to being a closed one, and so less energy is "lost." In our earth science investigations, we will never be dealing with a completely closed system, but we will try to approach that ideal situation as nearly as we can.

SUMMARY

1. The amount of heat involved in a temperature change is directly proportional to the amount of the temperature change and to the mass of the substance.
2. A calorie is the amount of heat needed to raise the temperature of one gram of liquid water by one degree Celsius.
3. The specific heat of a substance is the amount of heat needed to raise the temperature of one gram of that substance by one degree Celsius.
4. Water has the highest specific heat of all naturally occurring materials.
5. Heat lost or gained (in calories) is equal to the mass (in grams) times the amount of temperature change (in degrees Celsius) times the specific heat (in calories per gram per degree).
6. When heat is transferred in a closed system, the heat energy lost by the source (or sources) equals the heat energy gained by the sink (or sinks).

LATENT HEAT

Latent Heat of Fusion. Suppose we take some ice that is below its melting point (0°C). If the ice has been crushed or broken into small pieces, we can stick a thermometer into it and read its temperature. Let's now begin to add heat to the ice, and observe the changes in its temperature. As you would expect, the temperature of the ice begins to increase. This means that the heat energy being transferred to the ice is causing the average kinetic energy of its molecules to increase. The rate of increase of temperature depends on the usual three factors: the rate at which energy is being transferred; the mass of the ice; and its specific heat (about 0.5 cal/g/°C—lower than that of liquid water).

When the temperature of the ice reaches exactly 0°C, it begins to melt. This is no surprise. What *is* surprising is that while the ice is melting, the temperature does not change! Even though we are continuing to add heat at the same rate as before, the temperature of the melting ice remains at 0°C. In other words, the added energy is no longer being transformed into additional kinetic energy of the ice molecules. What is happening to the energy going into the melting ice?

To answer this question, you must know something about the structure of ice. Ice is a *crystalline* solid. That is, its molecules are arranged in a regular, repeating fashion. As the temperature of the ice increases up to 0°C, the added heat energy is transformed into kinetic energy. The molecules in the ice crystal vibrate more and more rapidly, but they do not break out of the crystal pattern.

When the temperature of the ice reaches 0°C, some of the molecules acquire enough kinetic energy to break free of the rigid ice structure. The ice then begins to melt and enter the liquid state. However, it takes energy to break up the crystal structure. While the ice is melting, all the heat energy that enters the ice is used to break up the crystal structure.

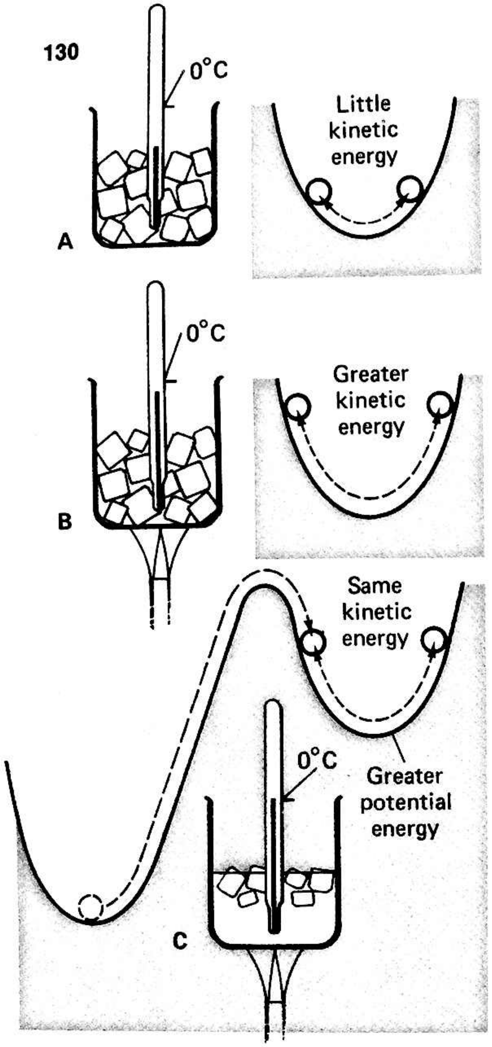


Figure 8-7. Latent heat of fusion. (A) In ice below 0°C, the molecules vibrate back and forth around fixed positions in the crystal. This is like a ball rolling from side to side at the bottom of a trough.

(B) As ice is heated toward 0°C, its molecules vibrate with greater average kinetic energy. This is like giving the ball more kinetic energy. It rides up higher on the sides of the trough, but stays in the trough.

(C) When ice reaches 0°C, it begins to melt. While the ice is melting, the molecules of water are not gaining kinetic energy. They are moving to positions of greater potential energy. This is like giving the ball enough energy to ride up to a trough at a higher level.

None of it goes into increased kinetic energy until the melting process is completed (see Figure 8-7). If heat is added slowly enough, and if there is constant mixing to distribute the heat uniformly, the temperature of the ice-water mixture remains constant at 0°C while the melting is going on. (In an actual experiment, these ideal conditions are usually not maintained, and the temperature does rise slightly before the ice is completely melted.)

The energy transferred during the melting process is transformed into a kind of potential energy called *latent heat*. This is energy that the ice molecules have as a result of changes in their relative positions. The fact that the energy is still there can be shown by letting the water freeze again. The same amount of energy that was stored as latent heat during melting, is released during freezing. This energy is called the *latent heat of fusion*.

Latent Heat of Vaporization. If we continue to add heat after the ice has melted, the thermometer again shows a steady rise in temperature. The added heat is again being transformed into increased kinetic energy of the water molecules.

When the water temperature reaches 100°C (under normal atmospheric pressure), the water begins to boil. It is entering the gaseous state. Once again the temperature stops increasing. And again the transformation of heat to kinetic energy stops, and transformation of heat to potential energy (latent heat) starts.

As in the case of melting, the energy transferred during boiling is being used to change the structure of the substance, that is, to change the relative positions of its molecules. Molecules of water are breaking free of their neighbors in the liquid. These molecules escape into the air and form a gas called water vapor. This process of changing from the liquid state to the gaseous state is called *vaporization*. It requires an input of energy called the *latent heat of vaporization*. The latent heat stored as potential energy during vaporization is returned to the environment when the water vapor condenses to a liquid.

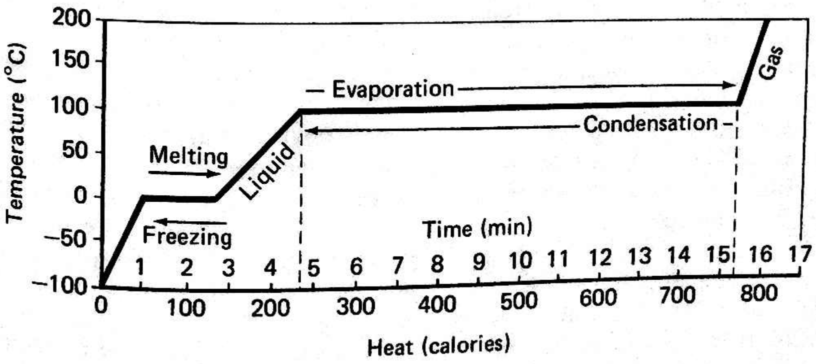
Vaporization of a liquid can occur below the boiling point. It occurs continuously from the surface of any liquid, at any temperature, and is called *evaporation*. Evaporation also involves a transformation of energy to potential energy or latent heat. The chief difference between boiling and evaporation is that in boiling, the vaporization occurs in the interior of the liquid, forming bubbles of vapor. Ordinary evaporation occurs only at the interface between the liquid and its environment.

Although water can evaporate at temperatures below the boiling point, it can't boil unless the water vapor has enough pressure to form bubbles inside the liquid. At normal atmospheric pressure, this happens at 100°C. At lower pressures (for example, on mountaintops), water boils at lower temperatures. In a pressure cooker, water boils at a higher temperature.

Heating Curves. While a substance remains in a single state, either solid, liquid, or gas, added heat energy is transformed into kinetic energy, which raises the temperature of the substance. However, while a substance is changing state from a solid to a liquid or from a liquid to a gas, added heat energy is transformed into potential energy (latent heat), and there is no increase in temperature. While a substance is changing state from a gas to a liquid or from a liquid to a solid, latent heat is released.

These observations are illustrated by the *heating curve* for water, Figure 8-8. This is a graph of the temperature of water (in its three states) as heat is added or removed at a fixed rate. The flat portions are periods of constant

Figure 8-8. Heating curve for water. The graph shows the temperature change of 1 gram of water as heat is added at a constant rate (50 calories per minute). If read from right to left, the graph is the corresponding cooling curve.



temperature during change of state.

You can see from Figure 8-8 that it takes a great deal more heat to change liquid water to water vapor than it does to change ice to liquid water. In fact, it takes nearly seven times the amount of heat. The latent heat for the change from ice to liquid water is 80 calories/gram, while the latent heat for the change from liquid water to water vapor is 540 calories/gram.

Heat Lost or Gained in Change of State. When a substance is changing state from a solid to a liquid or from a liquid to a gas, it must gain latent heat. When a substance is changing state from a gas to a liquid or from a liquid to a solid, it must lose latent heat. The amount of heat gained or lost during a change of state is equal to the product of the mass times the latent heat per unit mass.

SUMMARY

1. For a change in state to occur, there must be a loss or gain of energy.
2. While a substance remains in a single state, added heat energy is transformed into kinetic energy, which raises the temperature of the substance.
3. While a substance is changing state, heat energy that is added is transformed into a kind of potential energy called latent heat. There is no change in temperature during the change in state.
4. Latent heat is a form of potential energy that is gained or lost during a change in state.
5. A much greater amount of energy is needed to change liquid water to water vapor than is needed to change ice to liquid water.

OTHER ENERGY TRANSFORMATIONS

Gravitational Potential Energy. The movement of matter either away from or toward the earth's center of gravity results in a transformation of energy. In the movement of matter away from the earth, kinetic energy is transformed into potential energy. An object that is raised above the earth's surface has more potential energy than it does at the surface because of its position. When the object falls, some of its potential energy is transformed into kinetic energy.

Let's look at a couple of examples of this type of energy transformation. Think of a boulder sitting at the edge of a cliff. It has potential energy because of its elevation. If the boulder rolls off the cliff, it falls with increasing speed downward, toward the center of the earth. Some of its potential energy is transformed into kinetic energy.

In the swinging of a clock pendulum there is a continuous exchange of potential and kinetic energy. As the pendulum reaches the top of its swing, it has no kinetic energy (the pendulum is not moving), but it has maximum potential energy (the pendulum is at its maximum height). At the middle of its swing the pendulum has maximum kinetic energy (it's moving at its greatest speed) and minimum potential energy.

Absorption. Another type of energy transformation occurs when electromagnetic radiation is absorbed by a material. The quantity and wavelengths of electromagnetic energy absorbed depend on the color and texture of the material. Dark, rough surfaces absorb more visible light than smooth, shiny surfaces. Materials that are good absorbers of electromagnetic energy are also good radiators of electromagnetic energy.

In many processes at the earth's surface, electromagnetic energy of short wavelengths is absorbed by a material, which then reradiates energy of a longer wavelength. For example, in many cases ultraviolet and visible light from the sun are absorbed by a material. This energy is then transformed and reradiated as infrared radiation. This type of energy transformation is important for understanding certain earth changes that will be discussed in Chapter 9.

Friction. Another type of energy transformation occurs at interfaces, where friction develops because of movement along the interface. For example, there is friction between the moving water of a stream and the stream bed. The friction causes the transformation of some of the kinetic energy of the moving water to heat.

Another example of energy transformation at an interface can be found when a boulder rolls down a hill. Friction between the boulder and the ground causes the transformation of some of the kinetic energy of the boulder to heat and sound.

SUMMARY

1. The movement of matter either way from or toward the earth's center of mass results in an energy transformation from kinetic to potential or from potential to kinetic.
2. The characteristics of a surface determine the amount and type of electromagnetic energy that will be absorbed.
3. When electromagnetic energy of short wavelength is absorbed, it can be subsequently reradiated at longer wavelengths.
4. A material that is a good absorber of electromagnetic energy is a good radiator of electromagnetic energy.
5. There is a transformation of energy at interfaces where friction occurs.

REVIEW QUESTIONS

Group A

1. Under what conditions do objects give off electromagnetic energy?
2. In what form does electromagnetic energy travel through space?
3. At what speed do electromagnetic waves travel through space?
4. What is the chief difference between the various forms of electromagnetic energy?
5. What is the *electromagnetic spectrum?*
6. What can happen to electromagnetic radiation when it comes in contact with a material?
7. What happens during the process of radiation?
8. What is *conduction?*
9. Describe the transfer of heat by *convection.*
10. What is *temperature* a measurement of?

11. What is *heat?*
12. What is meant by the terms *source* and *sink?*
13. How is the amount of heat involved in a temperature change of a substance related to the mass and the amount of temperature change of the substance?
14. Give the definition of a *calorie.*
15. What is the *specific heat* of a substance?
16. Of naturally occurring materials, which substance has the highest specific heat?
17. How can you calculate the amount of heat gained or lost by a substance during a temperature change?
18. In a closed system, how does the amount of energy lost by the source compare with the amount gained by the sink?
19. Is energy flow involved in a change in state?
20. While a substance remains in a single state, what happens to any heat energy that is added?
21. While a substance is changing state, what happens to any heat energy that is added? What happens to the temperature of the substance during the change in state?
22. What is meant by the term *latent heat?*
23. How does the amount of energy needed to change ice to liquid water compare with the amount needed to change liquid water to water vapor?
24. What energy transformation occurs when an object is moved away from the earth's center of mass? Toward the center of mass?
25. Which surface characteristics determine the amount and type of electromagnetic energy that will be absorbed?
26. How does the wavelength of electromagnetic energy absorbed by a surface compare with the wavelength of electromagnetic energy reradiated by that surface?
27. If a material is a good absorber of electromagnetic energy, what can be said of its capacity to radiate electromagnetic energy?
28. Give an example of an energy transformation that takes place at an interface where friction occurs.

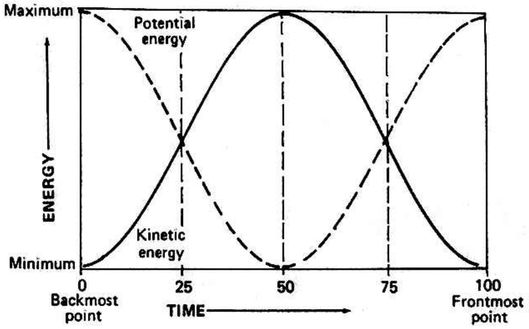
Group B

1. a. Define the term electromagnetic energy.
   b. Define the term wavelength as it applies to electromagnetic energy.
   c. List at least 5 different forms of electromagnetic radiation (energy) in order of increasing wavelengths.
   d. Describe the relationship between the wavelength of electromagnetic energy emitted by a radiating body and the temperature of that body.
2. a. Describe the general effect that temperature change has on the density of fluids.
   b. Based on the relationship described in 2-a, explain why fluids move as they do within a convection cell. Include in your answer an explanation of the role that the force of gravity plays in this type of heat transfer.
3. When two objects of unequal temperature are near each other, heat flows from the hotter object to the cooler. The size of the temperature difference between the two objects will have what effect upon the rate of flow?

4. a. How do the specific heats of most earth materials generally compare to the specific heat of water?
   b. Use Table 8-1, page 127, to answer this question. If equal masses of basalt and water received the same amounts of heat energy, how would their changes in temperature compare?
   c. Based on your answer to 4-a, which would heat up faster in the day during the summer, sand on the beach near a lake, or the water in the lake? Explain your answer. (Note: Both sand and basalt are rock materials whose specific heats are about the same.)
5. Explain what effect (a) the evaporation of ocean water, and (b) the melting of an iceberg would have on the temperature of the environment. Include in your answer references to the terms latent heat of fusion and latent heat of vaporization.

REVIEW EXERCISES

1. The graph below illustrates the theoretical energy transformations that occur as a playground swing moves back and forth. The graph shows the energy transformations of the swing beginning at its backmost point (time = 0) and ending at its frontmost point (time = 100).



   a. During which time interval, or at which specific time, did the following conditions exist?
      Potential energy increasing, kinetic energy decreasing ______
      Potential energy increasing, kinetic energy increasing ______
      Potential energy decreasing, kinetic energy decreasing ______
      Potential energy decreasing, kinetic energy increasing ______
      Kinetic energy maximum, potential energy minimum ______
      Potential energy maximum, kinetic energy minimum ______
   b. Are the events illustrated by the graph examples of cyclic or noncyclic change?
2. Trace the heat energy given off by your body back to its source—the sun.
3. Convection involves the transfer of energy by a moving fluid. Is the flow of gasoline from the gas tank of a car to the engine an example of convection?
4. Under what conditions could a glacier be a source of heat energy?