- The transfer of energy by conduction, convection, evaporation and condensation involves particles, and how this transfer takes place.
- How the arrangement and movement of particles determine whether a material is a conductor or an insulator.
- The role of free electrons in conduction through a metal.
- Convection explained in terms of increased particle separation making a fluid less dense.
- Applications of convection, such as heating a room or hot water systems.
- Evaporation and condensation.
- Kinetic theory explanation of evaporation and the cooling effect of evaporation.
- The factors that affect rate of evaporation and condensation.
- The rate at which an object transfers thermal energy depends on :
- Shape, The rate at which an object transfers thermal energy depends on :
  - Surface area and volume.
  - The material from which the object is made.
  - The nature of the surface with which the object is in contact.
- The bigger the temperature difference between the object and its surroundings, the greater the rate at which thermal energy is transferred.

THERMAL ENERGY TRANSFER PROCESSES

Thermal (heat) energy is transferred in substances from places at high temperature to places at low temperature by **CONDUCTION, CONVECTION And RADATION.**

Imagine a pupil at the back of the classroom who wants to pass an eraser to one at the front. There are three possible ways of doing this :

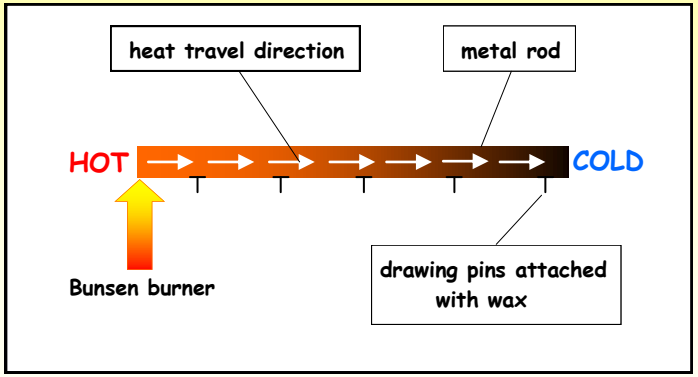
Throwing the eraser

Carrying the eraser

Passing the eraser from person to person

HEAT TRANSFER PROCESS	IS LIKE
CONDUCTION is the transfer of heat through a substance without any actual movement of the particles of the substance.	
CONVECTION is the transfer of heat through fluids (liquids and gases) by the actual movement of the particles of the substance.	
RADIATION is the transfer of heat from place to place by **infra red** waves.	

OBSERVING THERMAL CONDUCTION

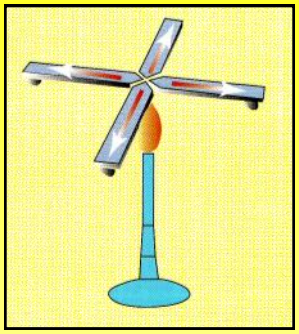


- As one end of the rod is heated, the heat travels along by conduction. As the heat moves along from the **HOT** end to the **COLD** end, it melts the wax and so causes the pins to drop off in order. The pins which are closest to the **HOT** end drop of first.

WHICH METAL IS THE BEST HEAT CONDUCTOR ?

- The apparatus shown opposite can be used to compare the thermal conductivity of four different metals. All four bars have identical dimensions and each has a small ball bearing stuck to its end with wax.

  The Bunsen flame is positioned in the centre and the heat is conducted along the bars and eventually melts the wax, causing the ball bearings to drop in a certain order.



BEST CONDUCTOR	SECOND BEST CONDUCTOR	THIRD BEST CONDUCTOR	WORST CONDUCTOR

CONDUCTION THROUGH LIQUIDS AND GASES

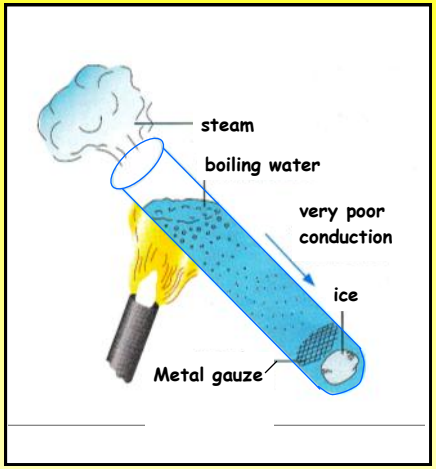
- With the exception of mercury, **ALL LIQUIDS ARE POOR HEAT CONDUCTORS**.
  This is because the particles in liquids are Further apart than the particles in solids.

- **GASES** are worse **HEAT CONDUCTORS** than liquids. They are good **HEAT INSULATORS**.
  This is because The particles in gases are much further apart than they are in liquids.

A THERMAL INSULATOR is a material that does not allow heat to travel through it easily by conduction.

SHOWING THAT WATER IS A POOR HEAT CONDUCTOR

- A piece of ice wrapped in metal gauze is dropped into the water in a boiling tube. When the Bunsen flame is directed at the top of the tube, the water there can be seen to boil while the ice at the bottom does not melt.



EXPLANATION

The heat from the water at the top of the tube can only travel towards the ice at the bottom by conduction, and the fact that it does not melt, even though the water at top is boiling, shows that **water is a poor heat conductor**.

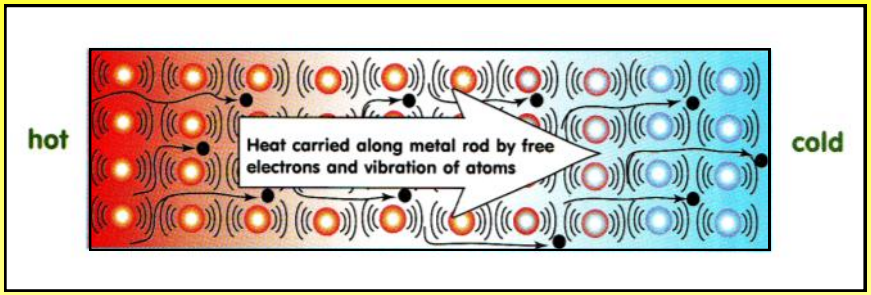
CONDUCTORS AND INSULATORS

- **ALL METALS** are excellent **HEAT CONDUCTORS** and they are used wherever we want heat to be transferred easily. For example the base and sides of a cooking pan are metallic.

- **INSULATORS** are wrapped around hot objects so as to reduce heat loss. A good example of this is the thermal insulating jacket which is wrapped around the hot water tank in a house. The jacket contains fibre glass layers which have many tiny pockets of trapped air.

  Clothing keeps you warm in cold weather because the interwoven fibres also contain pockets of trapped air and a garment also traps a layer of air between it and you body.

EXPLAINING THERMAL CONDUCTION



- In **non-metallic solids** the heat energy is passed on from particle to particle. The particles at **hot** end vibrate more strongly and this is passed on to neighbouring particles along the length of the rod.

  Because this conduction process is **very slow, non-metals** (e.g. plastic, wood, rubber etc.) are **poor thermal conductors (i.e. good insulators).**

- In **metals** the increased vibration of the atoms at the **hot** end of the rod is transferred to the **cold** end by two separate mechanisms :

  - **Inter-particle vibrations** as for non-metals, **and**
  - **Free electrons** which collide with strongly vibrating atoms at the **hot** end and then move through the rod, transferring their energy by collision with atoms and other electrons.

    This heat transfer mechanism is **much faster** than that due to vibrations from particle to particle and accounts for the fact that **metals are excellent thermal conductors.**

• PRACTICE QUESTIONS

1 Use the materials given below to complete the sentences :

PLASTIC **WOOD** **STEEL** **FIBREGLASS**

- ..... is used to insulate the loft in houses.
- Sauce pan handles are made of ..... or .....
- A radiator in a central heating system is made of .....

2 Which of the following statements is **true** and which is **false?**

(a) Conduction involves thermal energy passing between vibrating particles.

(b) Some metals are very poor thermal conductors.

(c) Solids are usually better thermal conductors than liquids and gases.

(d) Plastic is a poor thermal conductor because it contains free electrons.

3 Use the words in the list below to complete the sentences :

VIBRATE **ATOMS** **ELECTRONS** **COLLIDE**

- Heat transfer in a metal is due to particles called ..... moving freely inside the metal. They transfer energy when they ..... with the metal ..... and with each other.

4 **(a)** Give **one example** and **one use** of a good heat conductor.

(b) Give **one example** and **one use** of a good heat insulator.

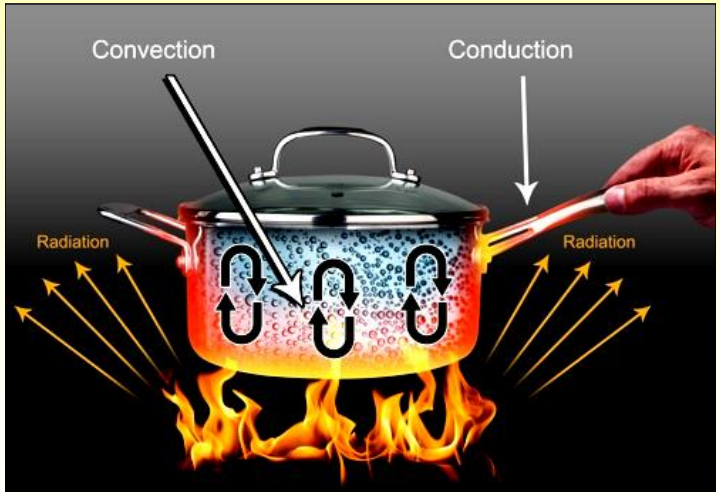
(c) Why do **metal** objects at room temperature feel colder than **wooden or rubber** objects at the same temperature ?

(d) **Explain** why **solids** are better heat conductors than **gases** and why **metals** are better heat conductors than **non-metals.**

THERMAL CONVECTION

- **Convection** is the transfer of heat in **fluids** (i.e. liquids and gases) caused by the hot fluid rising and the cold fluid sinking.
- **Convection** can only happen in liquids and gases but **not** in solids.

  This is because liquids and gases can flow and so they can transfer energy from regions of **higher** temperature to regions of **lower** temperature.
- When a fluid is heated, the more energetic, heated particles move from the **hotter** region to the **cooler** region and then transfer their energy by collision.
- The movement of the heated fluid is called a **convection current**.

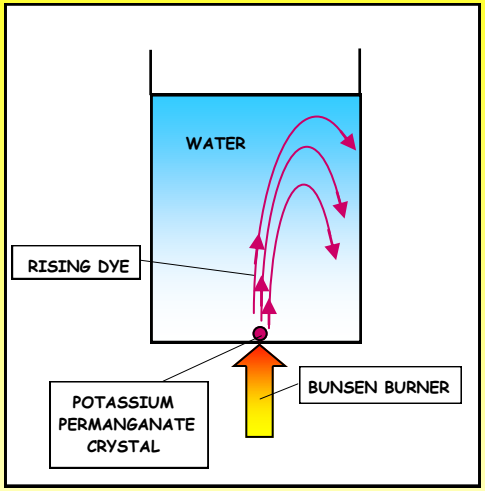


PRACTICAL WORK - OBSERVING CONVECTION CURRENTS

1. IN LIQUIDS

Using a glass tube, a small crystal of potassium permanganate is carefully placed at the bottom of a large beaker of water.

When the water is heated as shown, streamers of purple dye are seen to rise and sink, showing the path of convection currents.



EXPLANATION

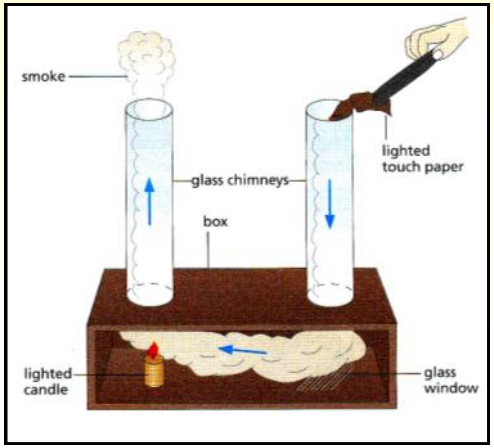
When the water at the bottom is heated, the particles move further apart (i.e. it expands). Its mass remains the same, so its density decreases. The heated water therefore rises and cooler, denser water from the top then sinks to take its place

2. IN GASES

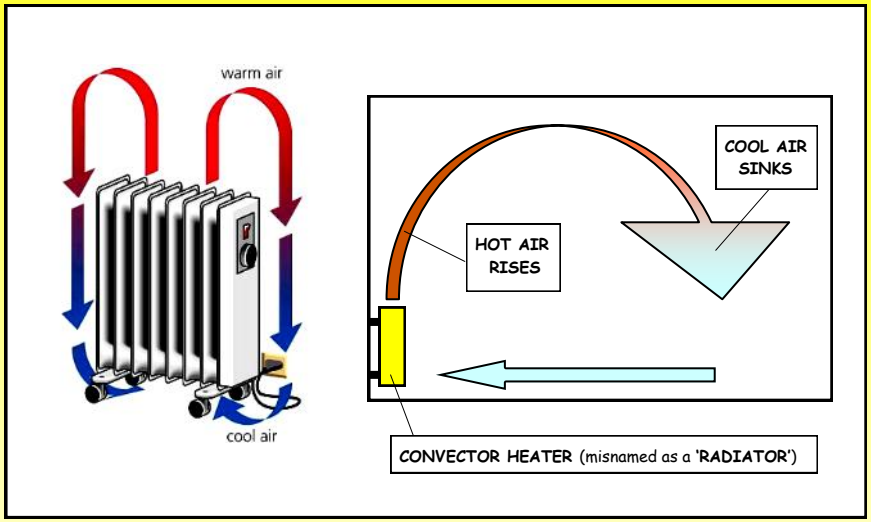
The burning candle heats the air above it, causing it to expand and rise through the chimney.

Cold air is sucked in through the other chimney to replace the hot air which is leaving the box.

The direction of the convection current created by the candle flame is made visible by the smoke from the lighted touch paper.



HEATING A ROOM BY CONVECTION



- As the air above the heater is warmed, it expands and because it then becomes less dense than the cooler air in the room, it rises.

  The cooler, denser air from other parts of the room sinks and comes in to take the place of the risen air.

  In this way the heat is transferred throughout the room by **convection currents**.

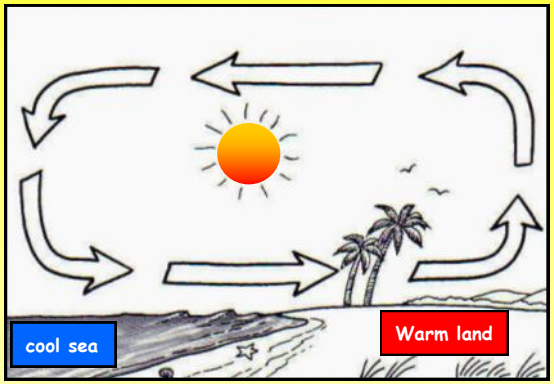
  Heaters that work in this way are wrongly called **'radiators'**, since they heat a room by **convection** and not by radiation.

LAND AND SEA BREEZES

SEA BREEZE

- **During the day** the land heats up more quickly than the sea, so the air above the land warms up and rises.

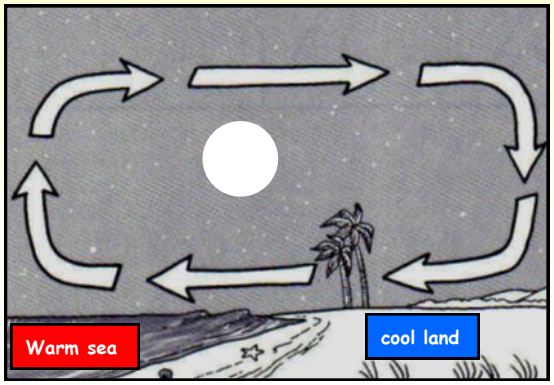
  Cooler air from the sea then flows in to replace the warm, risen air and this creates what we call a **sea breeze**.



LAND BREEZE

- **At night** the land cools down more quickly than the sea, so the air above the sea is warmer and therefore rises.

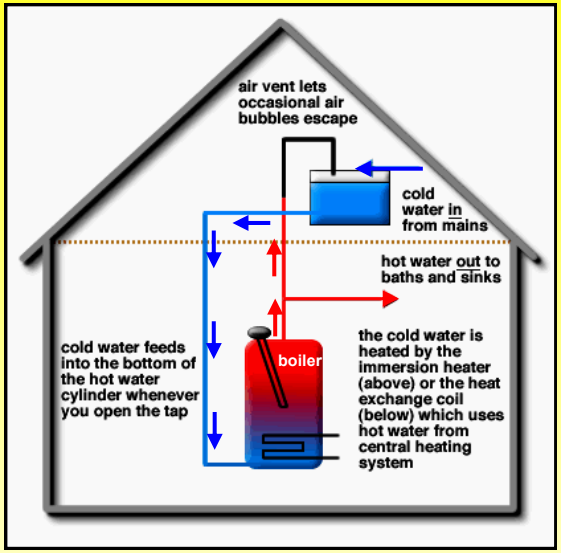
  Cooler air from the land then flows out to replace the warm, risen air and this creates what we call a **land breeze**.



DOMESTIC HOT WATER SYSTEM

- Convection currents are used to circulate water around the heating system of a house.

The diagram opposite shows the basics of such a system. The boiler is placed at the lowest point in the house and so the hot water rises towards the roof. It is then fed to baths, sinks and radiators around the house. Cool water from the mains-fed tank in the loft feeds the boiler as needed.



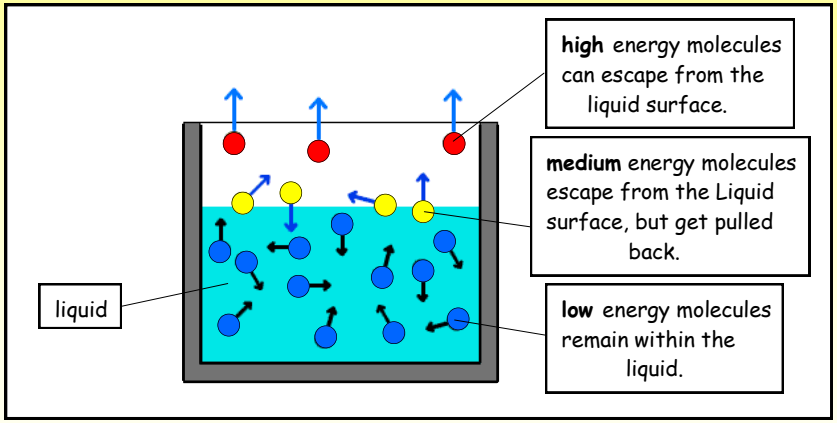
EVAPORATION is a process which occurs at all temperatures from the surface of a liquid.

- We are very familiar with the process of evaporation in our everyday life.

People have used it since time immemorial to dry clothes after washing and the rain that is so vital to the growth of crops is, after all, only water that has previously evaporated from seas, rivers and lakes.

- A heavy downpour is sometimes followed by bright sunshine and in these conditions, rapid evaporation becomes quite clearly visible.

MOLECULAR EXPLANATION OF EVAPORATION



- The molecules in a liquid have a range of kinetic energies. Those with **low** energy are bound within the liquid, whereas those having **high** energy can overcome the attraction forces of surface molecules and thereby escape to become vapour molecules. Some, having a **medium** amount of energy, escape momentarily, but are then pulled back by the attraction forces of surface molecules.

FACTORS AFFECTING THE RATE OF EVAPORATION

The **rate of evaporation** can be increased by increasing :

The temperature of the liquid.

- The higher the temperature of the liquid, the greater the number of molecules in the liquid which are moving fast enough to escape from the surface.
  (That's why it is preferable to hang out the washing on hot, sunny days).

The surface area of the liquid.

- The larger the area of the liquid surface is the greater the number of high energy molecules which will be near the surface and able to escape. **(That's why the clothes need to be spread out on the line).**

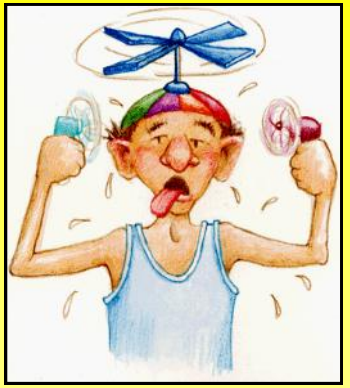
The airflow rate over the liquid surface.

- Increasing the airflow rate increases the number of medium energy vapour molecules which escape by carrying them away before they can return to the liquid. **(That's why the clothes dry faster on a windy day).**

THE COOLING EFFECT OF EVAPORATION

- Evaporation causes cooling. This is because it is the **fastest** moving molecules (i.e those with the **greatest** kinetic energy) which escape from a liquid surface. As a result the average kinetic energy of the molecules left behind will **decrease** and this means a **decrease** in the temperature of the liquid.

- We sweat on a hot day or after vigorous exercise and as the sweat evaporates, it cools us down. A fan blowing air over the body increases the rate of evaporation and so cools us down even more.



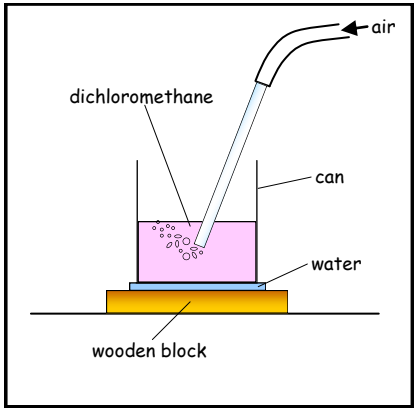
The evaporation of water from us can also be very dangerous. You can lose heat from your body very rapidly in wet and windy conditions. This can lead to **hypothermia,** a potentially lethal condition in which body temperature starts to fall.

COOLING EFFECT OF EVAPORATION - DEMONSTRATION

Dichloromethane is a liquid which evaporates readily at room temperature (i.e. it is a **volatile** liquid).

If air is blown through some dichloromethane in a can, it will evaporate rapidly.

The rapid cooling which this causes will freeze the water beneath the can.



- *Volatile liquids are used in perfumes and after-shave lotions which evaporate readily at room temperature and hence make the user smell nice as well as producing a **cooling effect** on the skin.*

- *Ether acts as a local anaesthetic by **chilling** (as well as cleaning) your arm when you are being given an injection.*

CONDENSATION

- This is the change of state from **gas (or vapour) to liquid**. Often observed on the interior surface of windows in winter when the moisture-laden air inside a house is rapidly cooled on contact with the cold glass.
- As the gas (or vapour) cools, the particles are slowed down and come much closer together.

• HOMEWORK QUESTIONS (1)

1 Some water is being heated in a saucepan placed on a hotplate. Complete the sentences using some of the words listed below :

evaporation / conduction / convection / radiation / insulator / conductor

(a) Thermal energy is transferred through the saucepan's base by .....

(b) Thermal energy is transferred through the water by .....

(c) The saucepan handle is wooden because wood is a good thermal .....

(d) Some thermal energy is transferred from the hotplate to the surrounding air by .....

2 Complete the sentences using words from the list below :

mixes **sinks** **cools** **rises**

When a fluid is heated, it ..... and ..... with the rest of the fluid. The fluid circulates and ..... and then it .....

3 Hot water is pumped through a radiator. Complete the sentences below : **18**

(a) Thermal energy is transferred through the walls of the radiator by the process of .....

(b) The air in contact with the radiator is warmed and this causes it to ....., become less ..... than the surrounding air and therefore ....., transferring thermal energy to the room by the process of .....

(c) Thermal energy is also transferred directly into the room by the process of ....., which involves the emission of electromagnetic ..... known as .....

4 A saucepan containing soup is being heated on a hotplate. Some heat (thermal energy) is lost through the saucepan's metal walls to the surroundings.
Questions **(a) to (d)** below refer to this.

(a) The thermal energy spreads through the soup by :

A. Free electrons colliding with ions. **B.** Heat rising.
C. The soup contracting and falling as it is heated.
D. The soup expanding and rising as it is heated.

(b) The thermal energy is transferred through the saucepan's metal walls by :

A. Free electrons colliding with ions.
B. Heated metal expanding and rising.
C. Infra red waves passing through the metal.
D. The atoms gaining energy and moving faster through the metal.

(c) The saucepan's outer walls transfer energy to the surroundings by :

A. Free electrons colliding with ions.
B. Infra red waves passing through the air.
C. Metal atoms gaining energy and escaping into the air.
D. The air contracting and falling as it is heated.

(d) The air in contact with the saucepan's outer walls :

A. Contracts and falls due to decreased density.
B. Contracts and falls due to increased density.
C. Expands and rises due to decreased density.
D. Expands and rises due to increased density.

- **HOMEWORK QUESTIONS (2)**

1 Explain the following observations, referring to the appropriate process of thermal energy transfer in each case :

(a) Two cups of coffee are poured at the same time and they are allowed to stand for 10 minutes. One of the cups has a metal spoon in it and the coffee in this cup is found to be cooler than that in the other cup at the end of the 10 minutes.

(b) Two fresh cups of coffee are poured out and a thin plastic lid is placed on top of one of the cups. After a 10 minute wait, the coffee in the lidded cup is found to be hotter than in the other cup.

2 **(a)** Explain how thermal energy is conducted along a solid non-metallic rod.

(b) Explain how thermal energy is conducted along a metal rod.

(c) Why are metals the best conductors of thermal energy?

(d) Why is water such a poor thermal conductor?

(e) Why are gases good thermal insulators?

3 **(a)** Explain why the heating element in an electric kettle is positioned very close to the bottom of the kettle.

(b) Using a diagram to illustrate your answer, explain how a 'radiator' uses convection currents to heat up a room.

4 **(a)** Explain the process of evaporation in terms of the energy of the molecules in a liquid.

(b) **(i)** Why does evaporation of a liquid produce a cooling effect?

(ii) Give one useful example of the cooling effect produced by evaporation.

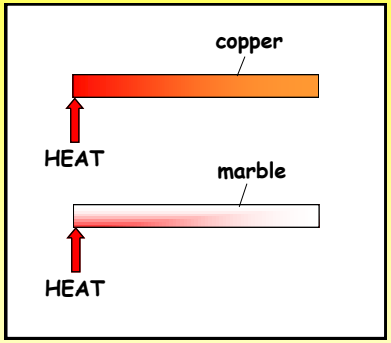
(c) State the factors which affect the rate of evaporation of a liquid and describe the effect each of them has.

EFFECT OF MATERIAL ON THERMAL ENERGY TRANSFER

Under similar conditions, different materials transfer thermal energy at

- A copper rod and a marble rod of the same size are heated at one end as shown in the diagram.

  As we already know from our study of thermal conduction, the thermal energy will travel much faster in the copper than in the marble. We say that copper is a much better thermal conductor than marble.



EXPLANATION

- In the marble, the thermal energy is transferred from particle to particle. Particles at the hot end vibrate more strongly and this increased vibration is slowly passed onto neighbouring particles along the length of the rod.

  Copper contains free electrons and these provide an additional thermal energy transfer mechanism which is much faster than the inter-particle vibrations.

- For this reason, if you touch a piece of **wood** and a piece of **metal** of the **same size** and at the **same temperature**, the **metal will feel colder**.

  This is because thermal energy (heat) is transferred out of your hand more quickly by the metal than the wood.

EFFECT OF TEMPERATURE DIFFERENCE ON THERMAL ENERGY TRANSFER

The bigger the temperature difference between the object and its surroundings, the greater the rate at which thermal energy is transferred.

This applies to thermal energy transfer by **conduction**, **convection** and **radiation**.

- For example, if a metal bar is being heated at one end, then the **higher the temperature** is at that end the **faster the thermal energy will be conducted** to the other end.

- The **hotter the heating element** in a boiler is, the **more vigorous the convection** will be and the **faster the water will be heated**.

- All objects emit **infra red (IR) waves**, but the **hotter the object is**, the **greater the rate at which thermal energy is radiated**.

FACTORS AFFECTING THE RATE OF THERMAL ENERGY TRANSFER

The rate at which an object transfers thermal energy depends on :

- **Shape**
- **Dimensions**
- **Mass**
- **Type of material**
- **What the object is in contact with.**

- **Conduction** in solids is the transfer of thermal energy by vibrations from particle to particle and in the case of a metal by the motion of energetic free electrons. Since a large piece of metal contains more particles and free electrons than a smaller piece, it will conduct thermal energy at a greater rate.

Large objects conduct thermal energy at a greater rate than small objects of the same material.

- Hot objects transfer thermal energy by the emission of infra red waves from their surface, so in the case of **radiation** :

The larger the surface area of an object, the greater is the rate of emission and absorption of thermal energy.

- The Shape of an object can also have an effect on the rate at which thermal energy can be transferred through it. **Convection,** for example, requires the free flow of a gas or liquid, so gaps in or around an object can increase thermal energy transfer by convection.

In examinations, you will be expected to explain the design of a device (e.g. cooling fins on A motorbike engine) and animal adaptations (e.g. relative ear size of a desert fox compared with an arctic fox) in terms of thermal energy transfer.

COOLING FINS ON A MOTORBIKE ENGINE

- All internal combustion engines generate a lot of heat and unless this heat is transferred out of the engine block, the temperature will rise to such an extent that the pistons will literally seize up.

- In a motorbike the heat is transferred out of the engine by the use of **cooling fins** around the engine block.

- The fins are **metallic** (aluminium alloy) and so rapidly **conduct** the heat out of the engine block.

- The finned design gives as large a **surface area** as possible in contact with the surrounding air ensuring maximum transfer of thermal energy to the air by **convection.**

- The large **surface area** of the fins also means that the transfer of thermal energy by **radiation** is also maximised.

- Sometimes the fins are also given a **matt black (best radiator)** powder coating which further enhances thermal energy transfer by **radiation.**

DESERT FOX-ARCTIC FOX RELATIVE EAR SIZE

- The **fennec fox** lives in the desert and is adapted to cope with temperatures in excess of **45 °C.** Relative to its body size, this creature has **long legs, long muzzle** and **very large ears.**
The enormous ears have a **very large surface area** to **maximise** the radiation of body heat and thus keep the animal cool.

- In sharp contrast, the **arctic fox** has adapted to withstand temperatures of **–40 °C** and below. Again, relative to its size this fox has **short legs, short muzzle** and **very small ears.**
All of these adaptations give **low surface area** relative to body size and so **minimise** radiated heat loss.

PENGUIN HUDDLE

- The dense feathers on penguins trap a lot of air and this together with the thick layers of fat under their skin provides good insulation which allows them to survive in temperatures of **–40 °C** and below.

Penguins huddle close together, sometimes in groups numbering over a thousand. This **reduces the surface area** of the body exposed to the extremely cold weather, which results in a **reduction in heat loss through conduction, convection and radiation.** Every so often, penguins shift position to allow those who have been at the edges to warm up in the centre of the group.

• HOMEWORK QUESTIONS (3)

1 In a laboratory experiment, an **aluminium** rod and a **glass** rod having **identical shape and size,** are heated at one end.

It is found that the thermal energy reaches the cold end of the aluminium rod much faster than the glass rod.

Explain this observation in terms of **particles** and **free electrons.**

2 The **cooling fins** on a motorbike engine are specifically designed to dissipate the heat produced by the engine as efficiently as possible.

(a) Why are the fins made of **metal?**

(b) What is the purpose of the **finned** design?

(c) Why would a **matt black** powder coating on the fins make them more effective?

(d) State the **methods by which the engine heat is transferred :**

(i) From the **engine to the surface of the fins.**

(ii) From the **surface of the fins to the surrounding air.**

3 Relative to their body size, **desert** foxes have much larger ears than **arctic** foxes.

(a) How does having **very large ears** help the desert fox to cope with **very high temperatures?**

(b) How does having **very small ears** help the arctic fox to cope with **very low temperatures?**

4 In order to help them survive extremely low temperatures, penguins **huddle together** in very large groups.

Explain how this helps them to keep warm.