EVALUATING
ACADEMIC READINESS
FOR APPRENTICESHIP TRAINING
Revised for
ACCESS TO APPRENTICESHIP

SCIENCE SKILLS
HEAT

AN ACADEMIC SKILLS MANUAL
for
The Construction Trades: Mechanical Systems

This trade group includes the following trades:
Electrician (Construction, Maintenance & Industrial),
Network Cabling Specialist, Plumber,
Refrigeration & Air Conditioning Mechanic,
Sprinkler & Fire Protection, and Steamfitter

Workplace Support Services Branch
Ontario Ministry of Training, Colleges and Universities

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In preparing these Academic Skills Manuals we have used passages, diagrams and questions similar to those an apprentice might find in a text, guide or trade manual.

This trade related material is not intended to instruct you in your trade. It is used only to demonstrate how understanding an academic skill will help you find and use the information you need.

SCIENCE SKILLS:
HEAT

An academic skill required for the study of the Construction Trades: Mechanical Systems

INTRODUCTION

Heating and cooling needs are a part of every construction project. An electrician might install an electrical heating system. An air conditioning mechanic sets up the cooling system. The mechanic installing the sprinklers needs to know where possible sources of combustion are located. During construction, insulating materials are carefully selected to keep heat loss to a minimum.

Construction mechanics have to be careful they don't tear the vapour barrier used to seal air leaks when they are working around the walls. All these applications require an understanding of what heat is and how it is transferred.

Working with mechanical systems requires you to be aware of how heat impacts these processes. This skills manual provides information on the concept of heat and its relationship to the concept of energy. The following topics are covered:

- Energy, force and work
- Heat and motion at the molecular level
- Heat and temperature
- Heat and physical states of matter
- Thermodynamics

ENERGY, FORCE AND WORK

Because heat is defined as a type of energy, we will look at the concepts related to energy.

- ***Energy*** *is defined as the ability to do work.*
- ***Work*** *is done when a force acts on matter and changes its motion or position.*
- ***Force*** *is anything that produces motion or tries to do so. It is felt by the object to which it is applied as a push or pull.*
- ***Motion*** *is a continuing change of place or position.*

Energy in an object can be stored as the potential to move or, if released, energy can cause motion. These two types of energy are called *potential energy* and *kinetic energy*

- ***Potential energy*** is stored energy. An object with stored energy has the potential ability to do work at a later time.
- ***Kinetic energy*** is the energy of motion. When a force is applied to an object and it results *in* the object moving, work is done.

Motion
In science, most changes that happen to both molecules and larger objects are described in terms of changes in the object's motion. The concept of motion is an important part of the definitions of energy, work and force.

The way objects behave can be reduced to a description of how they move. There are rules that describe how an object behaves when it is in motion or at rest. Things move according ***Newton's Laws of Motion****:*

1. The first law states that *an object will stay at rest or in uniform motion unless some force acts upon it.* This property of objects is called inertia.

2. The second law states that *the acceleration (rate in change of velocity) of an object becomes larger if the force acting on it increases*. If the force remains the same, the acceleration becomes smaller if the mass of the object increases. The acceleration is in the same direction as the applied force.

3. The third law states that *whenever one body exerts a force on a second body, the second body exerts an equal and opposite force on the first*.

HEAT AND MOTION AT THE MOLECULAR LEVEL

How does the concept of kinetic energy relate to heat? At the molecular level, heat and motion are basically the same thing. Heat energy of an object is expressed as the motion of molecules that make up that object.

- All molecules have some heat energy, and so they have some kinetic energy or motion.
  - When sunlight is absorbed by an object, the potential energy in the sunlight changes to kinetic energy in the molecules of the object.
- The more heat energy that molecules have, the more they vibrate or move around.

In brief:
- Heat is a form of energy.
- Heat absorbed by the molecules forming an object causes the molecules to **move** or vibrate more vigorously.
- On the molecular level, heat energy is kinetic energy or the motion of molecules.

Note: *While we are focusing on heat energy, it is important to realize that energy can exist in forms other than heat. Additional forms of energy include light, sound, electrical, chemical, mechanical and nuclear energy. All energy forms can change from one to the other.*

HEAT AND TEMPERATURE

Our Perception of Heat

When heat is absorbed by an object, the molecules which form the object move more vigorously.

- When you touch very hot water, that heat energy is transferred to the molecules of your skin. Your nerves send a message to your brain where the sensation of vibrating skin molecules is perceived as heat.
- If heat causes too much motion in skin molecules, the skin tissues break down. We say the skin is burned. From a safety point of view, our skin is only comfortable at a certain range of temperatures. If we are exposed to temperatures that are too high or too low, our skin and, eventually, our whole body can be damaged. That is why you wear protective clothing when you are exposed to the high heat of a welding torch.

Measuring Temperature

The amount of heat in an object is the amount of kinetic energy or motion in the molecules that form it. To refer to the amount of heat an object has, we say it is hot or cold. Cold is considered merely the absence of heat. However, it is still handy to use the terms hot and cold when discussing relative amounts of heat.

To get an accurate measure of the amount of heat an object has, we record its temperature. ***Temperature*** is a measure of the average kinetic energy or heat in the molecules of an object.

Absolute zero is a state where all motion in molecules ceases and so all heat disappears. Although scientists have come close to absolute zero, it has not yet been reached. Any amount of heat above absolute zero can be measured.

- Absolute zero is measured using the Kelvin scale, which starts at zero.

The more kinetic energy and, accordingly, the more heat the molecules of an object have, the higher its temperature. The temperature of a substance is measured using a recording device called a ***thermometer***.

- Most temperature scales on a thermometer are based on the freezing and boiling point of water.
- Mercury is commonly used because it expands and contracts at a constant rate as the temperature rises and falls.
- Mercury is placed in a narrow glass tube that has a scale written on the tube.
- As the temperature of the air, or whatever is being measured, rises or falls, the mercury in the tube rises or falls a similar amount through the scale of values.

- When you want to know the temperature, you look at where the mercury has risen on the scale.
- The number on the scale at the level of the top of the mercury gives the temperature of the substance.

The two most common scales used to indicate the temperature are the Fahrenheit scale (F) and the Celsius scale (C). In the Fahrenheit scale, water freezes at 32°F and boils at 212°F. In the Celsius scale, water freezes at 0°C and boils at 100°C. A comfortable room temperature is around 72°F or 23°C.

Thermal Expansion

Most solids and liquids expand slightly as the temperature rises and they contract slightly when the temperature falls. When solids are heated, they increase in length, width and thickness. The increased thermal energy causes their atoms or molecules to vibrate more vigorously and move farther apart from each other, although the amount of movement is not great. This thermal expansion has positive and negative consequences:

- A thermometer can record the temperature because the mercury in the tube expands and contracts in a consistent way as the temperature rises and falls.
- Expansion joints are needed in metal structures to take into account the slight shifts in size that occur because of temperature changes.

Water is an important exception to this rule. Water expands with a tremendous force as it changes from a liquid to ice. Ice has a regular, open crystal structure. The individual water molecules are held further apart in solid ice than in liquid water, so ice has a larger volume than liquid water.

- If the heat goes off in a building in the winter, water in pipes can freeze and then burst the pipes.
- The freeze and thaw cycle of water can even crack radiators if they are not protected by antifreeze.

Almost all other solids increase in length, width and thickness when heated. Different metals of the same length expand by different amounts for the same increase of temperature. This increase in length is called the thermal expansion of the metal. If the length of a metal rod is measured before and after it is heated, the change in its length can be recorded.

- An aluminum rod 1 meter long heated so that its temperature increases by 1°C will increase its length by 2.3×10^{-5} (.000023) meters.
- An iron rod the same size heated the same amount only increases in length by 1.1×10^{-5} (.000011) meters.

The change in unit length of a metal when its temperature is changed 1° C is called its ***coefficient of linear expansion*.** See Figure 1.

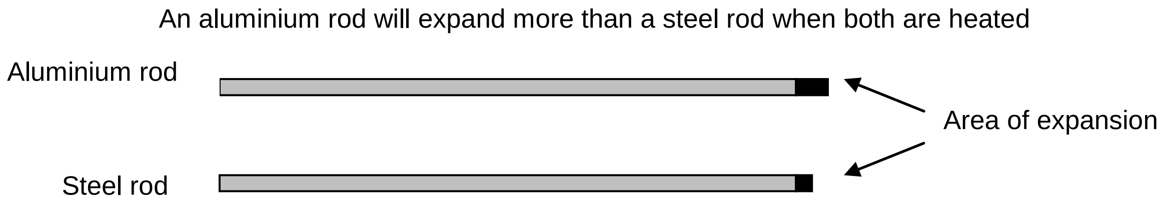

FIGURE 1: Aluminium and Steel Have Different Coefficients of Linear Expansion

Thermal expansion explains how a bimetal thermostat works.

- A bimetal thermostat consists of a strip formed from two separate pieces of metal such as brass and iron.
- When the thermostat is heated, the two metals each expand by a different amount. This causes the strip to curl a little.
- When the strip curls, it bends and opens the contact where the current had been running.
- When the contact is open, the current can no longer flow and the heat is switched off.

When you work with metals that will be exposed to temperature changes, the expansion and contraction of the material must be taken into consideration. If more than one metal is used, the different rates of expansion and contraction of each of the metals must also be accounted for.

THERMODYNAMICS

Heat (or molecular motion) is involved in some way in all interactions that take place on earth. Before the discovery of electricity, heat energy from machines such as steam engines was the main source of energy used to produce mechanical work. Because of the importance of heat energy, scientists studied the dynamics of heat and its transformation into work.

Thermodynamics *is the study of heat; its production, flow and conversion into other forms of energy*.

> **Example:** A vehicle engine illustrates the production, flow and conversion of heat energy. In a truck engine, the explosion of fuel molecules results in a large amount of heat being released (production). The heat drives the gas molecules apart (flow). The pressure from the rapidly expanding gas molecules drives the piston up and down. The moving piston changes the heat energy to mechanical energy used to drive the vehicle (conversion).

The ***Four Laws of Thermodynamics*** summarize some ideas about how heat reacts in different situations.

1. No heat flows between two bodies that are at the same temperature.

2. When heat is converted to work, some of the heat energy is not transformed to mechanical energy but is given up to the atmosphere.
   - When steam drives a piston, most of the heat is converted to mechanical energy, but some of the heat escapes into the air and warms the atmosphere. The total amount of energy present before the transformation is the same as after.

3. Heat flows "downhill" from an object at a higher temperature to an object at a lower one.
   - Two objects in a closed system will eventually reach the same temperature.
   - A cold spoon put in a cup of boiling water will gain heat from the water and become hot to the touch. At the same time, the hot water will become cooler. See Figure 2.

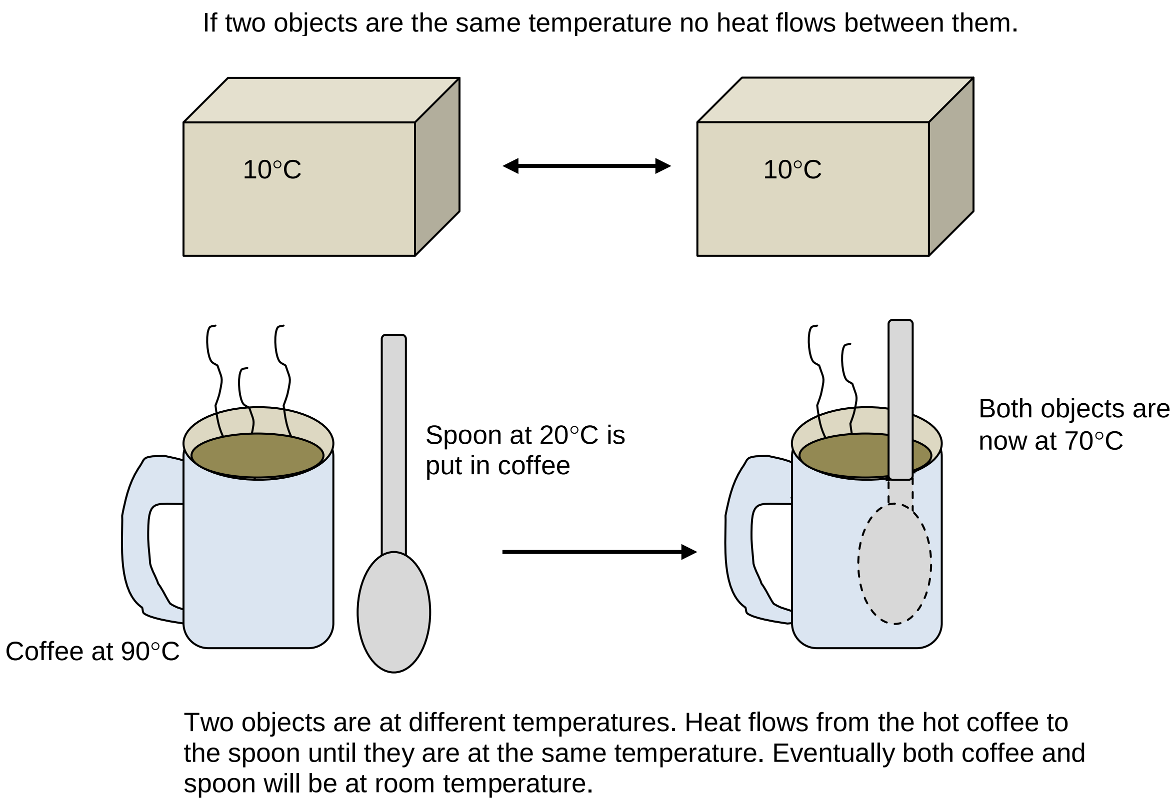

FIGURE 1: Heat Flows "Downhill"

4. A temperature of absolute zero, the lowest possible temperature in the universe, is the point at which all molecular motion ceases. Absolute zero is measured using the Kelvin scale. 0° Kelvin is absolute zero.

Let's look more closely at the different ways heat moves from a warmer area to a cooler one.

TRANSFER OF HEAT

There are several ways that heat flows between objects.

Radiation *is the transfer of heat through space by electromagnetic waves.* The sun's intense activity causes it to radiate electromagnetic waves of different wavelengths. Infrared radiation is the wavelength we are most likely to feel as heat. These waves can travel through empty space, and don't need a solid, liquid or gas material to move through. When they come in contact with an object, the infrared waves impart kinetic energy to the molecules of that object, causing those molecules to vibrate and heat up.

We feel this radiation as heat on our skin. When out in the sun, our skin molecules vibrate more quickly and become warmer when the sun shines on them. Infrared heat waves from the sun are the ultimate source of energy on earth.

Any object that is hot emits infrared radiation.

- A flame, an electric heater and a hot engine radiate heat that is quite noticeable. We feel this radiation as heat on our skin.
- When we are out in the sun, or near a heater, our skin molecules vibrate more quickly and become warmer.

Because all objects have some heat, they all radiate some heat. However, if they are cooler than their surroundings, they will gain more than they lose.

- If a cold sheet of metal is brought into a warm room, the steel will radiate some energy into the room but it will absorb a lot more from the warm air. Eventually, it will reach the same temperature as the room. The first law of thermodynamics remains true because the metal sheet ends up as warm as the room.

Infrared pictures show how much infrared radiation an object is emitting. These pictures are used to see where a building is losing heat to the outside.

- In an infrared picture of an area such as a window taken from the outside, the window will look redder than the insulated wall because it is emitting more heat.

When radiant heat comes in contact with an object, whether it is a solid wall, water in a pipe or an air molecule, the heat is then transferred through conduction or convection.

Conduction *of heat refers to the transfer of heat through solids by the spreading agitation of the molecules which make up the object.* If a solid object is heated at one edge by radiation from the sun or an electric heater, the molecules there vibrate with more energy. The energy spreads to neighbouring molecules until the whole object is at the same level of vibration or is at the same temperature.

- Heat from the cylinder of an engine travels through the cylinder walls by conduction. The heat from combustion causes the molecules on the inside wall to vibrate rapidly. This agitation flows through the metal until the whole piece of metal is hot. The heat on the outer surface is then dispersed by convection.
- If a steel rod is heated at one end by radiation from a propane torch, the molecules at that end vibrate with more energy. The energy spreads to adjacent molecules until the whole object is at the same level of vibration or is at the same temperature.

Different materials transfer heat by conduction at different rates. For example, a glass window in a vehicle cab conducts heat easily, causing the interior to heat up rapidly on a sunny day. On the other hand, the fiberglass and rubber mats placed between the engine and the cab conduct heat slowly. This keeps the heat and sound produced by the engine from coming inside the cab. See Figure 3.

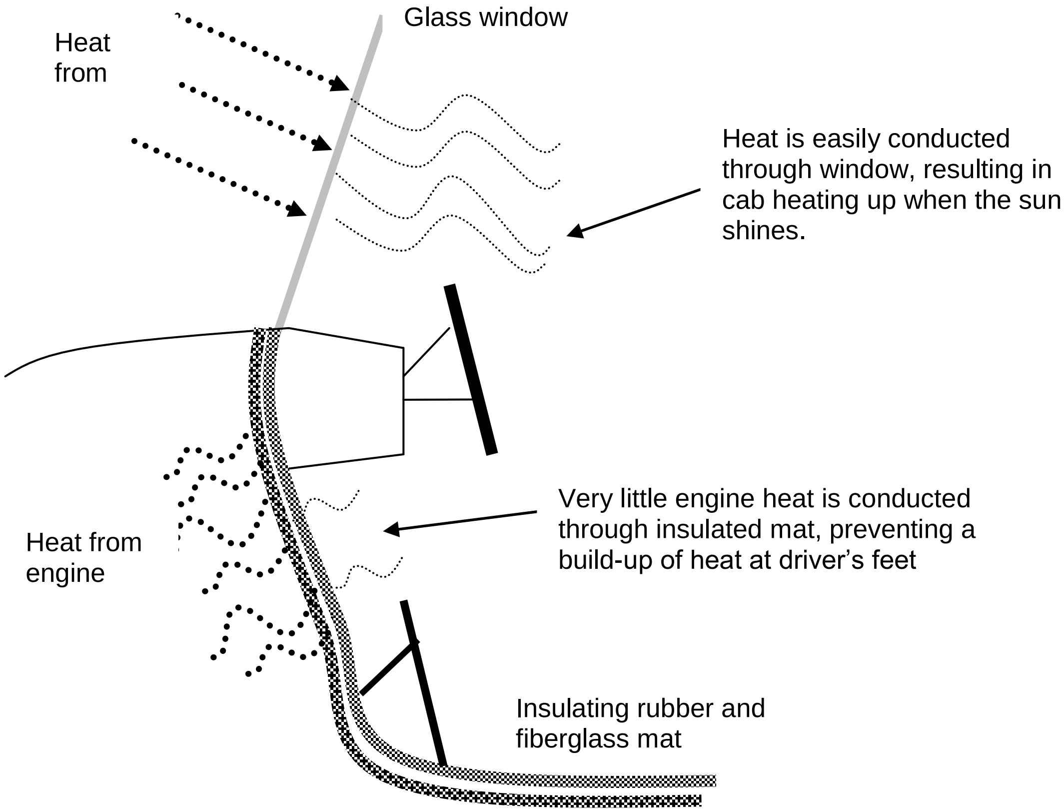

FIGURE 3: Rate of Conduction Varies With Different Materials

Convection *is the transfer of heat energy from one place to another by moving molecules of liquids and gases.* For convection to occur, there must be moving molecules. Air molecules coming in contact with a heat source, such as the fins on the outside of the cylinder, pick up heat from the hot surface. If they then come in contact with cooler objects, the heat is transferred to the cooler objects.

Convection is influenced by two processes. Warm air is lighter than cold air and rises while cool air sinks.

- As warm air rises, it loses its heat to the cooler air above.
- After the air is cooled, it sinks back down. If it picks up heat again, it begins to rise again.
- This movement of air particles is called a *convection current*.

The more outer surface of an object that is exposed to the air, the more opportunity there is for heat to be distributed by convection.

- The cooling fins on the outside of the cylinder allow engine heat to be rapidly dissipated.
- Water carries heat away more effectively than air.
  - Water cooled engines are surrounded by a water jacket.
  - As water is circulated by a small pump, it picks up heat from the engine.
- In a radiator, the hot water is pumped to thin tubes where cool air flowing over the tubes picks up the heat from the water and carries it away.
- In an outboard motor, an impeller pumps cool water around the motor. After cooling the motor, the warmed water flows back into the lake. See Figure 4.

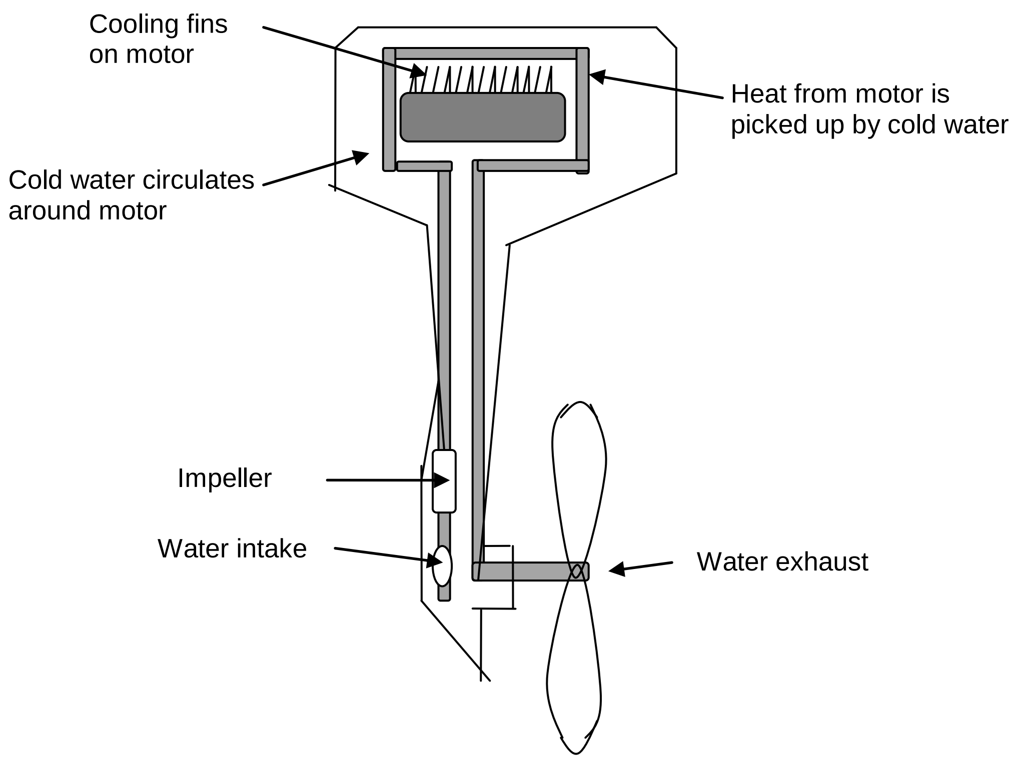

Figure 4: Outboard motor cooled by convection

CONCLUSION

The concept of heat as a form of transferable energy stored in different fuels led to the development of the industrial revolution. This heat is stored in the chemical bonds holding the fuel together as a substance. When these bonds are broken, heat energy is released.
The conversion of heat energy to mechanical energy is not perfect. Some of the heat is released to the atmosphere because of friction. Heat is also released when a substance changes to a physical state with lower energy.

The amount of heat of a substance is measured as its temperature. The amount of kinetic energy of a substance at a certain temperature determines whether it is a solid, liquid or gas at that temperature.

Heat normally flows from a hotter object to one with less heat, so work must be done in order to add heat to anything. No heat flows between two bodies at the same temperature. Heat can flow between objects by radiation, by conduction and by convection.

Mechanical construction technicians have to be aware of the role heat plays in many mechanical systems so that it can be controlled. In a heating system, excess heat is brought from the engine to the interior. In a cooling system, the heat absorbed when a substance changes to a higher energy state is used to cool or refrigerate. Heat energy is involved in of all these techniques.

Answer the following questions on basic thermodynamics by filling in the blank spaces. Answers are on the last page.

1. Heat is a form of ______________
2. The more _____________ an object has, the more quickly the molecules forming that object vibrate.
3. When a metal rod is heated, it _______________ slightly in length. The change in length of a metal when its temperature increases 1°C is called its coefficient of linear expansion.
4. Heat flows downhill from an object at a ______________ temperature to one at a ____________ temperature.
5. The transfer of heat through space in the form of electromagnetic waves is called ________________ .
6. When heat is carried from one place to another by moving molecules such as air or water, the heat transfer is called ________________ .
7. _______________ of heat refers to the transfer of heat which occurs as the result of the agitation of molecules in a solid object. The heat moves from one area to the whole object.
8. Warm air rises; cool air ___________ . This produces a ___________________ current.

Answer these questions by writing true or false in the blank spaces:

9. One type of energy, such as heat, can be transformed to another, such as mechanical energy. _________
10. Temperature is the measurement of the amount of heat in a substance. __________
11. If one end of a solid is heated, the heat moves throughout the solid by the heat transfer known as radiation. __________
12. Materials differ in the rate they conduct heat. ___________
13. Heat will flow between two bodies at the same temperature. ___________
14. If a cold spoon is put in a hot liquid, the two objects will eventually reach the same temperature. _____________

Answer page

1. energy
2. heat
3. increases
4. higher, lower
5. radiation
6. convection
7. Conduction
8. sinks, convection
9. true
10. true
11. false
12. true
13. false
14. true