CHAPTER 10

Heat and Temperature

10.1 HEAT AND HUMANS

Heat, and the lack of heat, have been important to humankind since the earliest times. Heat from the Sun and the cold of winter have always affected living conditions. From early childhood, hotness and coldness are two of the first feelings children encounter. Children experience these conditions early in life by sucking an iceblock or walking on a hot road. In fact it is the temperature change that initiates breathing when a child is born. The industrial revolution was based on heat and the generation of mechanical power from heat. Many industries in modern-day life are solely centred around the production of heat or the purposeful removal of heat, for example refrigeration, airconditioners and pot-belly stoves.

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Activity 10.1 HOT SPOTS

People have always wondered about the extremes of temperature. Consult the *Guinness Book of Records* or the Internet to find:

- the highest and lowest recorded human body temperature
- the places on earth that recorded the highest and lowest temperature
- the highest and lowest temperature ever achieved on Earth.

But what is heat?

10.2 HEAT AND TEMPERATURE

Up to the eighteenth century heat was regarded as some sort of invisible fluid, a 'caloric fluid' that bodies possessed. Hot bodies, it was believed, contained more of this fluid than cold bodies. When a body was warmed this caloric fluid was added to the body. But this did not explain why two ice cubes melted when they were rubbed together.

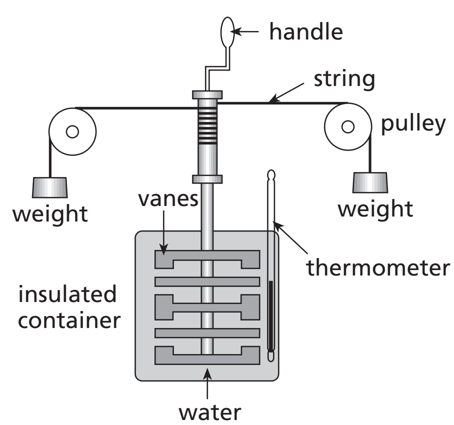
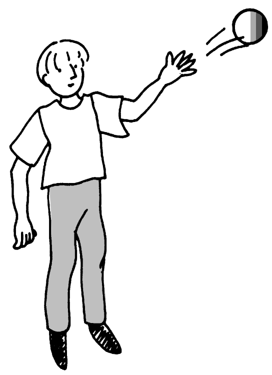


Figure 10.1
A schematic diagram of Joule's apparatus used to investigate the relationship between mechanical and thermal energy.

Figure 10.2
The energy contained in a ball in flight due to its motion and height.



English scientist **James Joule** (1818–89) was one of the first scientists to show that heat was a form of energy. He performed an experiment in which falling lead weights turned paddles in water. The work done by these weights caused the water to heat up. He showed that mechanical energy can be converted into heat. Joule concluded that heat is a form of energy, but what form does it take?

Consider a student throwing a ball. (See Figure 10.2.)

What energy does the ball possess?

Some might say it has kinetic energy because of its motion. Others might say it has potential energy due to its height above the ground. Some would say both. Is that all the energy it possesses?

Now consider the same student throwing a box full of bees (Figure 10.3). What is the total energy of the container?

It is easily seen that the container possesses both kinetic energy due to the motion of the box, and potential energy due to its height above the ground. However, it also possesses the kinetic energy the bees themselves might have.

Figure 10.3
The energy contained in a box of bees, including motion of the bees.

Up to this time we have considered the bulk energy of objects and not the internal energy the particles in the objects might possess. All objects contain particles, atoms and/or molecules, and it is the motion of these particles that makes up the internal energy of the object. This motion can be vibrational kinetic energy, as in solids; or rotational and translational kinetic energy, as in fluids. The particles of matter also possess many forms of potential energy in the bonds that hold particles together, as well as that stored in the nucleus of the atoms. (See Figures 10.4 **(a)**, **(b)** and **(c)**.)

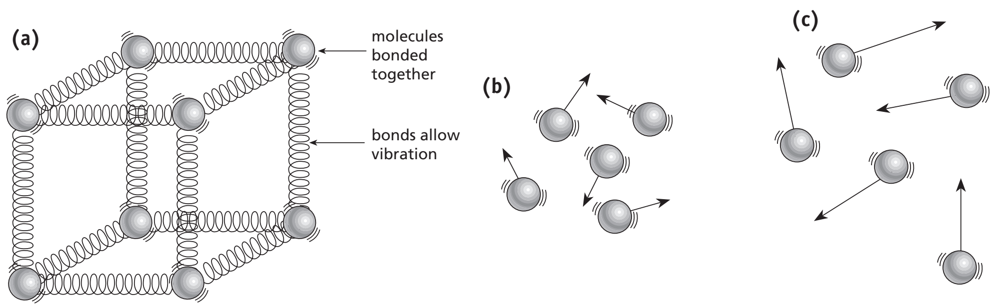


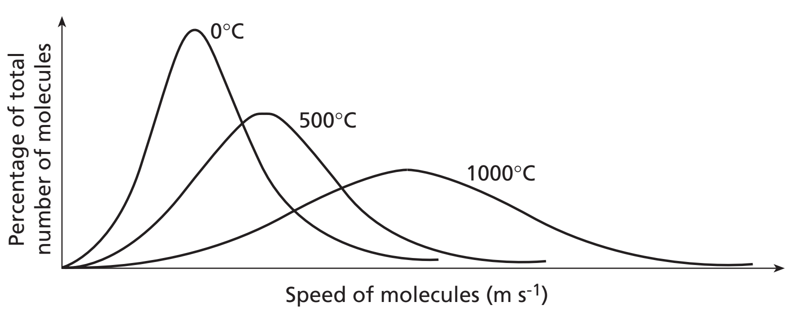
Figure 10.4
(a) A model of the movement of the molecules in a solid. The springs represent the molecular bonds. **(b)** A representation of the molecules of a liquid. They vibrate and are able to flow over one another. **(c)** The molecules of a gas have greater freedom. They have rapid straight line motion.

The sum of the kinetic and potential energies of all the particles is called the **internal** or **thermal energy** of the object. Heating is the term used when some of the thermal energy is transferred from hot objects to cold objects as in the case of a hot spoon being placed in cool water. The term heat is used to describe the internal energy transferred through this heating process. The study of these energy transfers is called **thermodynamics** (from the Greek *thermos* meaning 'heat', and *dynamis* meaning 'powerful').

It would be impossible to measure the motion of all the particles within a substance because of the number of particles and the great variation in speeds of the particles. Figure 10.5 indicates the variation of molecular speeds of a gas at various temperatures.

However, as objects gain heat and become hotter, the particles move faster. Temperature is a measure of the average kinetic energy of the particles of the object. Changing the potential energy of a substance without changing the average kinetic energy of its molecules does not change the temperature of the substance. This occurs when a change of state occurs. That is, when a substance changes from a solid to a liquid, or a liquid to a gas, or vice versa. A common misconception is that heat and temperature are the same, which is not the case.

Figure 10.5
The distribution of speeds of the molecules of a gas at various temperatures.



10.3 THERMAL EQUILIBRIUM

Everyone has observed that when a cool spoon is placed in a hot cup of coffee it eventually becomes hot — as hot as the coffee. Or when you use a thermometer to measure a person's temperature the thermometer becomes as warm as the person whose temperature is being measured. How does this occur?

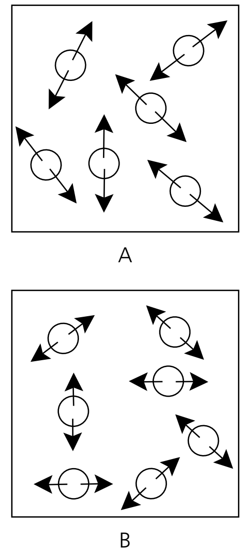
Consider a closed system (a system where there are no energy losses to the environment) in which a hot object A is in contact with a cooler one B. (See Figure 10.6.)

Because A is hot it contains more thermal energy than B, and its molecules have more potential and kinetic energy. The molecules move faster in object A than they do in object B. When A and B are placed in contact the molecules of A collide with the molecules of B, transferring kinetic energy to them. This causes the molecules of B to vibrate further apart, thus increasing object B's potential energy. Object B's thermal energy has increased. At the same time the molecules of A have slowed down and vibrate closer together, thus decreasing A's kinetic and potential energies. Object A has lost thermal energy. Thermal equilibrium is reached when the energy given to B equals the energy B is giving back to A. As the law of conservation of energy is true for all forms of energy:

heat lost by object A = heat gained by object B

So when you use a thermometer to measure a child's temperature, molecules of the child in contact with the thermometer jostle the molecules of the glass, which in turn jostle the molecules of the mercury in the thermometer. The mercury expands, indicating the temperature on an appropriate scale of temperature.

Figure 10.6
The flow of thermal energy from the molecules of a hot to those of a cold body.



Activity 10.2 FREEZING

1 Find out which freezes first — a cup of hot water or a cup of cool water placed in the freezer.

2 Do pets have the same body temperature as humans?

Questions

1 Which has more thermal energy: a cup of water at 100°C or a bath full of water at 40°C? Why?

2 Steam at 100°C will give you much more severe burns than water at 100°C.
(a) In which one are the molecules moving the faster?
(b) In which one do the molecules have greater potential energy?
(c) Why are steam burns more severe?

3 **(a)** What is the name given to the internal energy of a substance?
(b) What form(s) of energy does this involve?

4 If James Joule did 100 J of work on several quantities of water — 100 mL, 300 mL and 500 mL:
(a) which sample would gain the most thermal energy? Why?
(b) which sample's temperature would increase the most? Why?

NOVEL CHALLENGE

During the Second World War, Nazi scientists threw many prisoners overboard into the freezing waters of the North Sea to see how fast their body temperature dropped and how long it would take for them to die. Today, such data are needed by ocean rescue researchers to help to develop safety devices for ocean users.
Should we use this despicable 'Nazi science'? Develop an argument for or against its use.

NOVEL CHALLENGE

The table below shows the effects of changes to body temperature:

T (°C)	*Effect*
37.0 ± 1	normal oral
35	shivering
34	slurred speech
33	hallucinations
32	shivering stops
30	unconsciousness
26	appears dead

Death is defined as a failure to revive on rewarming above 32°C. When people freeze to death in cold water it has been reported that they do not seem to be in pain as they die. They often seem relaxed. *What could be happening here?*

10.4 MEASURING TEMPERATURE

Measuring temperature requires the use of some property of a substance that changes proportionally with increase in temperature. The property that most temperature measuring instruments use is expansion and contraction. This is the property used in most thermometers. The most common is mercury-in-glass or alcohol-in-glass thermometers that have