3 Transfer of Thermal Energy

Videos & questions on the CD ROM

Energy will always try to flow from areas at high temperatures to areas at low temperatures. This is called **thermal transfer**. Thermal energy can be transferred in three main ways:

- **conduction**
- **convection**
- **radiation.**

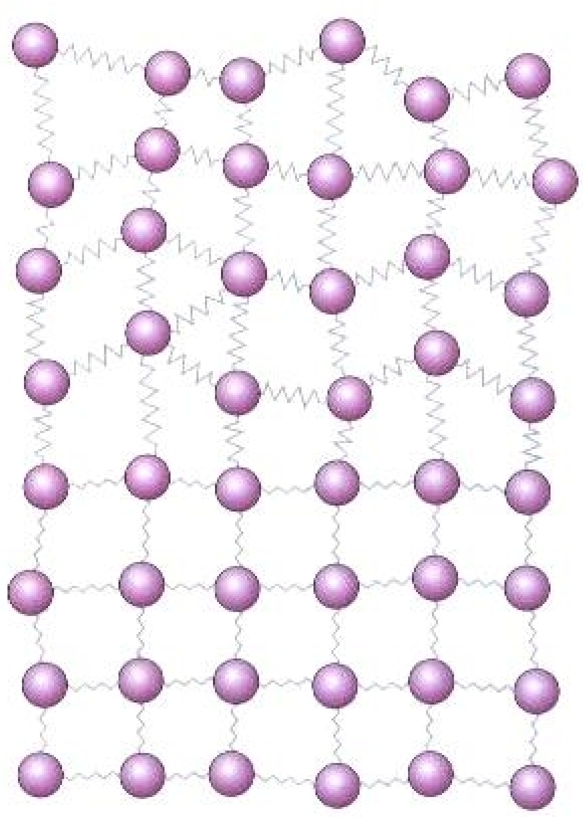
Conduction

Materials that allow thermal energy to transfer through them quickly are called **thermal conductors**. Those that do not are called **thermal insulators**. (If someone talks about an 'insulator', you may have to work out for yourself if he is referring to a thermal insulator or to an electrical insulator.)

If one end of a conductor is heated, the atoms that make up its structure start to vibrate more vigorously. As the atoms in a solid are linked together by chemical bonds, the increased vibration can be passed on to other atoms. The energy of movement (kinetic energy) passes through the whole material.

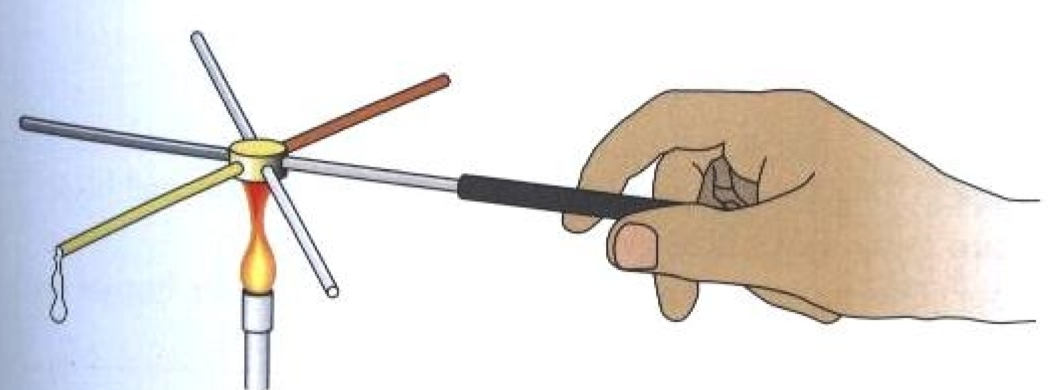
Metals are particularly good thermal conductors because they contain freely moving electrons which transfer energy very rapidly. As the electrons travel all over the piece of metal, they take the thermal energy with them. This is in addition to the thermal energy that is transferred by vibrations of the atoms that make up the structure of the metal.

Conduction cannot occur when there are no particles present, so a vacuum is a perfect insulator.



Conduction in a solid. Particles in a hot part of a solid (top) vibrate further and faster than particles in a cold part (bottom). The vibrations are passed on through the bonds from particle to particle.

EXPERIMENT TO SHOW CONDUCTION



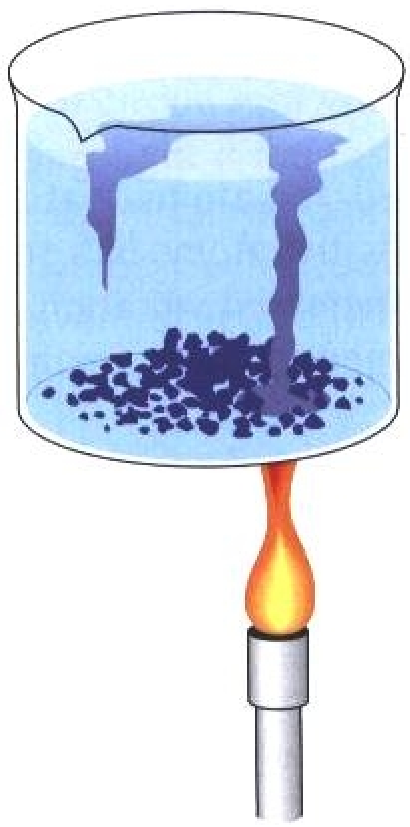
The rods are made of different metals, so the heat conducts along them at different rates. The better the conductor, the quicker the wax at the end of the rod melts.

Convection

Convection occurs in **liquids** and **gases** because these materials flow (they are 'fluids'). The particles in a fluid move all the time. When a fluid is heated, energy is transferred to the particles, causing them to move faster and further apart. This makes the heated fluid less dense than the unheated fluid. The less dense warm fluid will rise above the more dense colder fluid, causing the fluid to circulate. This **convection current** is how the thermal energy is transferred.

If a fluid's movement is restricted, then energy cannot be transferred by convection. That is why many insulators, such as ceiling tiles, contain trapped air pockets. Wall cavities in houses are filled with fibre to prevent air from circulating and transferring thermal energy by convection.

EXPERIMENT TO SHOW CONVECTION



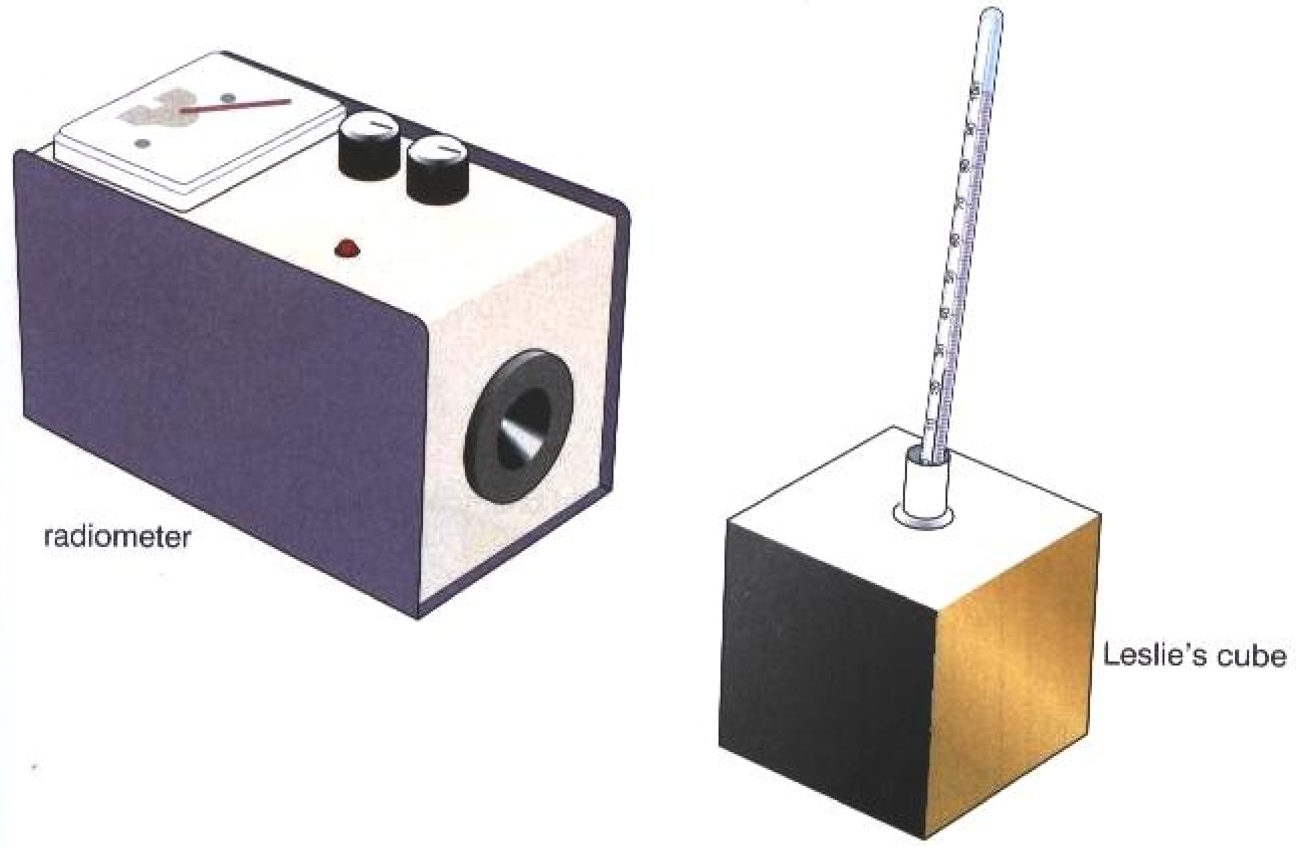
Potassium permanganate crystals in water demonstrate convection. The warmer water expands, becomes less dense and rises, making a trail as some of the dissolved potassium permanganate is carried along as well.

Radiation

Radiation, unlike conduction and convection, **does not need particles** at all. Radiation can travel through a vacuum. This is clearly shown by the radiation that arrives from the Sun. Radiated heat energy is carried mainly by infrared radiation, which is part of the electromagnetic spectrum.

All objects take in and give out infrared radiation all the time. Hot objects radiate more infrared than cold objects. The amount of radiation given out or absorbed by an object depends on its temperature and on its surface.

Type of surface	As an emitter of radiation	As an absorber of radiation	Examples
Dull black	Good	Good	Emitter: Cooling fans on the back of a refrigerator are dull black to radiate away more energy. Absorber: The surface of a black bitumen road gets far hotter on a sunny day than the surface of a white concrete one.
Bright shiny	Poor	Poor	Emitter: Marathon runners, at the end of a race, wrap themselves in shiny blankets to prevent them from cooling down too quickly by radiation (or convection). Absorber: Fuel storage tanks are sprayed with shiny silver or white paint to reflect radiation from the Sun.

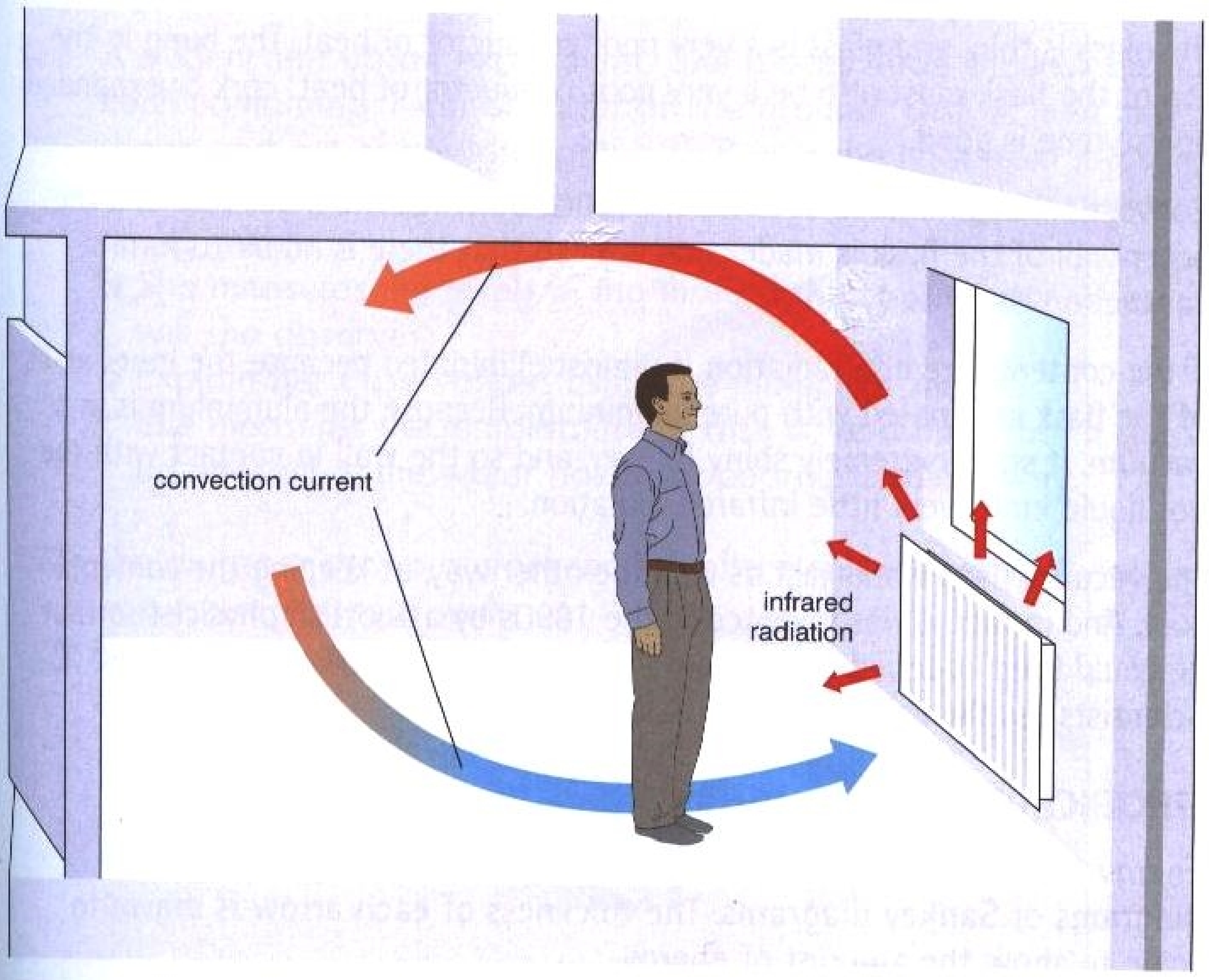


A radiometer is an instrument that allows you to measure the heat being radiated by a surface. If you want to compare the heat radiated by different surfaces, then Leslie's cube allows you to compare the effect of four different surfaces. These four surfaces, which might, for example, be shiny metal and dull metal, white paint and black paint, are heated to the same temperature by hot water inside. Hence any difference in the heat radiated is entirely due to the nature of the surface being measured.

Consequences of energy transfer

THE RADIATOR

A radiator does radiate some heat, and if you stand near a hot radiator your hands can feel the infrared radiation being emitted by the front surface of the radiator. However, this is only around one quarter of the heat being released by the radiator. *Three quarters* of the heat is taken away by the hot air that rises from the radiator. Colder air from the room flows in to replace this hot air, and a convection current is formed as shown.

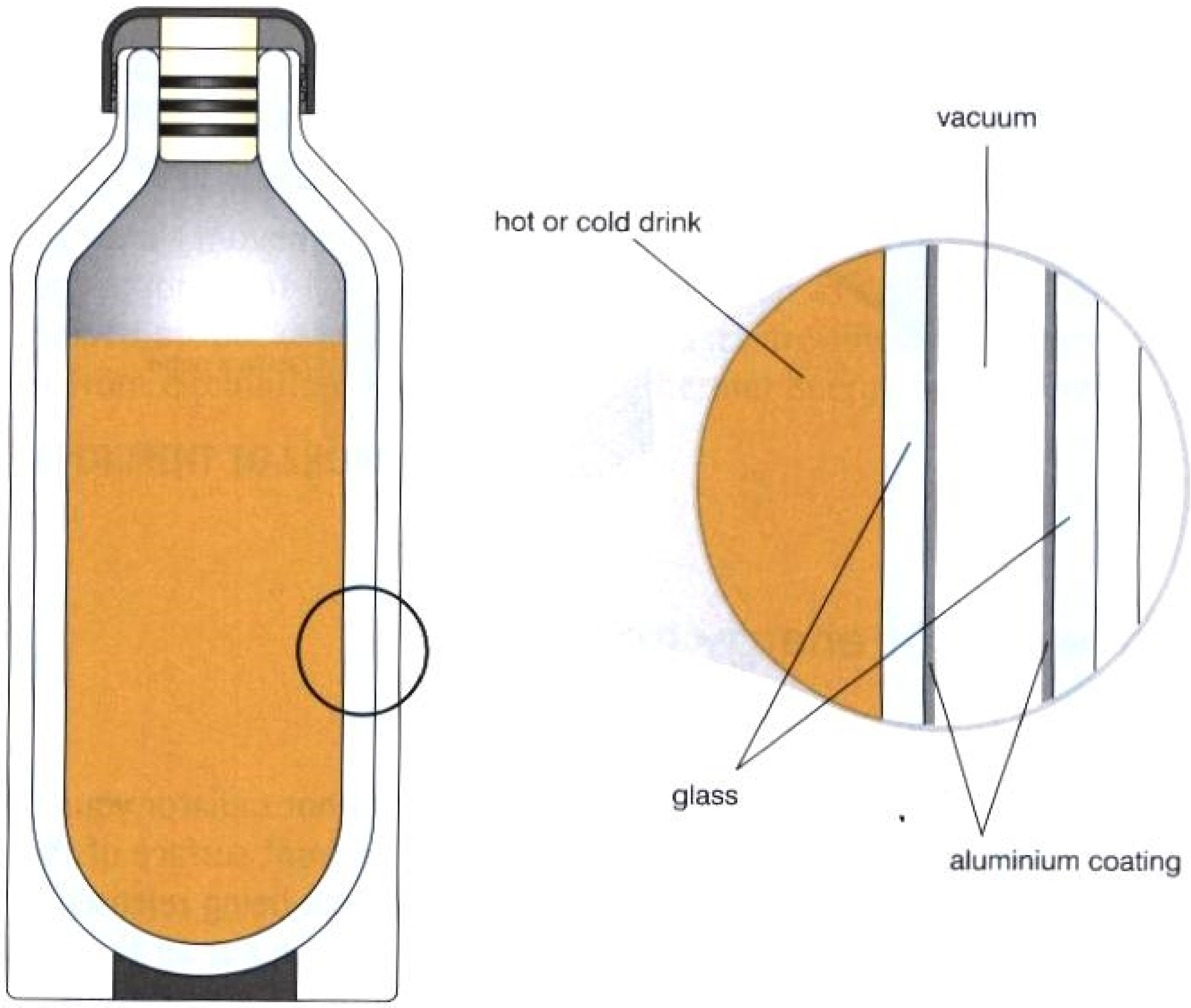


This shows a side view of a room with a hot-water radiator underneath the window.

You will note that the convection current is far more efficient at heating the top of the room than it is at heating the person standing in front of the radiator.

THE VACUUM FLASK

The vacuum flask will keep a drink hot or cold for hours by almost completely preventing the flow of heat out or in.



Conduction is almost eliminated by making sure that any heat flowing out must travel along the glass of the neck of the flask. The path is a long one, the glass is thin, and glass is a very poor conductor of heat. The bung in the top of the flask must also be a very poor conductor of heat: cork or expanded polystyrene is good.

Convection is eliminated because the space between the inner wall and the outer wall of the flask is made a vacuum so that there is no air to form convection currents.

If the contents are hot, radiation is almost eliminated because the inner walls of the flask are coated with pure aluminium. Because the aluminium is in a vacuum, it stays extremely shiny forever, and so the wall in contact with the hot liquid emits very little infrared radiation.

The vacuum flask works just as well the other way, at keeping the contents cool. And in fact it was invented in the 1890s by a Scottish physicist so that he could keep liquefied gases, such as liquid hydrogen that boils at −250 °C. Scientists usually call it a Dewar flask in his honour.

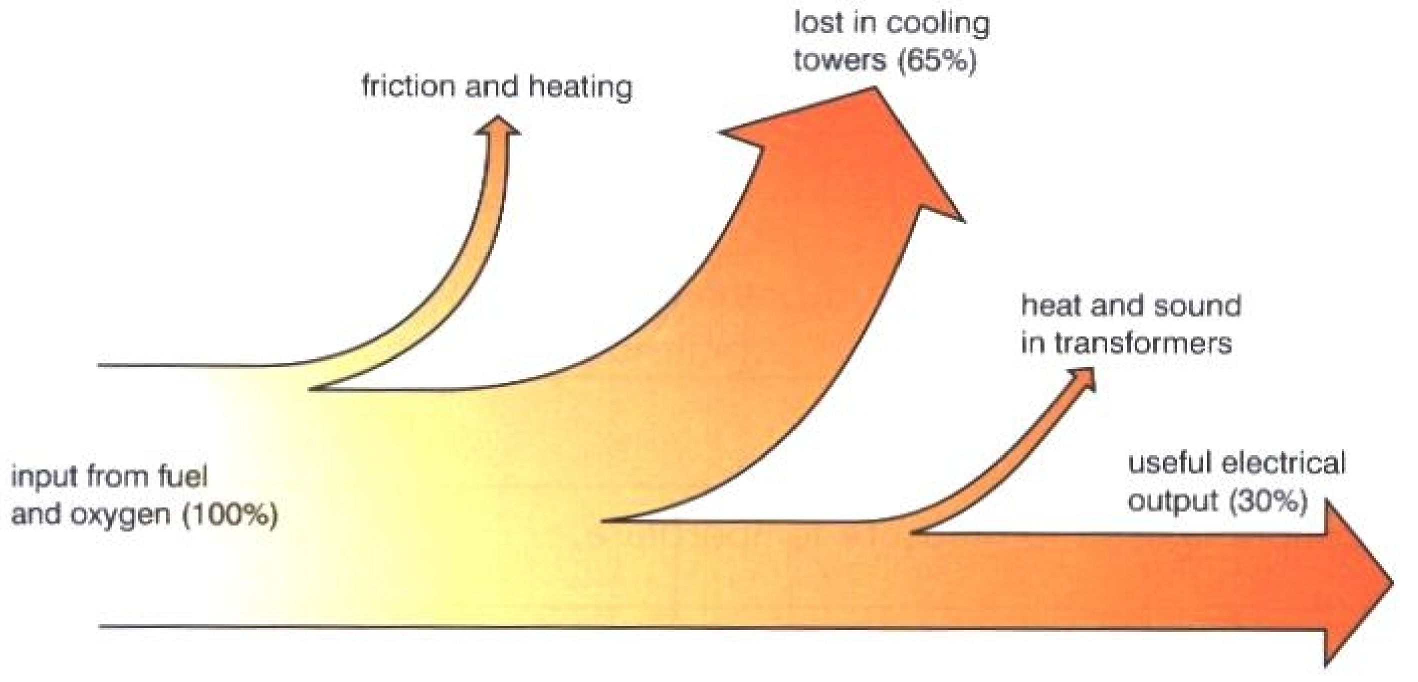
EFFICIENCY OF ENERGY TRANSFER

Energy transfers can be summarised using simple **energy transfer diagrams** or **Sankey diagrams**. The thickness of each arrow is drawn to scale to show the amount of energy.

Energy is always conserved – the total amount of energy after the transfer must be the same as the total amount of energy before the transfer. Unfortunately, in nearly all energy transfers some of the energy will end up as 'useless' heat.

In a power station only some of the energy originally produced from the fuel is transferred to useful electrical output. Energy **efficiency** can be calculated from the following formula:

$$\text{efficiency} = \frac{\text{useful energy output}}{\text{energy input}} \times 100\%$$



In a power station as much as 70% of the energy transfers do not produce useful energy. The power station is only 30% efficient.

Many power stations are now trying to make use of the large amounts of energy 'lost' in the cooling system. In some cities, the houses of whole regions of the city are heated by hot water from the power station.

REVIEW QUESTIONS

Q1 Why are several thin layers of clothing more likely to reduce thermal transfer than one thick layer of clothing?

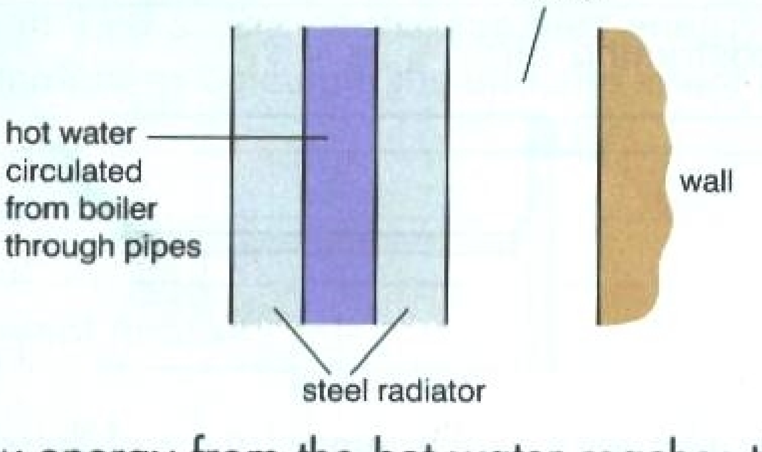
Q2 A student sets up an experiment. She places three shallow dishes each containing 1 cm of water on the ground. Dish A is in the shade and out of any draught; dish B is in the light from the sun; and dish C is both in the light from the sun and it is exposed to a strong wind.

a She measures the levels in the three dishes every hour. What will she observe?

b Explain her observations using the molecular model.

c She measures the temperature of dish B, and finds that it goes up after all of the water has disappeared. Explain why.

Q3 The diagram shows a cross-section of a steel radiator positioned in a room next to a wall.



Describe how energy from the hot water reaches the wall behind the radiator.

More questions on the CD ROM

Examination questions are on page 82.