Heat: An Agent of Change

Heat and Thermodynamics

STUDENT TEXT

Once Count Rumford's concept of heat as energy became generally accepted among scientists, the study of heat became an active area of physical science. Often this was in relation to inventions and technology, particularly the steam engine, and later the gasoline engine. Scientists were studying and inventors were controlling how heat moved. The study of heat's movement is called **thermodynamics**.

Three well-known conclusions about heat energy are among the most important scientific ideas ever formulated. These are the First, Second, and Third Laws of Thermodynamics.

The First Law of Thermodynamics states that heat energy is conserved. This means it cannot be created nor destroyed. There has always been the same amount of energy in the universe. It may change from one form to another, from light to heat or from electricity to radio waves, for example. But there is always the same total amount of energy.

The Second Law of Thermodynamics describes entropy, or disorder. As you know from trying to keep your room or locker neat, it takes energy to maintain order. Natural systems become less orderly over time unless energy is used to keep them ordered. It's not possible to change material from a low temperature to a high temperature without doing work.

As we study the challenges of the Genesis mission, we will concentrate on the Third Law of Thermodynamics. This tells us specifically about the movement of heat energy. If that doesn't sound too exciting or significant, just consider that it is the movement of heat that warms the earth, powers the water cycle, and makes all life possible on earth.

Heat is a form of energy related to the movement of atoms and molecules. The amount of heat energy, or the amount of motion of its particles, is measured as temperature. The Second Law of Thermodynamics states that heat energy always moves from a warmer area to a cooler area, and never in the opposite direction. If you put an ice cube in a pan of boiling water, the heat from the boiling water moves into the cold ice cube. The molecules of water in the ice cube are warmed up, start to move around more, and the ice melts. You would not expect the ice cube to lose heat to the water and get even colder. That would violate the Second Law of Thermodynamics.

So how does a freezer make an ice cube in the first place? Electric energy is required. The freezer uses the electric energy to remove heat from the water in the ice cube tray until the water molecules have lost enough energy to crystallize into ice cubes. This is consistent with the First Law of Thermodynamics, which says that heat energy cannot be created or destroyed. The heat energy can be moved or changed into another type of energy, but it does not disappear.

What happens to the heat energy that the freezer removes from the water? If you have ever looked behind the freezer you may have noticed that it gives out hot air. That hot air comes from the food and water inside the freezer.

This is consistent with the First Law of Thermodynamics that states that heat energy cannot be created or destroyed. Other kinds of energy, such as mechanical, electrical, chemical, or nuclear energy, can be changed into heat energy, causing a substance to become warmer, but that is still only a transfer of energy. No new energy is created or destroyed.

Heat can move in three ways: conduction, convection, and radiation. **Conduction** is movement of heat that occurs either when two objects are touching each other or within an object. This is the most common way heat travels between two solids, for example, two pieces of metal touching each other. The molecules in the warmer solid are more active than the molecules in the cooler solid. They are bumping into and colliding with each other more than the cooler molecules are. At the place where the two solids touch, the faster molecules in the warmer solid jostle and nudge the slower moving molecules in the cooler solid. This bumping and pushing slows down the faster molecules, but speeds up the slower ones. The jostling and pushing spreads through all the molecules in both objects until all are moving at about the same speed. Enough heat energy has been conducted from the warmer object to the cooler one so that they are now both at the same temperature and conduction stops.

Engineers in the Genesis mission must worry about the effects of conduction when they place two different materials next to each other in the spacecraft. This can be as simple as the metal bolts that hold wall panels together, or as complex as the gold coating attached to the diamond collector. Another source of heat that is conducted to the spacecraft is friction between the craft and the atmosphere during reentry.

Wherever two different materials touch each other, engineers must understand how they conduct heat from one to the other. Genesis design plans include a heat shield to protect the spacecraft from the heat of reentry. The heat shield is designed so that it does not conduct heat well into the spacecraft. Its job is to prevent heat movement.

In liquids and gases, heat moves most often by convection. **Convection** is a movement of warmer material through cooler material that would not be possible in the more tightly packed arrangement of a solid. When a portion of the liquid or gas becomes hotter than its surroundings, those molecules move around more and become less densely packed. The less dense material starts to rise upward through the surrounding material. People say, “hot air rises.” This is an example of convection. You can sometimes see convection currents in warm liquids, such as coffee, tea, or the hot water in which oatmeal is cooking.

As the warmer, less densely packed molecules rise through their cooler surroundings, they lose some of their heat energy to neighboring molecules. This is according to the Second Law of Thermodynamics, that heat moves from warmer material to cooler material. As the warmer molecules rise in the convection currents, they cool off, until they are the same temperature as their surroundings. But the heat energy that they acquired somewhere else was moved to a different place in the liquid or gas. Genesis engineers are not generally concerned with convection types of heat transfer.

The third type of movement of heat does not have to occur in matter. It has nothing to do with molecules. **Radiation** of heat as waves of energy can even occur in a vacuum. There are many types of radiation. If you look at the electromagnetic spectrum of the sun, you will notice several types of radiation that can travel to the Earth through space. **Infrared radiation** is the heat energy that the Sun puts out. Visible light accounts for most of the heat energy put out by the Sun. Genesis engineers are concerned about the heat radiation that will be hitting the side of the spacecraft facing the Sun as it orbits L1.

Scientists have studied heat for many years. Learning about the theories scientists use to describe the movement of heat at the molecular level is important in an engineer’s education. They often take a course called *Thermodynamics*, in which they study the properties of various materials and how heat moves through and between them. They later put this information to use designing materials such as the Sample Return Capsule and the Collector Arrays for space missions like Genesis.