CHAPTER 12

Heat Transfer

INTRODUCTION 12.1

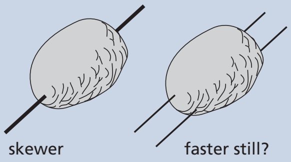
The transfer of heat energy from one place to another may seem unimportant to many. How does this affect me? What use is this to me? However, like many applications of physics, heat energy transfer unknowingly affects our everyday life more than a casual glimpse would suggest.

- On cold winter nights what keeps you warm? Why does that quilt, particularly a down quilt, keep you warm?
- Why do saucepans have plastic, wooden etc. handles? Would it not be better if they were all steel or aluminium? They would be easier to manufacture and clean.
- How do you feel the warmth of the electric heater from across the room? Could electric heaters be used in outer space to keep astronauts warm?
- If you were interrupted while making a cup of coffee, would it be better to leave it before putting in the cold milk, or put the milk in before you do that little job? In which case would the coffee be hotter when you return?
- How does the Sun's heat energy reach the Earth?
- Why are there heat shields on the Space Shuttle?
- Double glazing of windows is very beneficial in the conservation of energy for households or for large buildings. Why? (If you don't know what double glazing is, check the encyclopaedia or look in any building magazine.)

All the above examples have something in common. They all can be explained by the understanding of heat energy transfer. There are several ways in which heat energy can be transferred. Let's look at them in turn.

NOVEL CHALLENGE

Cooks sometimes put a metal skewer through potatoes to make them cook more quickly. *Would you speed things up by using a skewer of twice the diameter, or two of the smaller skewers? If you used two, where is the optimal place to put them? Why?*



Activity 12.1 HEAT LOSSES

You can probably think of many more situations where the loss, gain, or transfer of heat energy from one place to another plays a role in our everyday life. For example:

1. Why doesn't the Earth get hotter and hotter as sunlight falls on it? How does the term 'albedo' apply to this situation?
2. Computer CPUs have big metal 'heat sinks' with large-surface-area fins attached. What is the purpose of this?
3. The bony plates on the back of a stegosaurus have been claimed to be part of its cooling system. How might they work? Research this and discuss arguments for and against this proposal using 'discussion' genre.

NOVEL CHALLENGE

When you get out of bed in the morning, carpet feels warmer under your feet than tiles. Why is this if they are both at the same temperature?

12.2 CONDUCTION

Conduction (from the Latin *conducere* meaning 'to lead together') is the process by which heat energy is transferred through a medium by the vibrating particles of the medium, but without the particles actually moving. For example, when a metal teaspoon is placed in hot water the handle becomes hot. Heat energy travels from the hot water through the spoon to your hand. The reason this occurs has already been suggested in Chapter 10. (This may be the time to revise this section.) The molecules of the hot water are moving faster than those of the spoon — they have more energy because they are hotter. When they collide with the particles of the spoon they transfer some of their energy to those particles of the spoon. These molecules then collide with others adjacent to them. This continues until all the molecules of the spoon and water are in equilibrium. Heat energy is thus transferred from the hot water to the spoon and eventually to your hand. Of course, you might say that the spoon's handle does not get as hot as the water. This is true. But where else is the spoon's handle transferring some of its energy? The air around it has molecules! Notice that the energy is transferred from the hot water to the spoon and your hand but the particles themselves do not move. They may vibrate but they do not move with the transfer of heat energy.

So to transfer heat energy by conduction the medium must contain particles and the closer together the particles the better. Therefore solids, liquids and gases can **conduct** heat energy, but a vacuum cannot.

(From now on we will refer to heat energy transfer as heat flow, which is a simpler way of expressing the idea of a transfer of heat energy from one medium to another.)

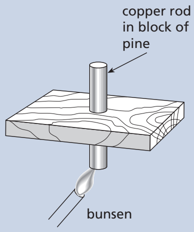
This would also suggest that solids are better conductors than liquids, which are in turn better than gases. This, in general, is true, as the particles in most solids make closer contact with each other than those of liquids or gases. Table 12.1 indicates the rate of heat flow through particular materials. It will be noticed that this table reinforces the above statement. This will be discussed more fully later. The table might also suggest why copper-based saucepans are better than iron-based saucepans.

Table 12.1 THERMAL CONDUCTIVITY OF SOME MATERIALS

MATERIAL	THERMAL CONDUCTIVITY, k (W m^{-1} K^{-1})
Silver	430
Copper	400
Aluminium	240
Brass	105
Iron	67
Steel	46
Concrete	0.8
Glass	0.8
Brick	0.6
Water	0.6
Asbestos, paper	0.2
Rubber	0.2
Plasterboard	0.13
Wood	0.08
Cork	0.05
Carpet	0.05
Bone	0.042
Fibreglass wool	0.04
Plastic foam	0.03
Air	0.024
Fat	0.021

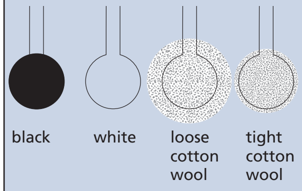
NOVEL CHALLENGE

A copper rod is placed through a hole in a piece of pine and heated. Charring occurs more along the grain that across it. *Now why is this? Propose a physics explanation.*



NOVEL CHALLENGE

Four thermometers as shown are placed in the Sun for 10 minutes. List them in order from highest reading to lowest. Explain.

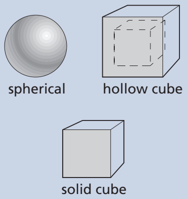


NOVEL CHALLENGE

How can you cook a hamburger thoroughly in the shortest time? Would you cook it on an open grill (large heat, but some charring) or in a pan (small heat). Explain using physics principles. Suggest to your physics teacher that you have an end-of-term BBQ and that the school pay for the hamburger patties. Good luck!

NOVEL CHALLENGE

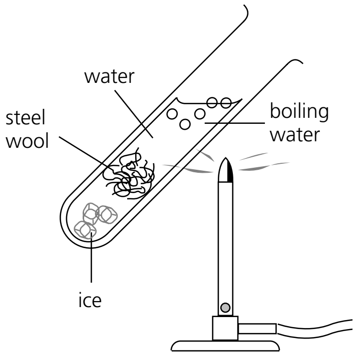
You have three ice-cubes of the same mass. *Which one will melt first? Why?*



Activity 12.2 CONDUCTIVITY OF LIQUIDS

Put some ice in a test-tube and hold it in place with some steel wool (Figure 12.1). Half-fill the test-tube with water. Hold the upper part of the tube over a candle or a Bunsen burner until the water boils. What do you notice about the ice? What does this suggest about the conductivity of liquids?

Figure 12.1
The water boils but the ice remains because water does not conduct heat very well.

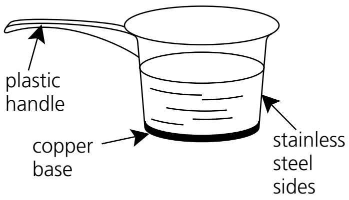


Bonding

The bonding of the atoms in materials controls how easily the atoms vibrate and therefore conduct. The bonds between the atoms in metals allow the atoms to vibrate freely in all directions, whereas the bonds in non-metals hold the particles more firmly, and are more rigid, thus not allowing the particles to vibrate as freely. So metals are good **conductors** whereas non-metals are poor conductors, or **insulators**. This again is shown in Table 12.1.

Both good conductors and poor conductors (insulators) have their uses. Good conductors are used for such things as the bases of saucepans, car radiators, cooling fins on air-cooled engines such as those used in VWs, and as heat sinks on semiconductor electronic devices. Poor conductors are used to insulate roofs, insulate water pipes in cold countries, and for jumpers, wet suits, and the handles on pots and pans.

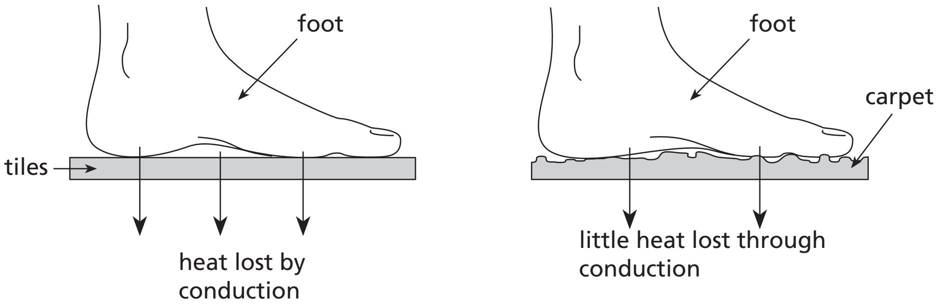
Figure 12.2
Copper-based saucepans conduct heat well whereas poor conductors are good for handles.



Staying cool or hot

A special mention has to be made of those materials (many synthetic) that are poor conductors because they trap air within their fibres. Since air is a poor conductor (Table 12.1), materials that trap air do not transfer heat energy very well. Materials such as wool, fur, polystyrene, carpet, fibreglass fibres, etc. all have these qualities. Fibreglass or wool insulation is used in the ceilings of houses as it does not allow the heat energy to be transferred readily from the atmosphere to the interior on hot days or the reverse on cold days, thus improving the living conditions within the house and reducing the cost of heating or cooling. Carpeted floors always feel warmer then wooden or concrete floors on cold mornings. Carpet reduces the rate at which heat is lost from your feet to the floor, therefore your feet will retain their heat longer and feel warmer, except for the loss of heat to the atmosphere — to stop this you had better wear slippers (woollen ones).

Figure 12.3
Carpet feels warmer than concrete because concrete conducts the heat from your feet more rapidly.



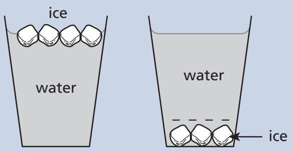
Rate of heat flow

Table 12.1 indicates that heat energy is transferred through materials at different rates. Heat reaches your hand quickly when the ends of some metals are placed in a Bunsen flame, while other materials such as wood do not transfer the heat energy nearly as fast or as readily. The rate of heat flow depends on several properties of the material. The rate of heat flow (R) is defined as the heat energy transferred per second, and is measured in joules per second or watts.

What do you think controls the heat flow from the stove through the bottom of a copper-based saucepan to the water in the saucepan?

NOVEL CHALLENGE

Which will cool the water more quickly — leaving the ice to float or keeping it submerged? Provide the physics principles behind this.



Commonsense would suggest several factors control the heat flow. These have been verified through experimentation:

- Experiments have shown that if the material were thicker, heat would take longer to pass through. That is, if our saucepan's base was thick it would take longer for heat to penetrate. The rate of heat flow (R) is inversely proportional to the thickness (d).

$$R \propto \frac{1}{d}$$

- The rate of heat flow has also been shown to be dependent on the temperature difference across the material. That is, if the temperature difference on either side of the saucepan's base is greater, heat will flow more quickly.

$$R \propto (T_2 - T_1)$$

- The area of the material influences the flow rate. The greater the area the quicker the energy transfer.

$$R \propto A$$

- The rate of heat flow also depends on the type of material. As already suggested, heat flows readily through some materials and not so readily through others. The **thermal conductivity** of a material (k) is a measure of the rate of flow of heat energy through 1 m^2 of a material of thickness of 1 m and having a temperature difference of 1 K between the sides. For example, copper has a thermal conductivity of 400 $\text{W m}^{-1}\text{ K}^{-1}$, which means 400 joules per second flow through a 1 m square, 1 m thick piece of copper when there is a temperature difference of 1 K between the sides.

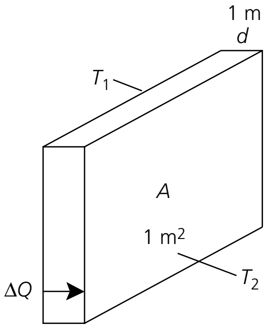


Figure 12.4
Heat flow through a piece of copper 1 $\text{m}^2 \times 1$ m.

Putting all the above variables together the rate of heat flow becomes:

$$R \propto \frac{(T_2 - T_1) \times A}{d}$$

then

$$R = \frac{k(T_2 - T_1)A}{d}$$

The units for thermal conductivity, k, result from the above equation:

$$k = \frac{Rd}{(T_2 - T_1)A}$$

The units thus become W m/K m^2, or $\text{W m}^{-1}\text{ K}^{-1}$.

Table 12.1 gives the thermal conductivity of several common substances. This table is worth more than a passing glance. It indicates why plastic, wood etc. are used for handles of saucepans; why fibreglass, wool and plastic foam are used for insulating in houses; why cork is used for place mats for hot materials; and why animals that live in very cold climates have a great deal of fat on their bodies.

NOVEL CHALLENGE

Does dark water (e.g. tea) cool more quickly or more slowly than white water (e.g. milk in water)? Explain this before you try it. While you're thinking about it, here's another: does brown bread toast more quickly than white bread?

INVESTIGATING

Have you ever been over the Gateway Bridge in Brisbane and noticed the huge storage tanks for BP oil?

The ones filled with unrefined oils or lubricants are painted black, whereas the tanks filled with petrol are painted silver. Propose a reason for this and if you are able to, find out why they really do it. We had to ring BP in Melbourne.

Example

Calculate the initial rate at which heat flows through a copper-based saucepan that has a 15 cm diameter, 1 cm thick, base. The temperature of the water in the saucepan is initially 18°C while the stove hotplate is 120°C.

Compare this with a saucepan made of steel.

Solution

$$R = \frac{k(T_2 - T_1)\,A}{d}$$

$$= \frac{400(120 - 18)\pi 0.075^2}{0.01}$$

$$= 7.2 \times 10^4 \text{ W}$$

For the steel saucepan:

$$R = \frac{k(T_2 - T_1)\,A}{d}$$

$$= \frac{46(120 - 18)\pi 0.075^2}{0.01}$$

$$= 8.3 \times 10^3 \text{ W}$$

The flow of heat energy through copper is approximately 10 times that of steel. This should have been seen from Table 12.1, since all other variables were the same.

Photo 12.1
The Texas TI-83 graphing calculator and the CBL (Computer Based Laboratory) are another useful way of accumulating temperature/time data.

NOVEL CHALLENGE

80 mL of cold water is placed in a polystyrene cup and the cup is placed in a beaker of hot water. Thermometers are placed in both containers. Predict the shape of the temperatures versus time graph. The experiment is repeated but a small cube of ice is placed in the cold water. Now show how the graph shapes will change (in red ink). If you had a TI-83 graphing calculator with temperature probes (see photo 12.1), you could follow the progress.

Questions

1 When one end of a piece of glass rod is placed in the flame of a Bunsen burner the other end becomes hot.
(a) Explain how the heat energy travels from one end to the other.
(b) What other laboratory materials would transfer heat faster?

2 Many birds on cold winter mornings are seen to ‘fluff’ their feathers. What is the purpose of this?

3 **(a)** Calculate the rate at which heat energy is lost through a 1.0 m^2 laboratory window on a day when it is 15°C on the outside and 25°C inside. The glass is approximately 5.0 mm thick. **(b)** How much heat energy is lost in 1 hour?

4 Calculate the heat lost from a seal in 30 minutes. Assume the seal’s total surface area is 1.1 m^2 and the thickness of the fat is 2.0 cm . The atmosphere temperature is –25°C and the seal’s body temperature is 37°C.

Fire-walking

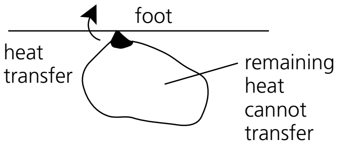
Though fire-walking has long been associated with Far East mysticism it has recently been adopted by the New Age movement in California. It has also recently come under the scrutiny of physicists in search of an explanation for how people can walk on 600°C red-hot coals in bare feet and not get burnt.

To obtain the coals a pile of wood is set on fire and allowed to burn to red-hot over a period of an hour or two. The bed, about 4 m long and 1 m wide, is raked evenly and when paper is thrown on it will burst into flames. People can then walk over it, taking about 7 seconds, without getting burnt. How do physicists explain this?

Two effects are in operation:

- poor thermal conductivity of coals.
- the Leidenfrost effect.

Figure 12.5
Coals provide a poor conductor and there is little surface area in contact with the feet.

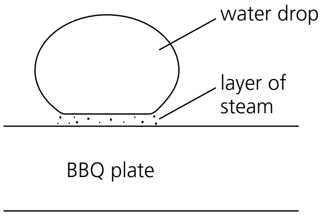


Coal is a poor conductor of heat, unlike, say, a steel barbecue plate. The heat leaves the edge of the coal but does not transfer to the feet very quickly.

The other effect is called the Leidenfrost effect. If you have ever poured water on a very hot barbeque plate, you would have noticed that the water forms little drops and they dance around on a layer of steam on the plate (Figure 12.6).

In a similar way this layer of steam keeps the skin away from the coals and protects the foot even more. The Australian Skeptics often arrange demonstrations of fire-walking to debunk the mysticism of the process. There is no magic in it — just pure physics. But do not try it! People have been burnt.

Figure 12.6
Water bubbles floating on steam on a barbecue plate.

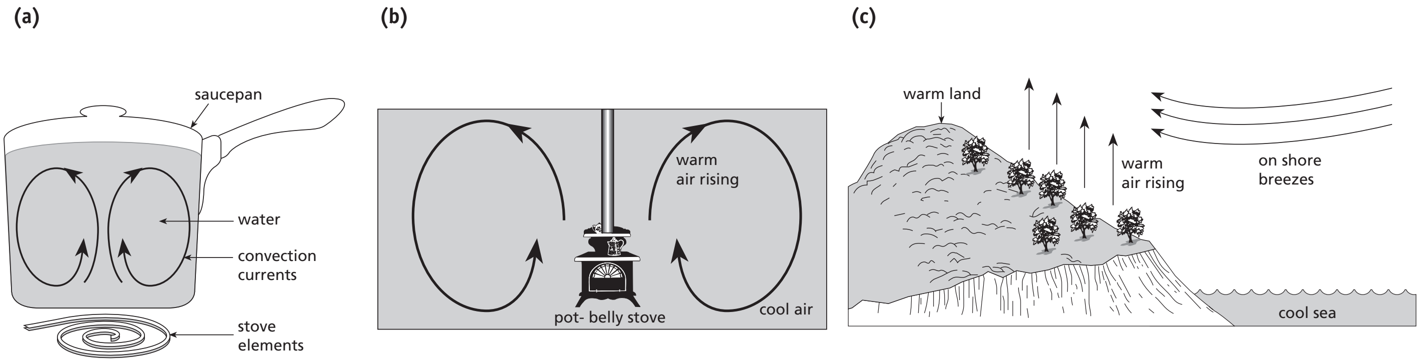


12.3 CONVECTION

The second method of heat transfer is by the **convection** process. (The word convection comes from the Latin *convehere* meaning 'to carry together'.) Convection is similar to conduction but in this case the particles of the materials themselves actually move. While conduction is the transfer of heat by the vibration of particles of the material, convection is the transfer of heat by the movement of particles. As solid particles do not move, convection is confined to liquids and gases.

Convection is used to explain how pot-belly stoves heat rooms, why fireplaces 'draw' properly, how water is heated in saucepans, and how onshore and offshore sea breezes develop.

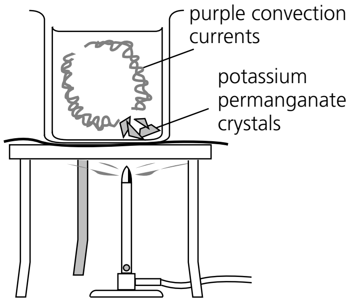
Figure 12.7
Convection. **(a)** Convection currents in a saucepan of water; **(b)** a pot-belly stove warms a room by setting up convection currents; **(c)** convection currents arise because the difference in temperature creates onshore breezes.



For example, when a pot-belly stove is placed in the centre of the living room it heats the air in its immediate vicinity. This air expands, becoming less dense and thus rising. Cooler surrounding air moves in to replace the hotter air that rises. The hot rising air cools as it goes higher and therefore recirculates, as shown in Figure 12.7**(b)**. Convection currents are thus set up. A similar process happens when water is heated in a saucepan on the stove.

Convection can be demonstrated very effectively in the laboratory. If one or two crystals of potassium permanganate are placed in a beaker of water as shown in Figure 12.8 and heated, the crystals dissolve as the surrounding water becomes hot. Purple convection currents of potassium permanganate solution are formed.

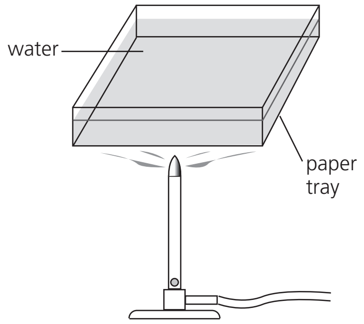
Figure 12.8
Heating potassium permanganate crystals produces observable convection currents.



Activity 12.3 BOILING WATER IN A PAPER BAG

Make a small paper container out of paper (Figure 12.9). Put some water in it and hold it over a candle. You can boil the water without burning the paper. Describe these effects in terms of conduction and convection.

Figure 12.9
Water will boil in a paper tray when heated.



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Activity 12.4 RESEARCH

Research one of the following and be prepared to explain your research to the class:

- Count Rumford spent his summer holidays in 1794 by the Italian beach. Instead of swimming he investigated convection currents. What did he find out?
- How are convection currents associated with afternoon onshore breezes and morning offshore breezes?
- How do gliders and hang-gliders use convection currents (‘thermals’)?
- How is convection used in solar hot water systems?
- What is the difference between convection ovens and fan-forced ovens?

In cold countries many homes are heated by convection (Figure 12.10). Proper design of convection systems allows the hot air to circulate and the cool air to return to the furnace to be reheated. The rush of air this creates near the vents can be very noticeable.

Figure 12.10
Convection currents are used to circulate heat throughout houses.

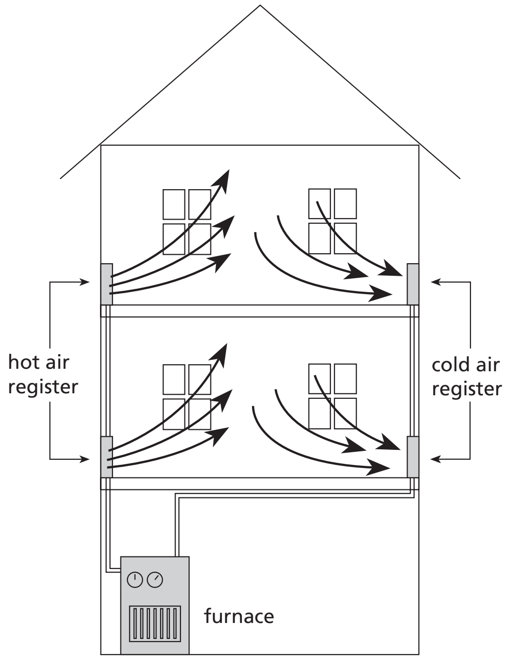
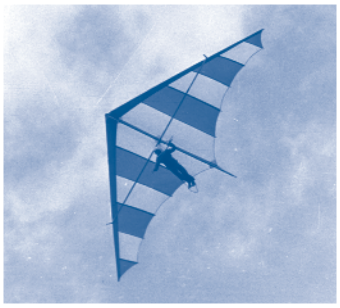
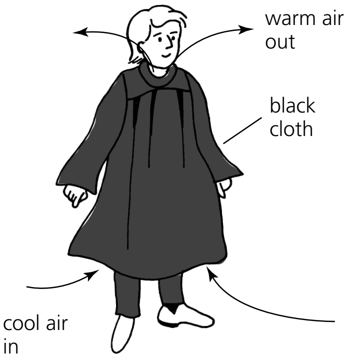


Photo 12.2
Hang-glider and thermals.



Some currents formed in the oceans, for example the gulf stream and the Japan current, are large-scale examples of convection.

Figure 12.11
Loose black clothes set up convection currents to control the temperature.



Staying cool in the desert

In even the hottest regions of north Africa, nomadic travellers wear black loose-fitting clothing to keep cool. We wear white to keep cool; so what is going on? The answer is that the black cloth heats up the air between the cloth and the skin creating an updraft, which draws cool air in as the warm air exits through the neck opening. This keeps the people from overheating.

Questions

5 What is the advantage of placing the heating element at the bottom of an electric kettle?

6 Why can heat energy from the Sun not be transferred to the Earth by conduction or convection?

12.4 RADIATION

In conduction and convection the vibration or the movement of particles results in heat energy transfer, but how does heat energy move between places where no particles exist? How does heat energy travel between the Sun and the Earth through the vacuum of space?

The heat is transferred by a process called **radiation**. The word radiation is from the Latin *radiate* meaning 'to emit beams'. This process involves the movement of heat energy by waves — **electromagnetic waves**. The properties of waves will be discussed in Chapters 13, 14 and 15.

SR Activity 12.5 HOT BULBS

Put your hand on the glass of a light bulb that is turned off (and is cool). Turn the light on and immediately you will feel the heat from the electromagnetic radiation. Turn if off. Is the glass hot? Explain.

All bodies radiate energy in the form of electromagnetic waves whose wavelength is in the infrared region. The wavelengths of these waves are longer than those of visible light and therefore cannot be seen. However, they can be detected. Most people have seen films in which various pieces of apparatus are used to detect the differences in infrared radiation given off by humans compared with those of the surroundings.

Hot bodies give off more of this radiation than cooler ones. The wavelength of the infrared radiation emitted depends on the temperature of the radiating body. For example, a table in a darkened room can be photographed with infrared sensitive film while it cannot be seen by the naked eye. This property of bodies to emit infrared radiation has many applications in industry and medicine, as well as for the military:

- Tumours below the skin's surface have a higher metabolic rate than the surrounding tissue. They therefore produce more heat. Infrared **thermography** is used to map the infrared radiation given off by the tumour and surrounding tissue. Electronic processing can produce coloured pictures of a person's body.

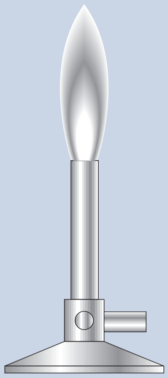
INVESTIGATING

For thirty years the science literature has reported that warm water freezes more quickly than cold water. This sounds like nonsense, but under certain conditions it will happen. It all has to do with the different convection currents. Your design should include: different conditions (lid on/off); different container (polystyrene/glass; tall/short); and a search for trends (try 40°C, 60°C, 80°C). It is a perfect experiment for using a TI-83 and CBL data-logger (or similar).

Photo 12.3
A thermogram. An infrared photograph shows the different amounts of heat emitted from different parts of the human body.

NOVEL CHALLENGE

The temperature around a Bunsen burner is lower the further you are from it. But does the temperature fall away evenly in all directions? Draw a Bunsen flame as in the diagram below and predict where points of similar temperature will be, keeping in mind that both convection and radiation are operating. Join these points of equal temperature — they are called 'isotherms' (Greek *iso* = 'equal'; *thermos* = 'heat'). Try it!



- Some animals such as rattlesnakes and some birds use special heat receptor cells to detect and track their victims. The sidewinder missile used by air force fighters to 'home in' on the heat emissions from the exhaust of enemy aircraft obtains its name from the rattlesnake (or sidewinder).
- The military has developed many applications of the detection of infrared radiation. In the Second World War infrared sensitive film was used to detect the damage done to enemy factories even when there was cloud cover. With the Vietnam conflict, sophisticated scopes for rifles were developed. These could pick up and amplify the body heat of the enemy, let alone the heat from a match or the glow of a cigarette in the mouth — not a good idea!
- Satellites using infrared photography are now in regular use. They have been used to detect troop movements and missiles being launched, as well as to detect hot underground rock formations. One coal-mining community in Pennsylvania in the USA disappeared when oxidation of coal seams caused huge underground caverns to cave in. Another community was saved when satellite controllers using infrared photography were able to give sufficient warning.

The Sun, a very hot body, radiates infrared heat energy, which reaches the Earth. Approximately 1400 joules of heat energy is arriving per second at every square metre of the upper atmosphere of the Earth. When this radiation strikes an object it causes the molecules of the object to gain energy and vibrate faster, resulting in the object becoming hotter. Some objects absorb this radiation better than others. Dark objects absorb radiation better than white objects, while white shiny surfaces also reflect heat.

- Why is it that sports-people who play sport in the Sun (cricket, tennis etc.) wear white clothing?
- What colour is the traditional clothing of desert peoples of north Africa?

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Activity 12.6 HOUSEHOLD APPLIANCES

It would be a worthwhile exercise to check the appliances around the house to identify those that rely on the reflection of radiation to improve their performance. Make a list of these and select one to explain its operation.

FURTHER APPLICATIONS

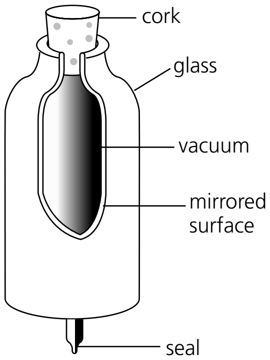
12.5

An understanding of conduction, convection and radiation is useful in the designing of better appliances and improving living conditions.

- A thermos flask or vacuum flask is a good example of how an understanding of heat energy transfer has produced a more efficient product.

  Double glass walls containing a vacuum reduce the loss of heat by convection and conduction. The walls are also silvered to reflect heat back into the flask and reduce the loss of heat by radiation. However, the fluid in a vacuum flask does change its temperature with time. Can you suggest where most heat loss occurs?
- Greenhouses have always been efficient at maintaining a warm environment for better plant growth. Shorter high energy infrared waves from the Sun pass through the glass walls and heat the plants and the soil. These in turn emit longer, lower energy infrared waves that cannot penetrate glass. Thus the inside of the glass house remains hot. Carbon dioxide and other gases in the environment act in the same way as the glass in a glasshouse. These gases in the atmosphere let in ultraviolet waves, which are converted to infrared and cannot get out, thus heating the Earth. This produces the 'greenhouse effect'. However, a certain level of this is needed. It has been suggested that the Earth's atmosphere would be, on average, 133°C cooler but for the greenhouse effect.

Figure 12.12
A simple thermos flask.



NEI

Activity 12.7 INSULATION

'Silver batts' are advertised as being an excellent method of insulating houses. Investigate the characteristics of these 'batts' that might help you to determine the truth in these advertisements.

SR

Activity 12.8 BUNSEN ISOTHERM

EI

The temperature around a lit Bunsen burner gets lower the further you are from the flame. But it is not a regular decrease because of convection currents taking hot air upwards.

1 Predict the shape of lines joining points of equal temperature about a Bunsen flame (as viewed from the side). These lines are called **isotherms** (Greek *iso* = 'equal').

2 Use a thermometer to measure temperatures around the flame at say 10 cm intervals away from the flame. Do this for points directly above the flame (12 o'clock), 1 o'clock, 2, 3, 4 and 5 o'clock. Do you need to do both sides of the flame? Now draw an isotherm diagram. Explain why the shape is not symmetrical.

NOVEL CHALLENGE

The roofs of two houses are covered in snow. *In which house is the ceiling insulation better: the one in which the snow melts quickly or slowly?*

NOVEL CHALLENGE

Cut a grape almost half-way through and pull each half apart slightly so that there is a thin bridge of skin between the two halves. Put it in a microwave and give it 10 seconds on high. *Now explain that!*

Practice questions

The relative difficulty of these questions is indicated by the number of stars beside each question number: * = low; ** = medium; *** = high.

Review — applying principles and problem solving

*7 Which allows heat to flow better: cork or iron? Why do you think this is so?

*8 Explain why convection occurs in fluids but not in solids.

*9 If a couple of blocks of ice are placed in a test-tube with water as shown in Figure 12.13, the ice will float at the top — ice is less dense than water. Explain the process by which the ice obtains heat energy needed to melt.

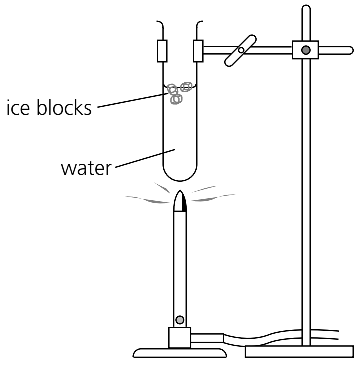


Figure 12.13
For question 9.

*10 Explain how a hot cup of coffee sitting on the kitchen table loses heat energy.

*11 A concrete floor is 15 cm thick. If the temperatures on opposite sides of the floor are 4°C and 20°C, calculate the rate of heat flow per unit area of the floor.

*12 Calculate the heat lost through a 3 m by 3 m brick wall if the wall is 30 cm thick and the temperature of the exterior is 5°C and the internal temperature is 28°C.

INVESTIGATING

The Space Shuttle has 27 416 tiles each of area 15 cm^2 as surface insulation. They are made of low-density silica fibre coated with waterproof borosilicate coating. They can stand 1648°C whereas the aluminium skin underneath melts at 660°C. Find out the thermal conductivity of these tiles.

INVESTIGATING

Sunflower seeds germinate faster if microwaved for 30 s first. But if you do it for 60 s they don't germinate at all. On the other hand, carrot seeds take 14 days whether they are given 30 s or 60 s. Propose a testable hypothesis.

***13** Calculate the heat lost in 30 minutes through a 2 m × 1 m × 6 mm thick glass window if the temperature difference between the two sides is 20°C.

***14** Does wood burning in a pot-belly stove warm the room by conduction, convection, or by radiation? Explain.

***15** What colour are the copper pipes used in solar hot water systems? Why are they this colour?

***16** What is the difference between infrared radiation and visible light?

***17** Explain why an iron rod at 1000 K is red-hot while a similar rod at 2000 K is white-hot.

***18** Why on a cold morning do the silver handlebars of bicycles feel colder than the black rubber hand-grips?

***19** On a cold winter's morning why does a metal spoon feel colder than the table it rests on?

***20** Why do knitted jumpers keep you warm in winter?

***21** Brass bases are good for saucepans, but why are the sides not made of brass? There may be economical and weight reasons for this, but what is a good reason in terms of conduction?

***22** A 375 mL can of 'Coke' and a 375 mL bottle of 'Coke' were placed in the freezer at the same time.

(a) Which would cool the faster?

(b) What other physical characteristics of the containers would be worth considering in arriving at your answer to part **(a)** of this question?

***23** Metal roofs of houses were traditionally left white or silver, but manufacturers over recent years have been producing them in all colours. Is this a good move? Explain.

***24** In cold countries where icy conditions can make roads slippery, gravel or soot is thrown on the icy roads. What effect would this have?

***25** Why do many people die in intense bush fires without being touched by the flames?

***26** A Davy Safety Lamp consists of a wire mesh box placed over a lit candle (see Figure 12.14). If a stream of Bunsen burner gas is directed at the mesh cage the gas burns but the flame does not come through and ignite the Bunsen burner. Explain why this is so and its advantage in coal mines.

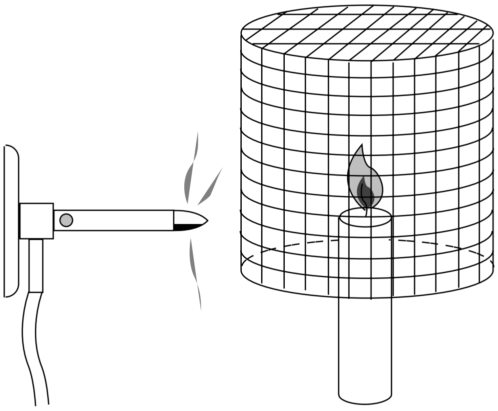


Figure 12.14
A Davy Safety Lamp.

***27** A glass box is equipped with glass chimneys. A small candle is placed under one of the chimneys and smoke is introduced into the other chimney.

(a) In what direction does the smoke move? Explain why.

(b) A lid is put on the top of the chimney above the candle. What happens now?

***28** Will a candle burn in zero gravity, such as on board a space shuttle, even if there is a normal supply of oxygen? Explain your answer.

*****29** A candle is lit and placed in a can open at the top. The can is dropped from shoulder height to the ground but remains upright while it descends. Will the candle go out? Explain. If you cannot decide, try it.

*****30** A match held near a powerful light bulb (say 100 W) will not ignite, but if you blacken it with graphite from a 'lead' pencil it will. Explain.

*****31** People can dip their moist fingers in molten lead (400°C) without getting burnt. How can this be? Do not try it!

****32** Do you think you could make a lens out of ice and use it to focus the Sun's rays on some paper to ignite it? Would the ice melt before the paper was hot enough to catch on fire? Explain in terms of radiation and conduction.

Extension — complex, challenging and novel

*****33** Modern house designers pay a great deal of attention to the conservation of energy. In doing so they insulate houses to reduce the loss of heat in winter and the absorption of heat in summer. Heat is lost through the roof, the walls, the windows, the doors and cracks. Suggest where most heat is lost. Also suggest how these losses can be reduced. This will involve describing the types of materials that may be used.

*****34** Heat sinks on CPUs and transistors have certain characteristics that improve their performance. They are normally black, thin, made of aluminium, and have many vanes to increase their surface area. Critically analyse each of these characteristics and the ability of each to help to remove heat from the device.

*****35** Windows in office buildings are double glazed to conserve energy. Analyse the construction of double glazed windows to determine how they achieve this purpose.

*****36** Many modern low-set school buildings are constructed of 20 cm concrete blocks. If a school room has dimensions of 4.0 m × 3.5 m × 2.5 m, calculate the heat lost from this room through the walls to the exterior in 30 minutes if the external temperature is 15°C and the internal temperature is 25°C.

*****37** Imagine a baby duck's body to be a perfect sphere of 7 cm diameter with an internal temperature of 32°C (Figure 12.15).

Some data:

- Volume of a sphere = $\frac{4}{3}\pi r^3$.
- Surface area of a sphere = $4\pi r^2$.
- Thermal conductivity of feathers = 0.03 W/m/°C.

(a) Calculate the rate of heat flow from the duck on a day when the outside temperature is 15°C. Make whatever assumptions about the duck and its feathers you find necessary.

(b) How much heat does the duck have to generate per hour to maintain its body temperature at 32°C?

(c) Due to some genetic engineering, if the baby duck was a perfect cube instead of a sphere but still had the same volume, would the rate of heat loss be any different? Explain!

Figure 12.15
Spherical duck.