CHAPTER 12

Heat Transfer

INTRODUCTION 12.1

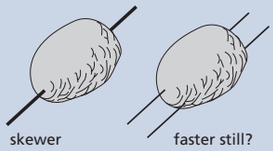
The transfer of heat energy from one place to another may seem unimportant to many. How does this affect me? What use is this to me? However, like many applications of physics, heat energy transfer unknowingly affects our everyday life more than a casual glimpse would suggest.

- 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?*



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?

Activity 12.1 HEAT LOSSES

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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.

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.)

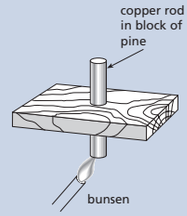
This would also suggest that solids are better conductors than liquids, which are in turn better than gases. This, in general, is true, as the particles in most solids make closer contact with each other than those of liquids or gases. Table 12.1 indicates the rate of heat flow through particular materials. 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

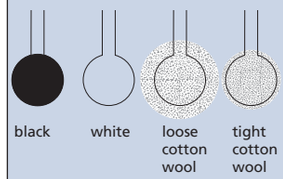
NOVEL CHALLENGE

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.

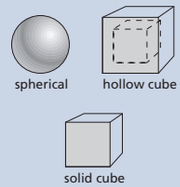


NOVEL CHALLENGE

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

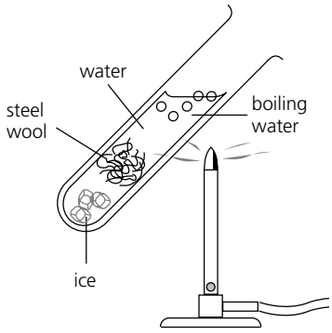
You have three ice-cubes of the same mass. *Which one will melt first? Why?*



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.

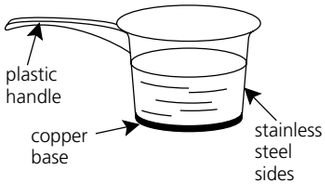


Bonding

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.

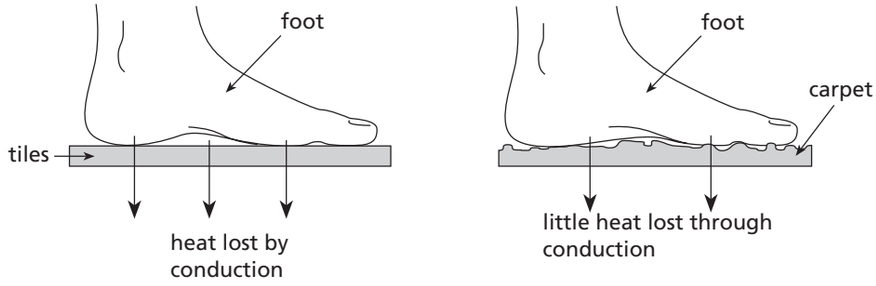
Figure 12.2
Copper-based saucepans conduct heat well whereas poor conductors are good for handles.



Staying cool or hot

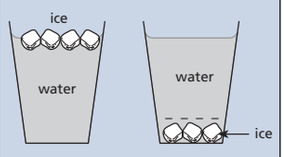
A special mention has to be made of those materials (many synthetic) that are poor conductors because they trap air within their fibres. Since air is a poor conductor (Table 12.1), materials that trap air do not transfer heat energy very well. Materials such as wool, fur, polystyrene, carpet, fibreglass 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.



NOVEL CHALLENGE

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



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?