Lesson Twelve

Physics: Convection and Radiation

Aims

By the end of this lesson you should:

- understand how convection transfers heat in fluids
- know how heat is transferred through a vacuum by radiation
- know which surfaces are better at emitting and absorbing radiation
- understand how to minimize heat loss

Context

This lesson completes the study of heat and how it travels that was begun in Lesson Nine.

Oxford Home Schooling

Introduction

In Lesson Nine we learned about the difference between heat and temperature, about how thermometers work, and about how heat travels by **conduction**.

Conduction is the only way in which heat can travel through a solid, because its particles are in fixed positions. But in a **fluid** (a liquid or gas) the particles are moving about and the fluid can flow. This means heat can travel in a second way in fluids – by **convection**.

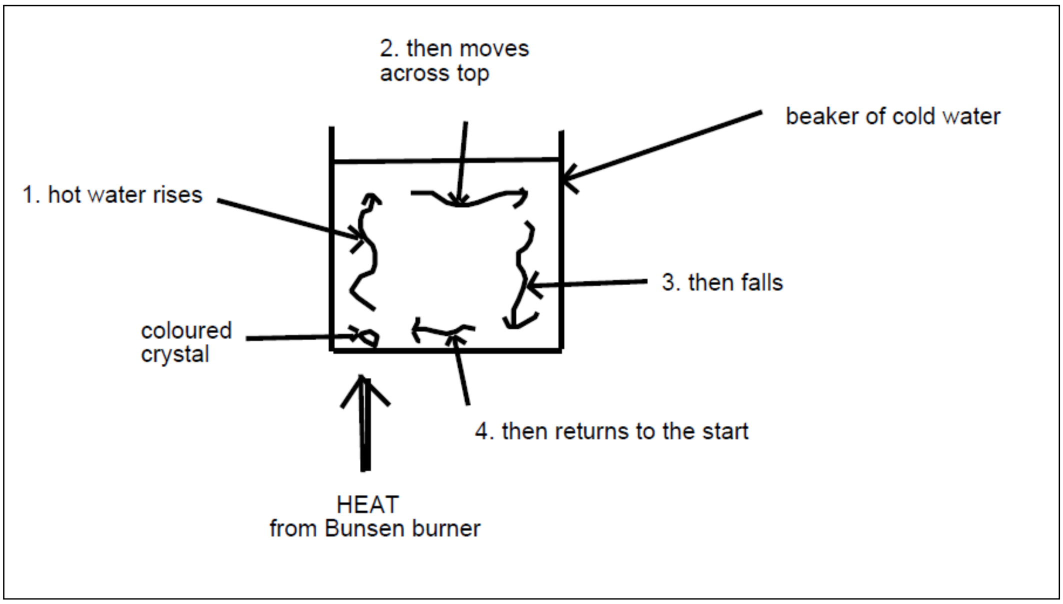
Neither conduction nor convection can carry heat across a **vacuum**, because in a vacuum there are no particles to carry it. But heat can cross a vacuum in a third way – by **radiation**.

In this lesson we look in detail at convection and radiation, and some practical situations in which they are important. We then draw our study of heat together by looking at two important places in which heat transfer needs to be minimised.

Convection

Convection in Liquids

If this apparatus is set up, with the Bunsen burner heating only the part of the beaker directly below the coloured crystal, something strange happens.



The crystal dissolves slowly in the water, making the liquid around it dark purple. Then a stream of dark purple water rises straight up to the top, turns right along the top, falls back down on the right and returns along the bottom to the crystal. The process continues, and very soon all the water in the beaker has turned dark purple – and much quicker than if the Bunsen burner had not been used.

The stream of purple water is called a **convection current**, and the convection current carries hot water (and therefore heat) to the colder parts of the water warming them up. This is *much* quicker than conduction could achieve the same result, because water is a poor conductor of heat.

So – how does it work?

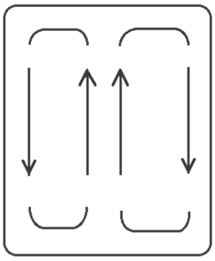
When the water around the crystal becomes hotter, its particles move faster and so spread out a little more. This makes the hot water *less dense* than the cold water around it. The less dense hot water *floats* on the colder denser water, so it moves up to the top. (For density, floating and sinking, see Lesson Three of the Year 7 Science course.) This water, as it cools, completes the rest of its circuit pushed by new hot water coming up behind it. It finally fills the gap at the start left by new hot water rising.

Immersion Heaters

Suppose you have a hot water tank heated by an electric **immersion heater** in a home. Should you put the heater at the top or bottom of the tank? The answer is: it depends!

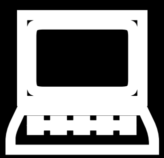
- If you put the heater at the *top* the less dense hot water floats on the more dense cold water and there is no convection current. As water is a poor thermal conductor, heat moves down the tank only slowly. The water in the top half gets very hot while the water at the bottom stays cold. Result: you get a *small amount* of piping hot water for a shower, or for washing up, without having to heat the whole tank up. This is cheaper, because you don't have to heat water that you don't need.

- If you put the heater at the *bottom*, the heat will be spread out evenly by a convection current. It will take longer, and cost more, to get any of the water hot enough for your shower. But once it *is* hot there is lots of it.



So it depends – it depends upon how much hot water you are planning on using.

Activity 1



1. You can see lots of pictures and diagrams of immersion heaters at Google Images. Put "immersion heater" in the search box.
2. You can see videos of the experiment with the coloured crystal on You Tube at www.youtube.com. Put "convection current" in the search box.

Convection in Gases

You get convection currents in gases like air for exactly the same reason as in liquids. In hot air the particles move faster and are more spread out, and the air becomes less dense. So hot air will rise above denser cold air, carrying heat with it.

Twig

Log on to Twig and look at the film titled: **Hot Air Balloons**

www.ool.co.uk/1528bw

Hot air balloons rely on heat alone to keep them in the sky. How does this work?

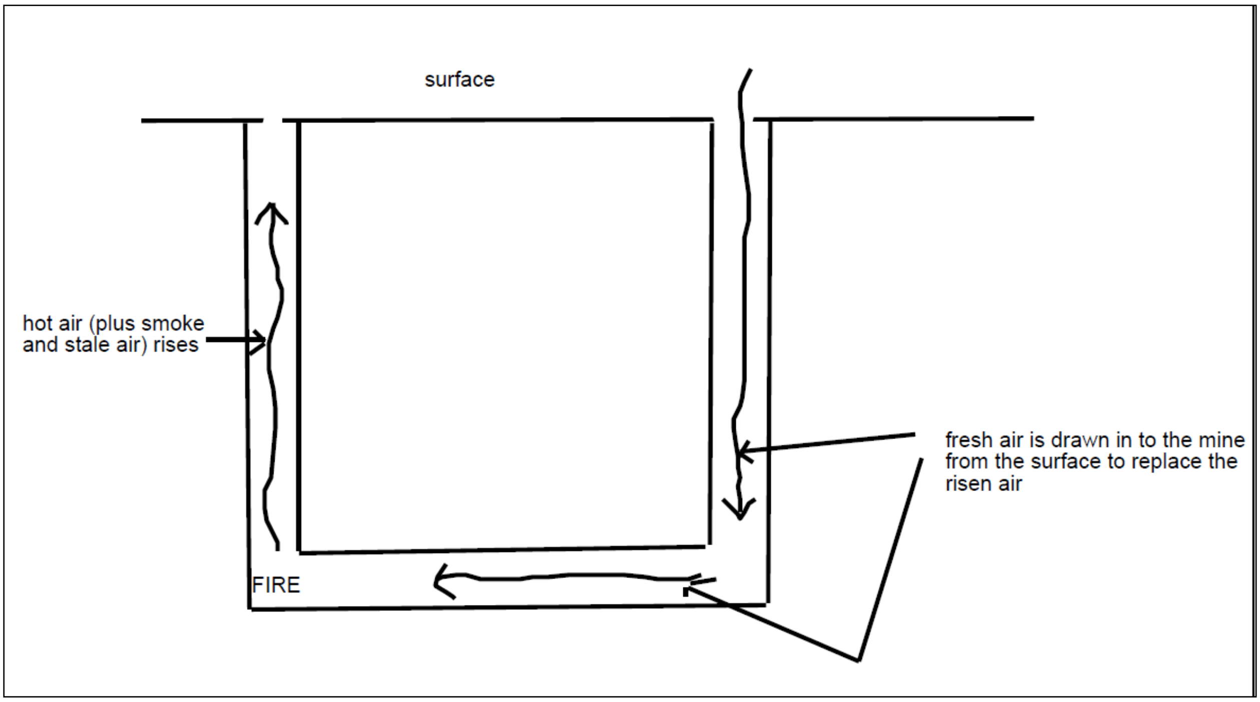
Hot air balloon

A hot air balloon rises because the hot air inside it is less dense than the colder air outside.

Get it right! People say "heat rises", but that is not quite right. Hot air rises above cold air, carrying heat with it.

Ventilation in Mines

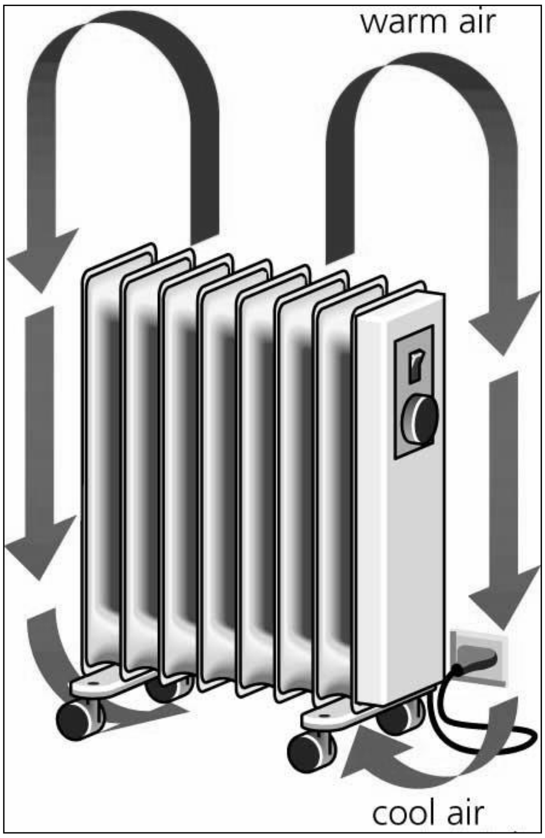
Years ago, convection currents were used to provide ventilation (give fresh air) in deep mines such as coal mines. Miners would dig two vertical shafts, connected by a horizontal tunnel, like this.



They would light a fire under just one of the shafts. This would produce a convection current, drawing fresh air in down the other shaft so the miners could breathe. Of course, the smoke from the fire went straight up the first shaft, so this was not a problem.

Radiators in a Room

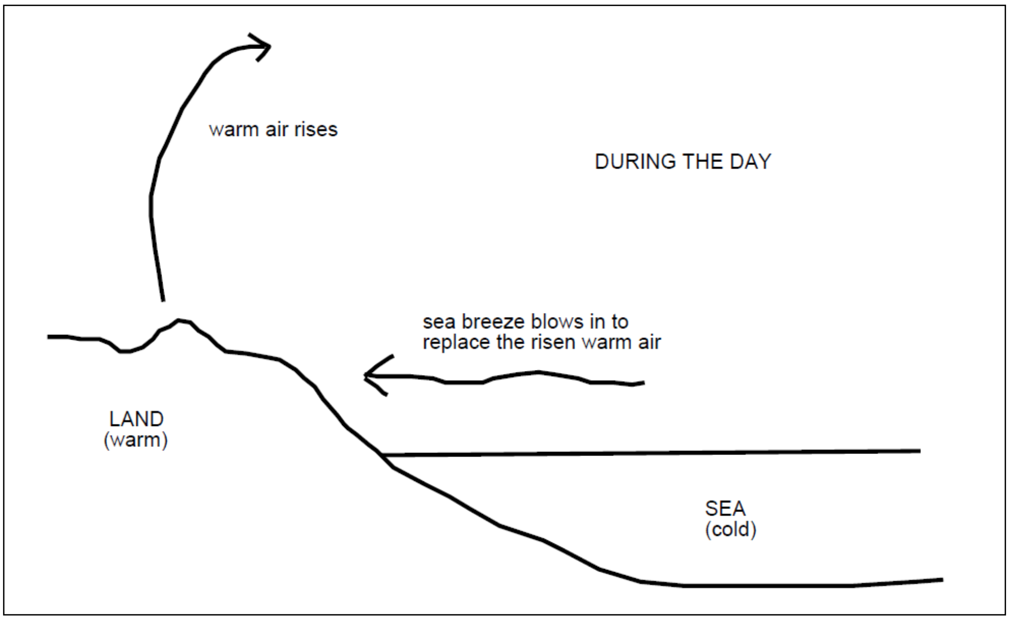
Convection currents are also used to keep rooms warm. The room's radiator warms the air around it. This sets up a convection current that circulates around the whole room, spreading the heat from the radiator out evenly.



Notice that "radiator" is a bad name for this device: "convector" would be more accurate!

Land and Sea Breezes

During the day at the coast, the land heats up faster than the sea. (You will have noticed how cold the sea remains, even when the sand on the beach is baking hot from the sun!) This sets up a convection current, with air rising over the land and sinking over the sea.

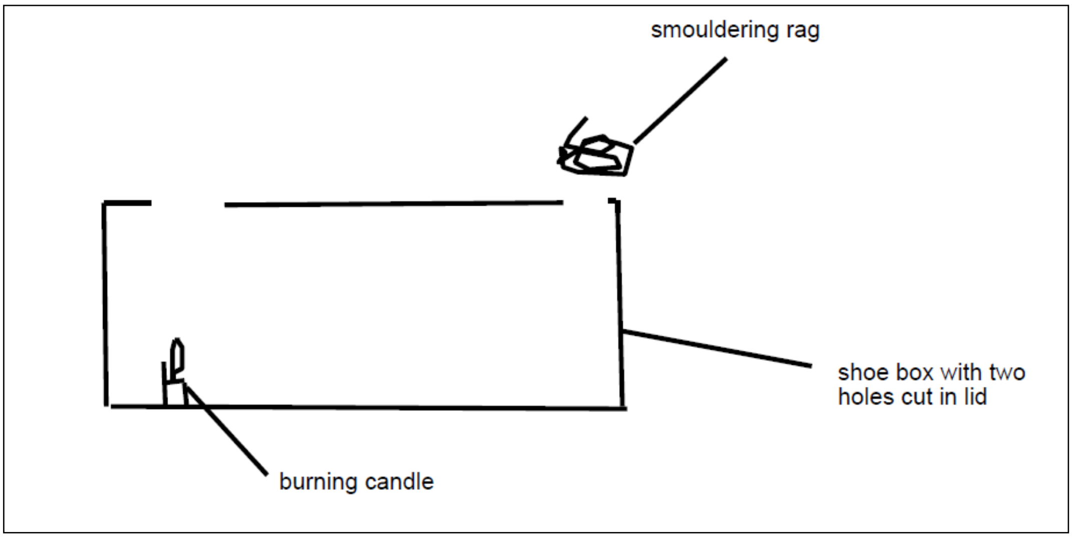


At the coast itself a **sea breeze** blows in off the sea and keeps the coast cool during the hot day.

At night the land cools down faster than the sea and is soon colder. The direction of the convection current is reversed and a **land breeze** blows off the land and out to sea.

Activity 2

Under adult supervision you can try the following to imitate the ventilation system from a coal mine. You should find that smoke from the smouldering rag is drawn into the box, and then out the other side, by the convection current set up by the burning candle.



Safety: (1) Never leave a candle, or a cloth, burning or smouldering unattended, and keep well away from curtains, clothes and hair. (2) Open windows for ventilation, and avoid inhaling smoke.

Radiation

Both conduction and convection depend upon the presence of particles:

- In conduction the vibrations are passed from particle to particle by them banging into each other

- In convection, the heat is carried in the faster-moving particles that rise in the less dense water or air.

However, between us and the sun there is about 150 million kilometres of space with no particles in it at all – a vacuum. So if heat is to reach us from the sun it cannot travel by conduction or convection!

Fortunately there is a third way in which heat travels, which actually happens best of all through a vacuum. This is **radiation**. When you feel the warm sun on your skin in the summer, or heat from a fire on your face, that heat is arriving at your skin by radiation.

Log on to Twig and look at the film titled: **Radiation**

www.ool.co.uk/539hc

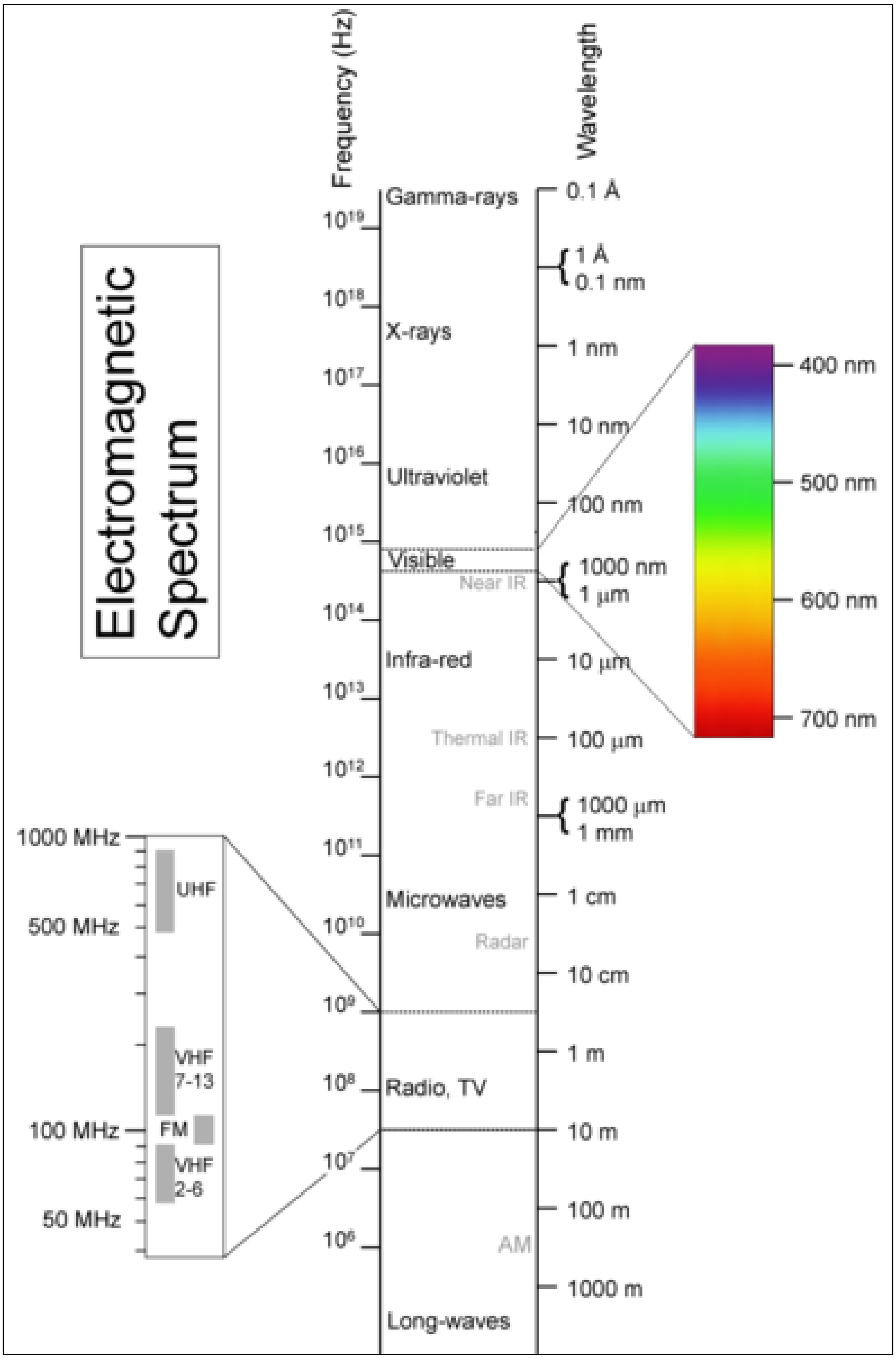
Though often used more narrowly to refer to ionising radiation, the term radiation refers to any form of energy that travels through a medium, radiating outwards from a source.

Types of Radiation

Light can also travel through a vacuum, so it too is a form of radiation. The same is true for:

- Radio waves (which carry signals to radios and TVs)
- Microwaves (used for cooking in a microwave oven)
- Ultraviolet radiation (that causes sunburn)
- X rays (used to take pictures of the bones inside your body)

Physicists call all these **electromagnetic radiation**, because they involve both electricity and magnetism in how they work. They call “heat radiation” **infrared radiation**, because it is most similar to the red end of the spectrum of visible light.



The Electromagnetic Spectrum

The full electromagnetic spectrum, showing the "wavelength" of each type of radiation. Notice that "infrared" is next to red light, and "ultraviolet" is next to violet light. Note well: you do NOT have to remember all this information!

Log on to Twig and look at the film titled: **EM Spectrum**

www.ool.co.uk/1443ve

The range of electromagnetic radiation in the electromagnetic spectrum is huge. Where does this radiation come from and how do the frequencies and wavelengths vary?

Heating things up

Heat radiation travels best through a vacuum. When it hits matter (solid, liquid or gas) it is **absorbed** (taken in). Its energy is transferred to the particles of the matter that absorbed it, making them move faster. This warms the matter up. This is what is going on when you feel the sun's warmth on your skin.

Absorbing, Emitting and Reflecting

Not all surfaces are equally good at absorbing heat radiation:

- dull, black surfaces are the best,
- shiny white or silvery surfaces are the worst

White, shiny surfaces are best at *reflecting* heat radiation rather than *absorbing* it. (This is true for light as well, which is why they look brighter.) This is the reason you get hot very quickly if you wear dull black clothes in warm sunshine. White clothes reflect most of the heat, so keep you cooler!

Interestingly, dull black surfaces are best at *emitting* (giving out) heat radiation as well as absorbing it. So your kettle is white or silvery for a reason – it keeps its heat in better that way!

Activity 3

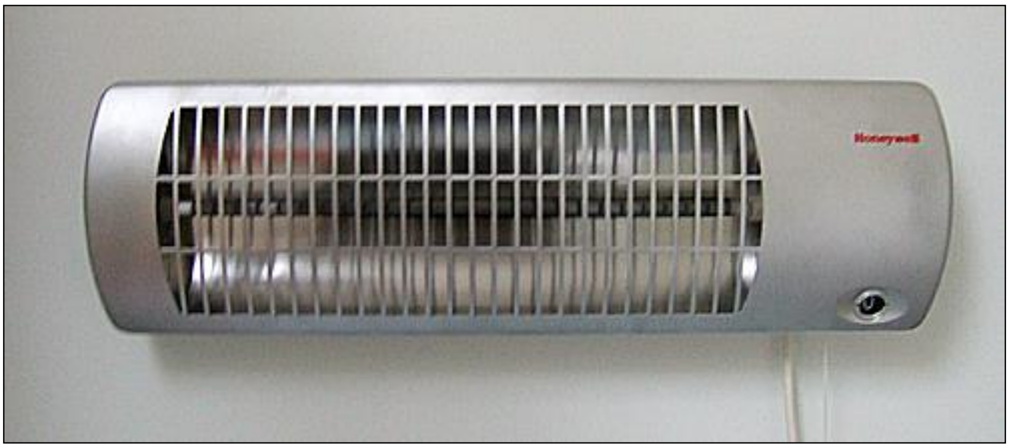
Start to make a small collection of different-coloured plastic bottles (before recycling them) and on a very sunny day fill them with tap water. Put them in the sunshine and leave them for one hour. After that time, feel the water in each bottle.

1. Does the colour of the bottle have any effect on the amount of heat it has absorbed?

2. What do you need to keep the same to make this investigation a fair test?

Grills and Fires

Grills, and old-fashioned electric bar fires ("radiant heaters") also give out heat radiation. In a grill, the food absorbs the radiation, which heats it up. With the fire, you, the furniture and the walls absorb the radiation, which then warms the air by conduction and convection to warm the room up.



A radiant heater

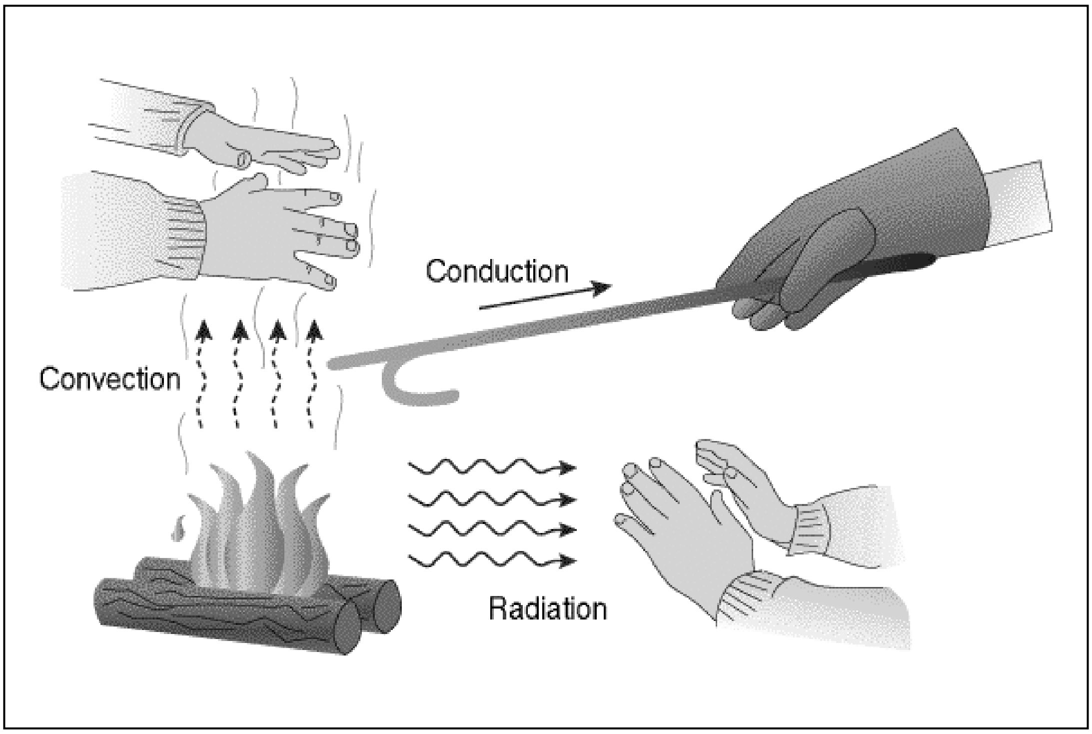
Space Blankets

Normal blankets keep you warm because they contain a thick layer of insulating air. This stops body heat escaping across them by *conduction*.

However the thin silvery space blankets, given to accident victims and finishers of the London Marathon to keep them warm, are too thin for this to work. Instead they reflect back the heat *radiation* that the body gives off.

Minimising heat loss

We now know that hot objects can lose heat in three ways: by conduction, by convection and by radiation.



If you want to keep a hot object warm, you need to minimise the most important of these – or even all three if you can.

Thermos Flasks

Believe it or not, the **thermos flask** (also called a **vacuum flask**) was first invented by a physicist to keep cold liquids cold! It will do this as well. But its main use these days is to keep hot drinks hot for several hours when on outings away from home.

Thermos flasks

The thermos flask has an inner glass container (shown above) made of two glass walls with a vacuum between them.

The flask reduces heat losses from the hot liquid inside in many ways:

- The cork bung contains air so little heat passes through by conduction
- The gap between the two layers of glass is a vacuum, so no heat can pass across by conduction or convection
- The inside glass wall is silvery on its outside (i.e. next to the vacuum) which makes it a poor emitter of heat radiation
- The outside glass wall is silvery on its inside (again, next to the vacuum) which reflects back any radiation that does get emitted

Keeping a House warm

It costs a lot of money to heat your house or flat! So it obviously makes sense to stop as much of that heat as possible leaking out. In an average house the heat is lost in approximately these amounts:

- 35% through the walls
- 25% through the roof
- 15% through the floor
- 10% through the windows
- 15% in drafts

The main problem is escape of heat by *conduction*. So the best way to minimise this is with the use of several form of *insulation*:

- **Cavity wall insulation**: foam, containing trapped insulating air, is pumped into the gap between the inside and outside layers of the walls. This is rather like getting the house to put on a thick pullover!

- **Loft insulation**: a thick layer of fibreglass, again with trapped insulating air, is laid down on the floor of the loft. This stops most of the heat getting out through the roof.

- **Double glazing**: windows with a vacuum between the two layers of glass, so no heat passes from the warm inner to the cool outer glass by conduction or convection. (Notice how similar this is to a thermos flask.)

- Thick carpets, again with trapped insulating air, stop heat moving out by conduction through the floor

Log on to Twig and look at the film titled: **Insulator**

www.ool.co.uk/706gj

Material that conducts heat or electricity very poorly, and so can be used to provide some measure of protection.

Activity 4

Carry out a survey of your home. How many of these features does your home have fitted?

Safety: Only enter the loft space of your house (if you have one) under adult supervision, and do not touch any of the insulating material found on its floor.

Activity5

Visit BBC Bitesize at

www.bbc.co.uk/schools/ks3bitesize/science/. Click on "Energy, electricity and forces". Under "Energy transfer and storage", investigate the last page of "Revise" and then do "Activity".

Keywords

Conduction
Convection
Radiation
Fluid
Emit
Absorb
Reflect
Vacuum flask
Cavity wall insulation
Convection current
Sea breeze
Land breeze
Electromagnetic radiation
Infrared radiation
Thermos flask
Double glazing
Loft insulation

Suggested Answers to Activities

Activity 3

(1) The dark coloured bottles should absorb most heat.

(2) The size of the bottles; the shape of the bottles; the amount of water in each bottle; the amount of sunshine each bottle receives.

Tutor-Marked Assignment D

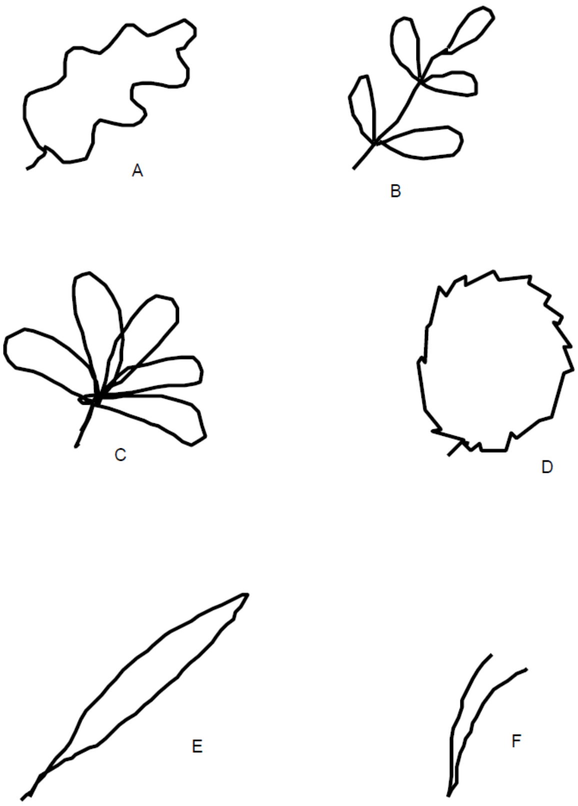
Please answer the questions below on lined paper and send to your tutor for marking.

Question 1

(a) Give the correct scientific term for the following:

(i) All the organisms in an ecosystem (1)
(ii) Deciding which species an unknown organism belongs to (1)
(iii) Moving to a different location to avoid winter (1)
(iv) A lake, a wood and a rocky seashore are all one of these (1)
(v) Trees which lose their leaves over winter (1)
(vi) The precise place within an ecosystem that a species lives in (1)

(b) A to F below are leaves from six common British trees. Use the key underneath to identify the trees (6):



1. Leaf has two or more leaflets .... go to 4
   Leaf has a single leaflet .... go to 2

2. Edge is simple .... Willow
   Edge is toothed or wavy .... go to 3

3. Edge is toothed .... Elm
   Edge is wavy .... Oak

4. Leaflets needle-like .... Pine
   Leaflets wide .... Go to 5

5. Leaflets paired .... Ash
   Leaflets in fan .... Horse Chestnut

(c) In each case, suggest *one* feature that adapts the species to its habitat, and explain how it helps it to survive there:

(i) ivy (a climbing plant which lives inside woods) (2)

(ii) rabbit (lives in grassland) (2)

(iii) goldfish (lives in ponds and lakes) (2)

(Total mark 18)

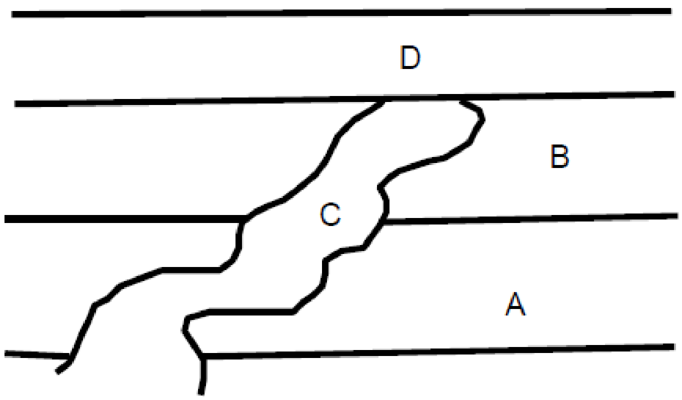
Question 2

(a) Give the correct scientific term for the following:

(i) A rock formed by heat and pressure from an earlier rock, without melting (1)
(ii) The name of an igneous rock that has large crystals (1)
(iii) The liquid which forms lava when it reaches the surface (1)
(iv) The rock formed when limestone is subjected to heat and pressure (1)
(v) The rock from which slate is formed by heat and pressure (1)

(b) Explain why basalt has very small crystals (3)

(c) A geologist discovered this arrangement of rocks in a cliff:



(i) What sort of rock is A most likely to be? (1)
(ii) What sort of rock is C most likely to be? (1)
(iii) Which is the older rock, C or B? (1)
(iv) Give a reason for your answer to (1)

(d) Explain what is meant by The Rock Cycle (4)

(Total mark 16)

Question 3

(a) Give the correct scientific term for the following:

(i) A movement of water set up by hot water rising (1)
(ii) What happens to heat radiation when it neither passes through a material nor is reflected from it (1)
(iii) Liquids and gases are both this, but solids are not (1)
(iv) Wind felt at the seaside on a hot day (1)
(v) The full scientific name for heat radiation (1)

(b) Explain why:

(i) convection is not possible in a solid (2)
(ii) conduction is not possible across a vacuum (2)
(iii) winds usually blow from the land towards the sea at night (3)
(iv) in hot countries like Spain, the outsides of house are often painted white (2)

(c) If a car is standing in direct sun with all the windows shut, the inside heats up very quickly. Suggest the reason for this. (2)

(Total 16 marks)
(Total mark 50)