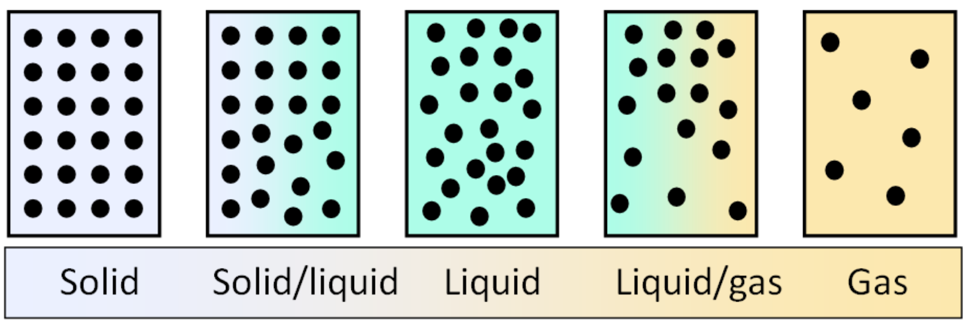
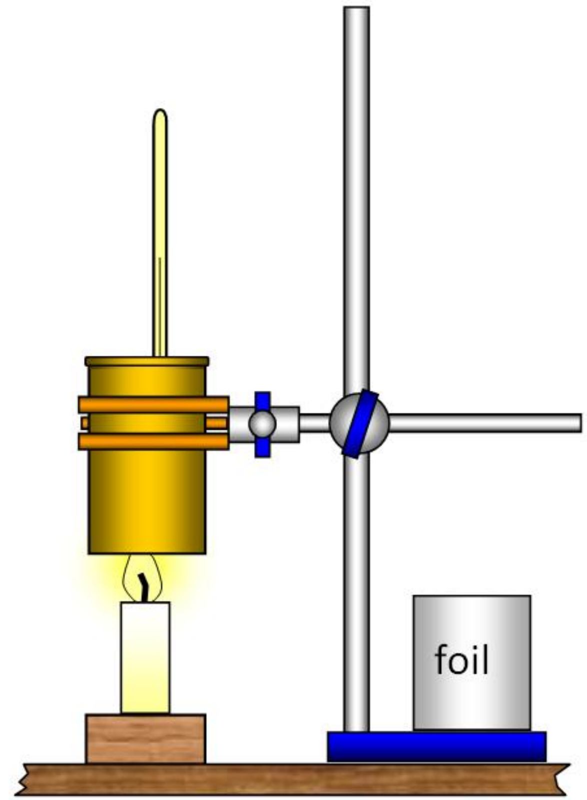
Heat energy (11-16)





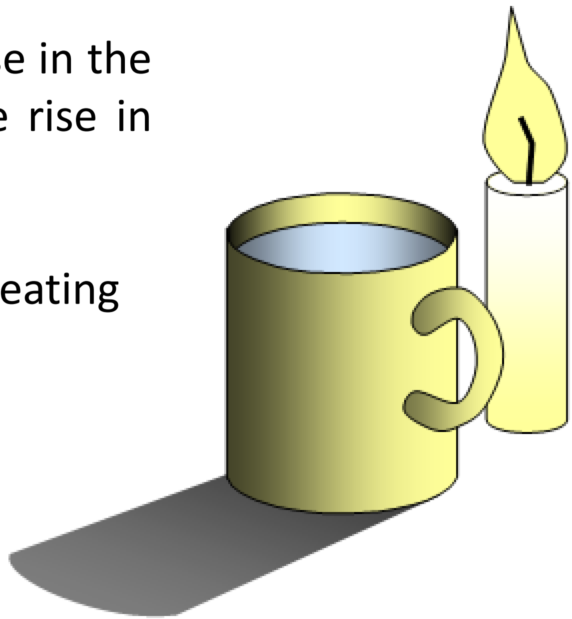
Contents

Heat energy and temperature

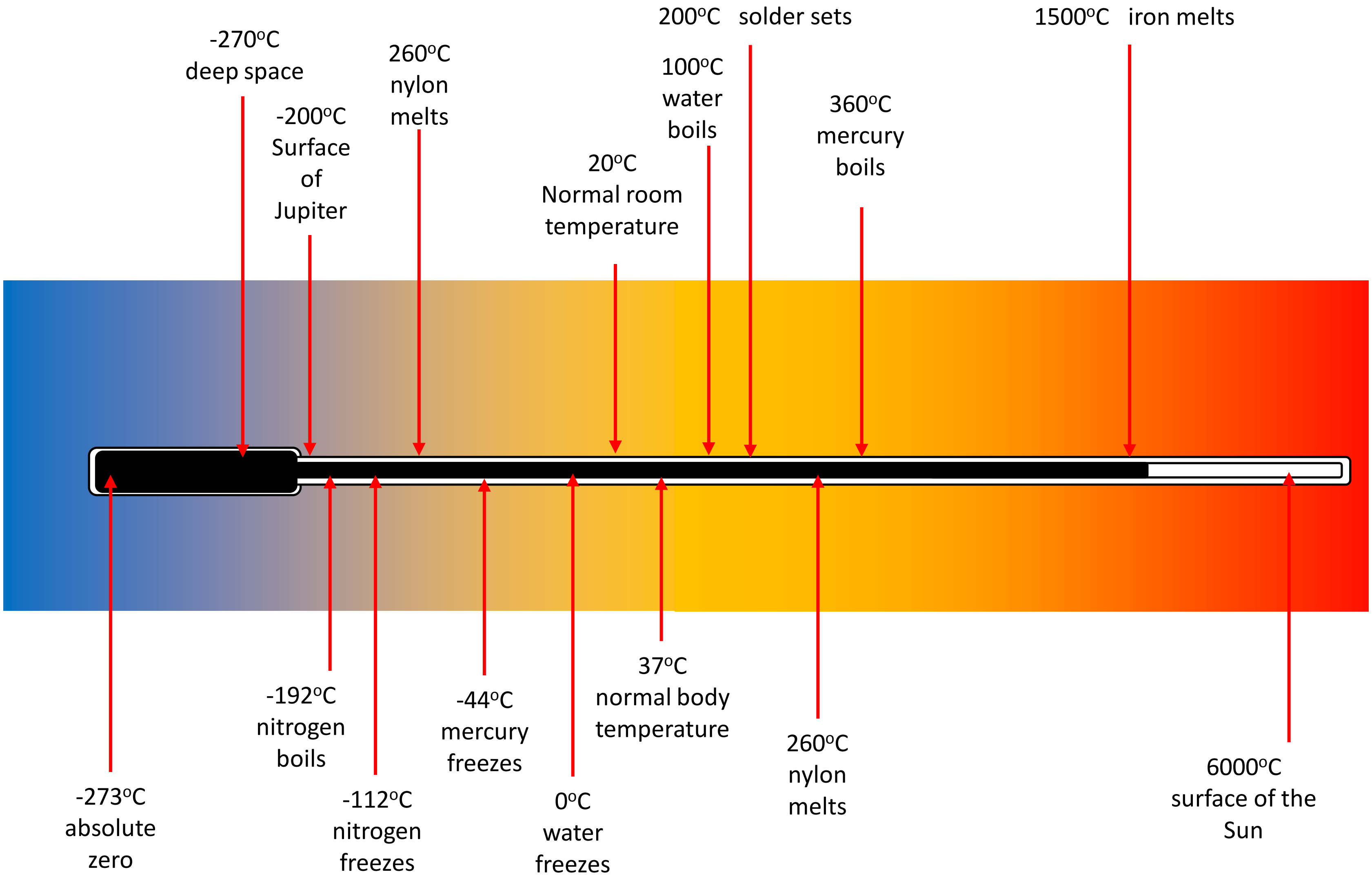
The difference between heat energy and temperature is very obvious if you think about a candle flame and a beaker of boiling hot water. The candle flame is at a much higher temperature (about 900^{o}C but there is a lot more heat energy ‘locked away’ in the beaker of boiling hot water.

For the same amount of heat energy put in the rise in the temperature of different objects is different. The rise in temperature will depend on three things:

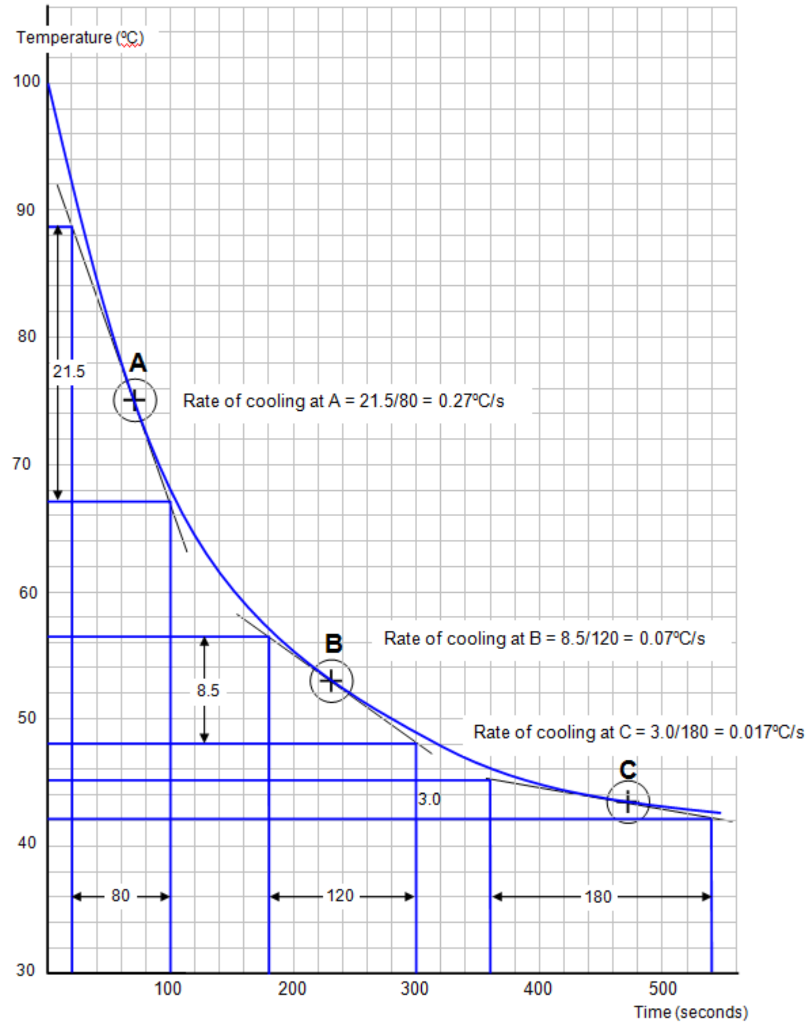
(a) the amount of heat energy that you put in
(b) the amount (mass) of the object that you are heating
(c) the material from which the object is made.



Interesting temperatures



A cooling curve



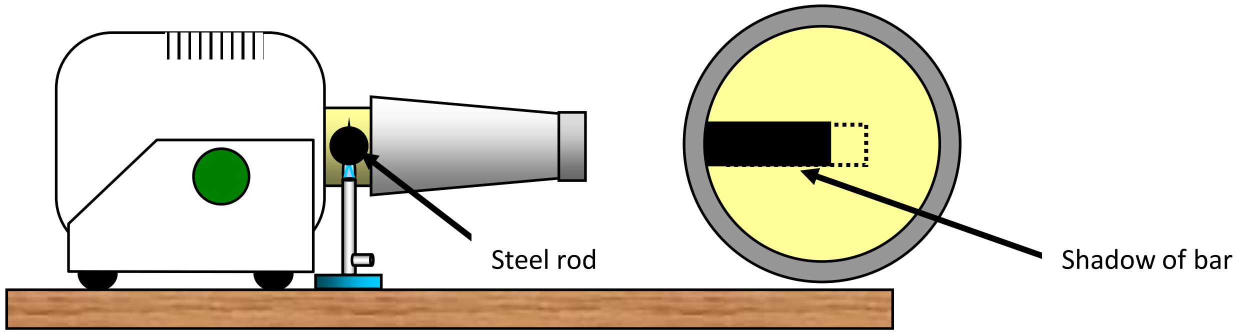
Room temperature = 22ºC

Things cool more quickly when their temperature is well above the temperature of their surroundings.

Expansion of solids

When a material gets hot it expands - this is because the molecules in it are moving about more vigorously and so need more room.
As a solid is heated the molecules vibrate more violently and the solid expands in all directions. We will just look at the increase in length for simplicity. The hotter it gets and the longer it was to start with the more the solid expands. Different materials expand by different amounts for the same rise in temperature.
The amount of expansion depends on
(a) what material it is
(b) how big the temperature rise is
(c) how long it was to start with

The bar in a projector beam can be heated using a Bunsen flame and the bar's shadow will grow. If the width of the bar and the shadow are measured you can work out the magnification of the projector and then the actual expansion of the bar.

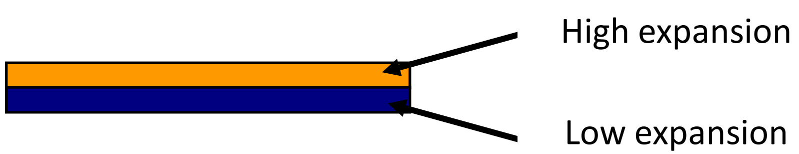


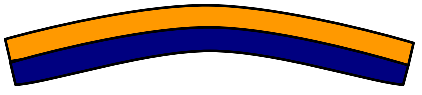
Expansion of solids - formula

The amount that a solid expands when its temperature is raised by a certain amount by using the following formula:

Expansion = original length x rise in temperature x linear expansivity

The linear expansivity is a constant for a material and is how much a unit length of the material would expand for a 1^{o} rise in temperature — it is a very small number:
0.000 0012 for iron. This means that a 1 m length of iron would expand by 0.000 0012 m when its temperature is raised by 1^{o} C.

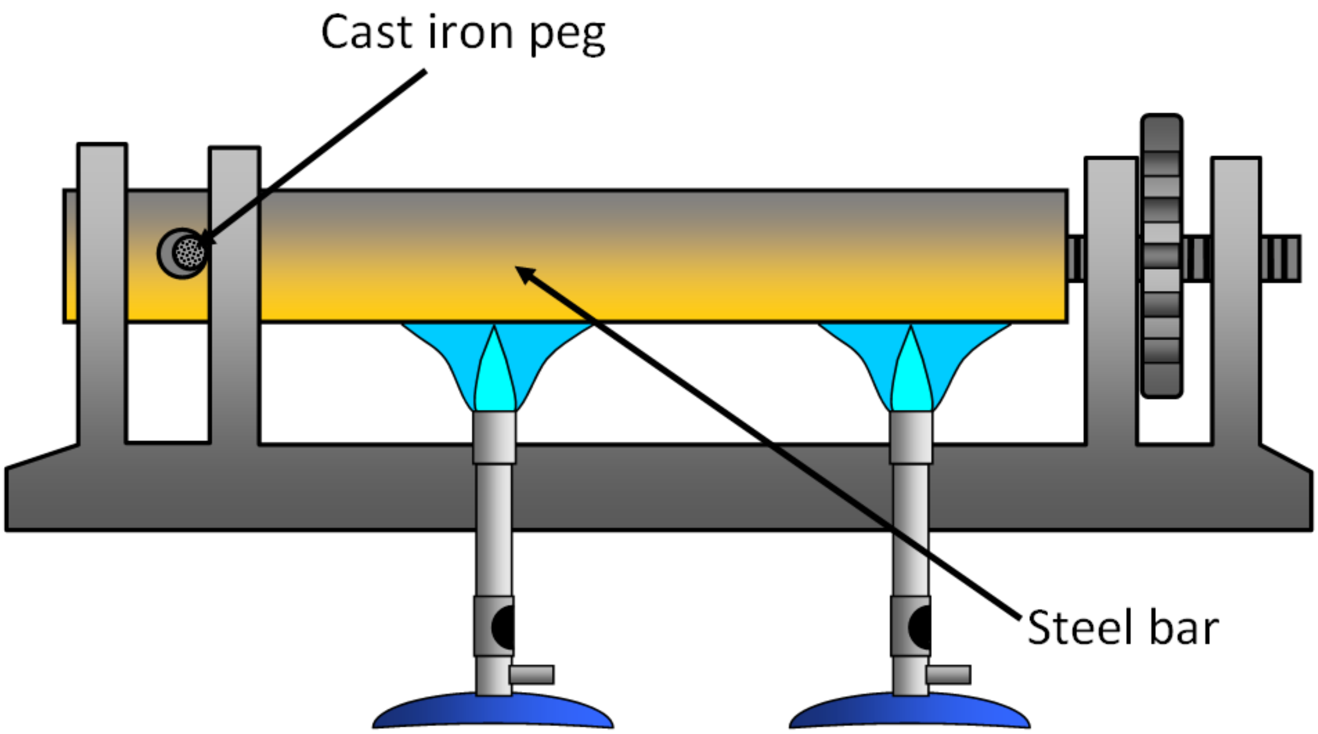




Bimetallic strip when hot

The bar breaker

A strong steel bar is fixed in the frame of the apparatus by a large nut at one end a cast iron peg at the other. When the bar is heated the peg breaks because of the huge force in the bar. It is also possible to make the peg break when the bar contracts on cooling by tightening the nut when the bar expands.

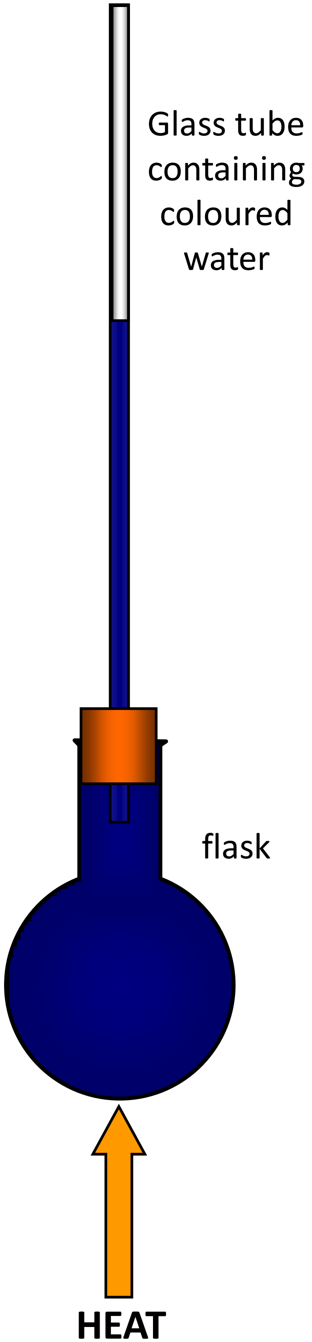


Expansion of liquids

All liquids expand more than all solids.

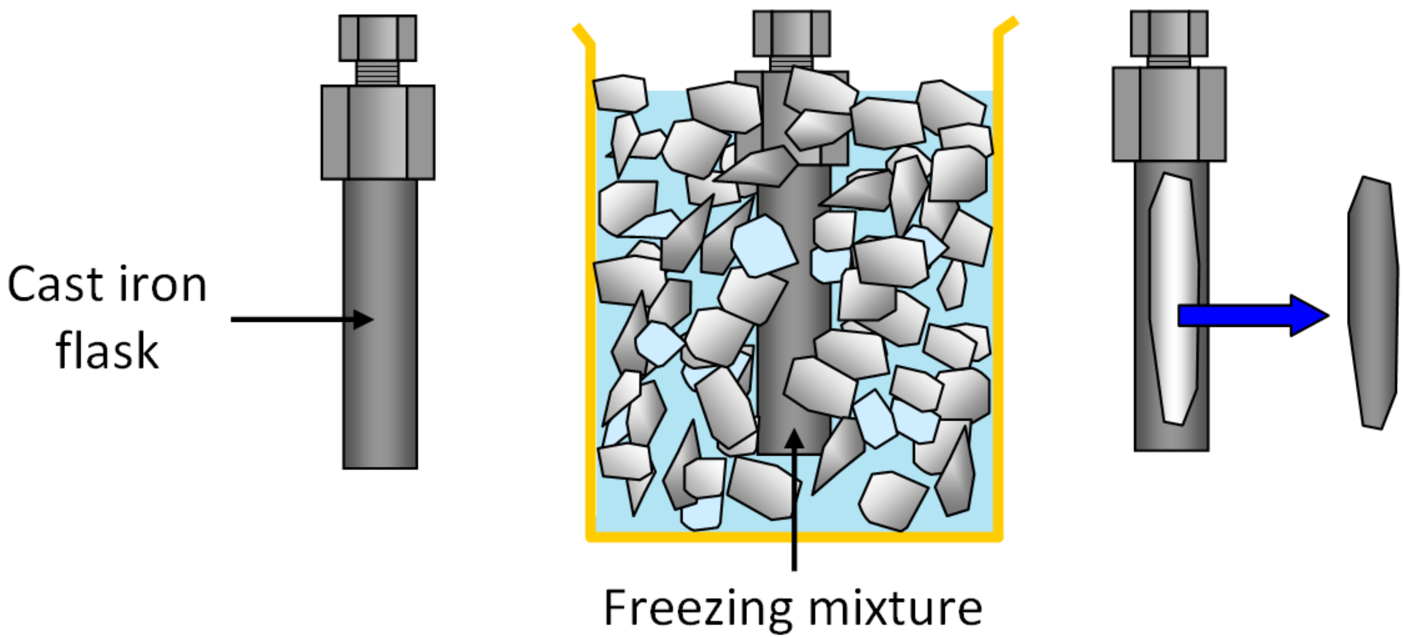
The volume of the liquid gets greater as it is heated. The greater the rise in temperature the more it expands. The actual change in shape of the liquid depends on the shape of the container that it is in.

In the experiment with the coloured water in a glass flask if you watch very carefully you will see the level of the water go down when you first start heating. This is because the glass gets hot first and so expands and the volume of the beaker therefore increases. This means that the water level will drop. Then the water starts getting hotter, it expands more than the glass and so the water level rises.



Expansion of water on freezing

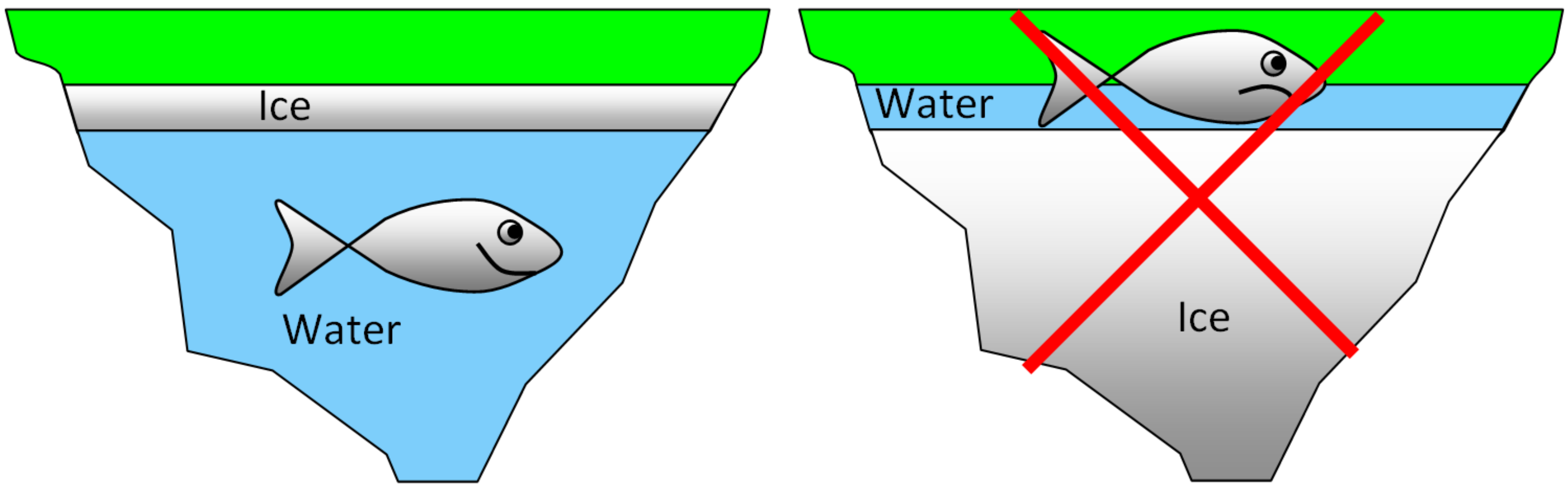
A cast iron flask is filled with water and the screw top fitted firmly in place. The flask is then put in a freezing mixture in a plastic beaker so that the water in the flask freezes. The increase in volume of the water as it turns to ice is enough to shatter the flask.



Freezing ponds and fish

As ice has a greater volume than water it is less dense than the water and so it floats, this means that ponds freeze from the top downwards – good news for fish. If this were not so the oceans would be solid ice to quite close to the surface!

At 4^{o}C water has its greatest density and so it will sink to the bottom of the pond. The water above will be colder until just below the ice it is at 0^{0}C. (The top of the ice may be well below 0^{0}C.)



Immersion heaters

The hot water tank shown in the diagram has three ways of heating the water.

(a) a heat exchanger coil

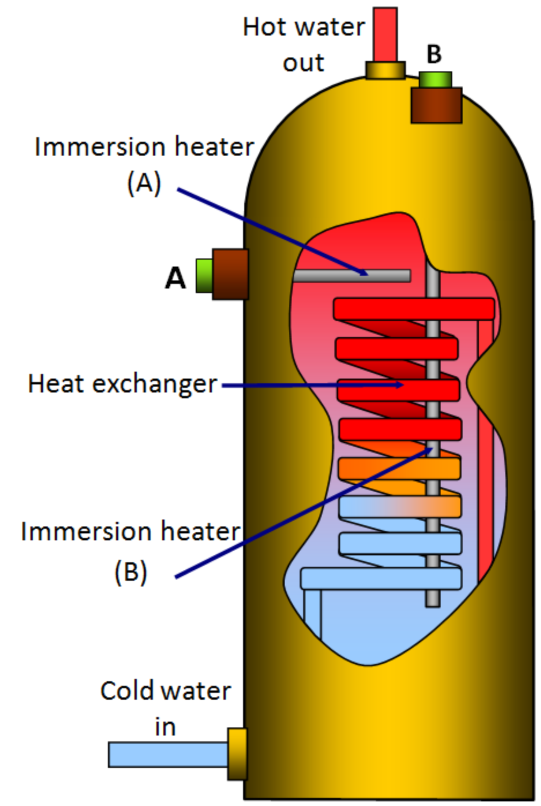
(b) a small immersion heater (A)

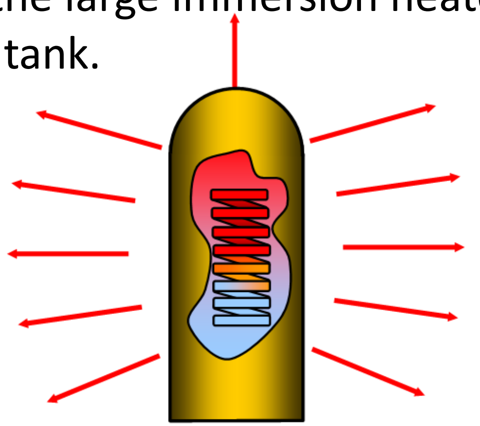
(c) a larger immersion heater (B)

(a) very hot water from the boiler travels through this copper coil. It loses heat energy to the water in the tank.

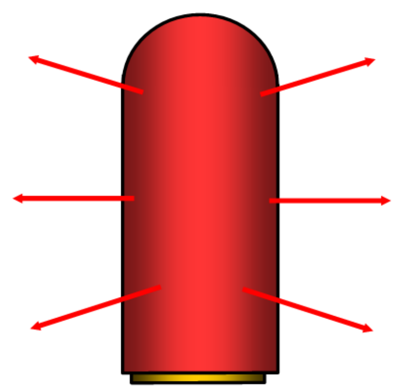
(b) the small immersion heater only heats the water at the top of the tank because hot water rises.

(c) the large immersion heater will heat all the water in the tank.





Non lagged tank - high energy loss



Lagged tank - low energy loss

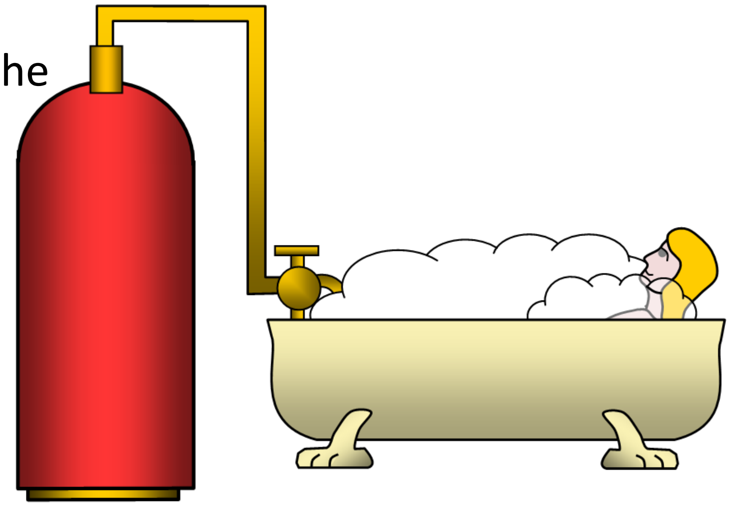
Specific heat capacity

The amount of heat energy needed to change the temperature of a substance depends on:

(a) what the substance is;

(b) how much of it is being heated;

(c) what rise in temperature occurs.



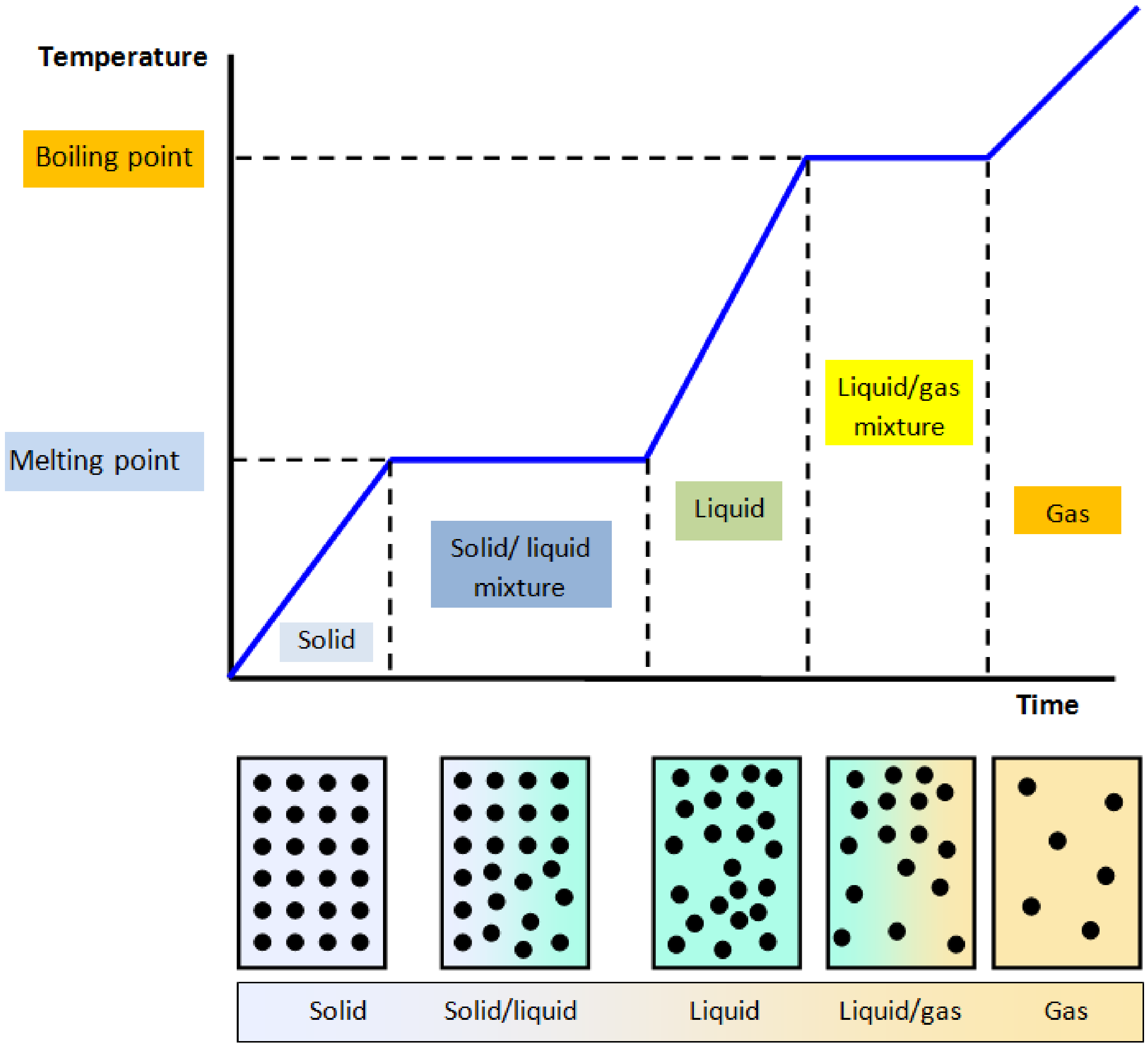
The SPECIFIC HEAT CAPACITY of a substance is the heat needed to raise the temperature of 1 kg of the substance by 1K (or by 1^{o}C).

Specific heat capacity is given the symbol c. The units for c are J/(kg K) or J/(kg^{o}C).

Substances with high specific heat capacities can contain a lot of heat energy, and so it takes a long time to heat them up and also a long time for them to cool down.

Heat energy = mass x specific heat capacity x temperature change

Change of state

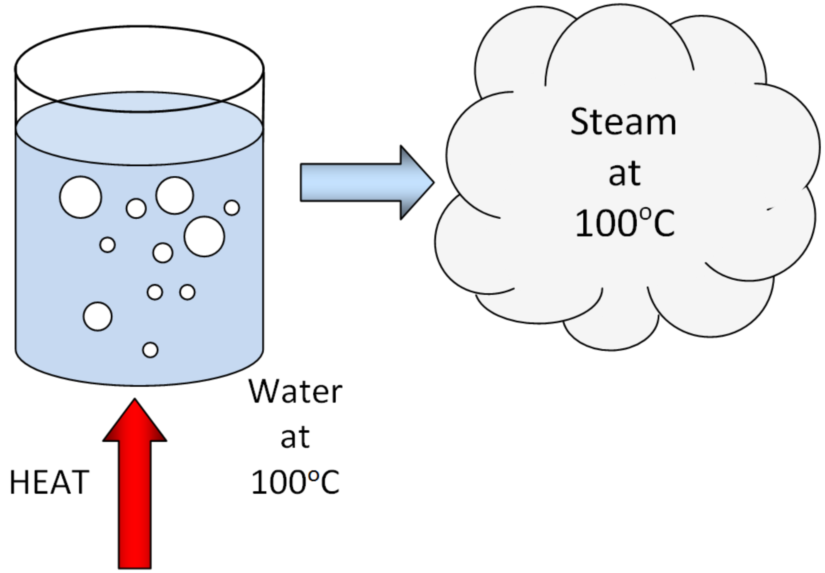


Latent heat energy

When a substance changes its state from a solid to liquid or from a liquid to a gas heat energy is needed. This energy is used not to heat up the substance but to separate the molecules from each other. This energy is called **LATENT HEAT** energy.

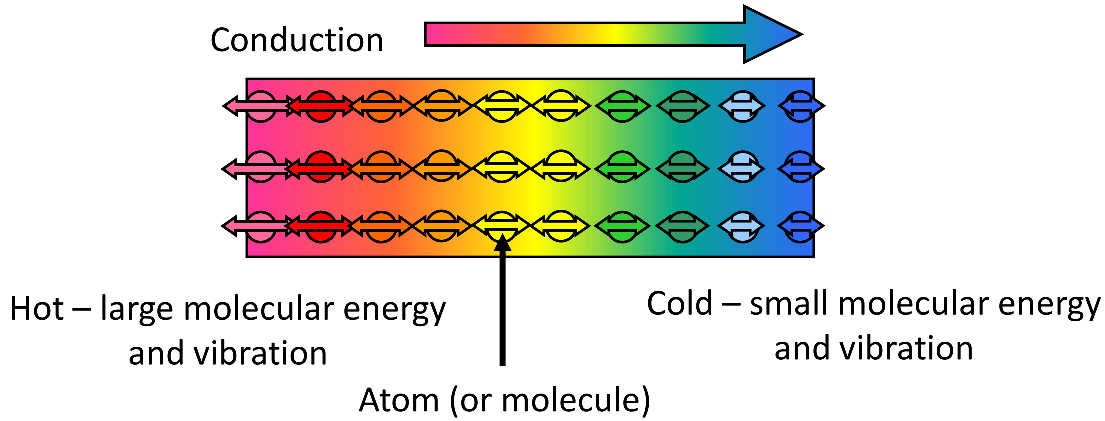
While a solid is melting and while a liquid is boiling there is no temperature change. The temperature only changes when the change of state is complete.

The amount of heat needed to change the state of 1 kg of a substance is called the **SPECIFIC LATENT HEAT** of the substance.



The specific latent heat of fusion is the heat energy needed to turn 1 kg of solid into a liquid at its melting point.
The specific latent heat of vaporisation is the heat energy needed to turn 1 kg of liquid into a gas at its boiling point.

Conduction of heat energy



When one end of a solid rod is heated the atoms (or molecules) at that end vibrate – the more it is heated the more they vibrate. This vibration is passed on from one atom to the next as they are all linked together in the solid. Heat energy is therefore transmitted down the rod. This is called conduction.

In metals there are also a lot of free electrons wandering about and these play a big part in the energy transfer. That is why metals are nearly always better conductors than non-metals. The following list shows some common materials, starting with the ones that conduct heat best and ending with the worst conductors:

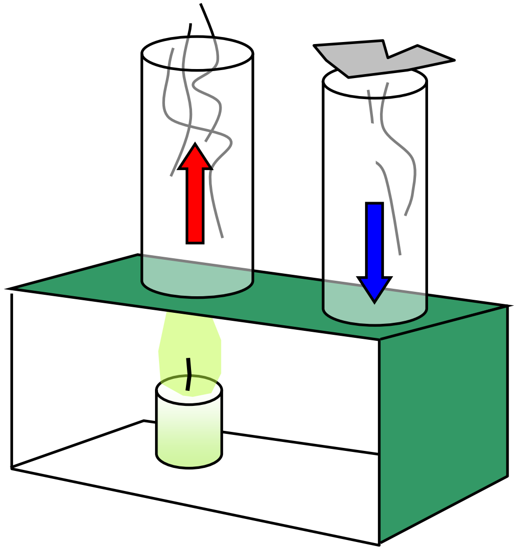
silver copper aluminiun brass iron zinc lead rock water glass rubber air

Convection

Unlike conduction, in convection it is the material itself that moves, therefore you can't have convection in a solid.

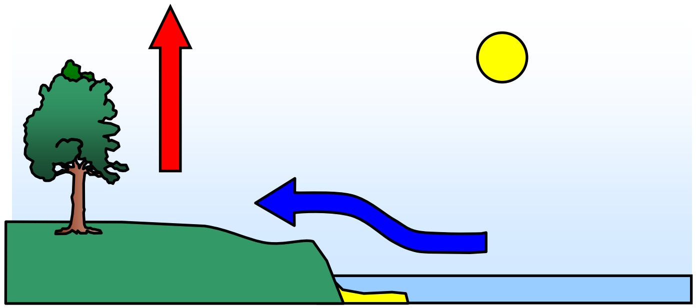
In liquids and gases convection takes place because the hotter, low-density fluid rises taking the heat energy with it - this is called a convection current. The bigger the surface area of an object the more air can move round it in convection currents and the faster it will cool.

Convection in air can be shown by using the apparatus shown in the diagram. If the candle is lit and then a piece of smouldering paper or string is held over the top of the other chimney the smoke should be pulled down that chimney and rise up the other chimney with the hot air above the candle.

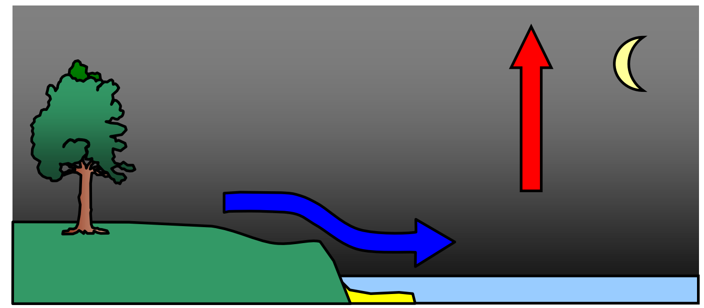


A fun way of showing convection currents in air is to make a small rotor out of stiff aluminium foil and hold it above a Bunsen burner or candle. It will spin round as the hot air rises from the candle.

Land and sea breezes



On shore sea breeze in the daytime

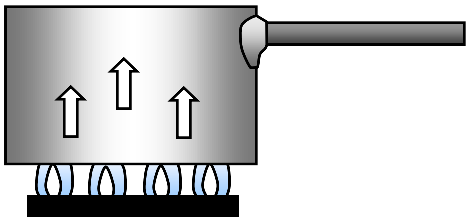


Off shore sea breeze at night

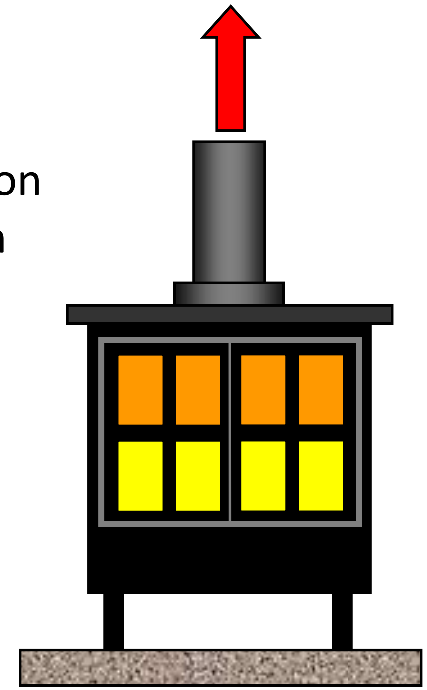
In the daytime the land heats up more quickly than the sea. This means that the air above the land rises, and cool air is drawn in from the sea. This gives an onshore breeze during the day.

At night the sea cools down more slowly than the land. This means that the air above the sea is warmer – it rises and causes an offshore breeze at night.

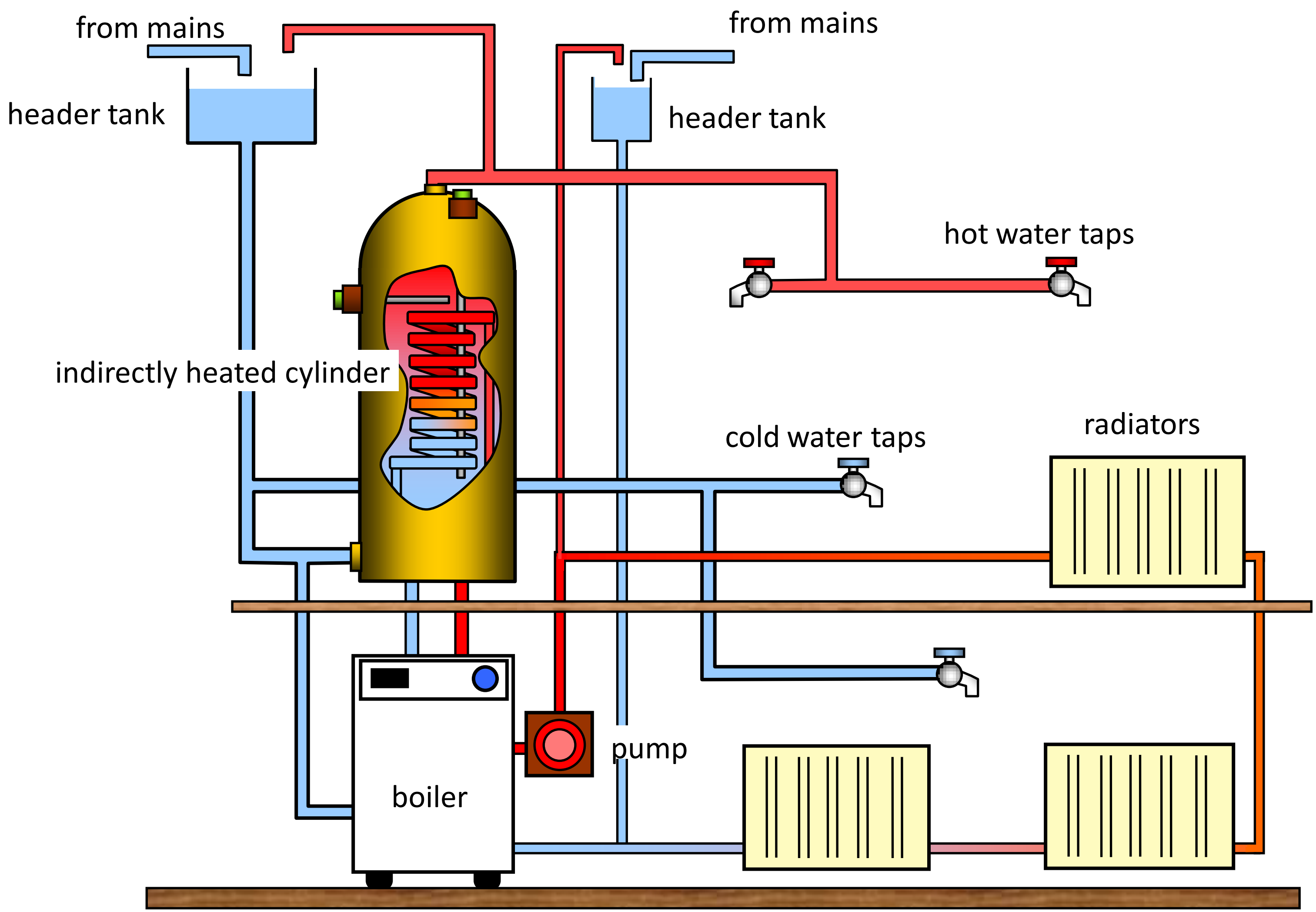
Convection in the home



Cooking in hot water
Christmas decorations – a candle under a mobile
Convector heater – hot air rises through the heater
Central heating boiler
Immersion heater at the bottom of a hot water tank
Kettle with the element at the bottom
Cool air flowing off the outside of windows
Air movement in cavity walls before putting in foam insulation
Radiators – they work by air convection and not by radiation
Chimney to an open fire or a boiler
Lava lamp – if you know what that is
Chest freezer – it does not matter too much if you open the top for a little while because the colder air will sink to the bottom of the freezer.



House hot water system



House hot water system (2)

The diagram shows a simplified version of a house hot water system. You can follow the temperature of the water around the system – red for hot and blue for cold. Notice that there are two separate circuits. One for water used for washing and drinking and the other for water used in central heating.

As you know the hot water rises to the top due to convection and this would meant that all the downstairs radiators and hot taps would get cold. To stop this happening an electric pump is used to keep the water moving round the system to make sure that downstairs dies not get cold. So, if there is a power cut your central heating would not work because although the boiler might light (probably not because the programmer would stop) the electric pump would not work.

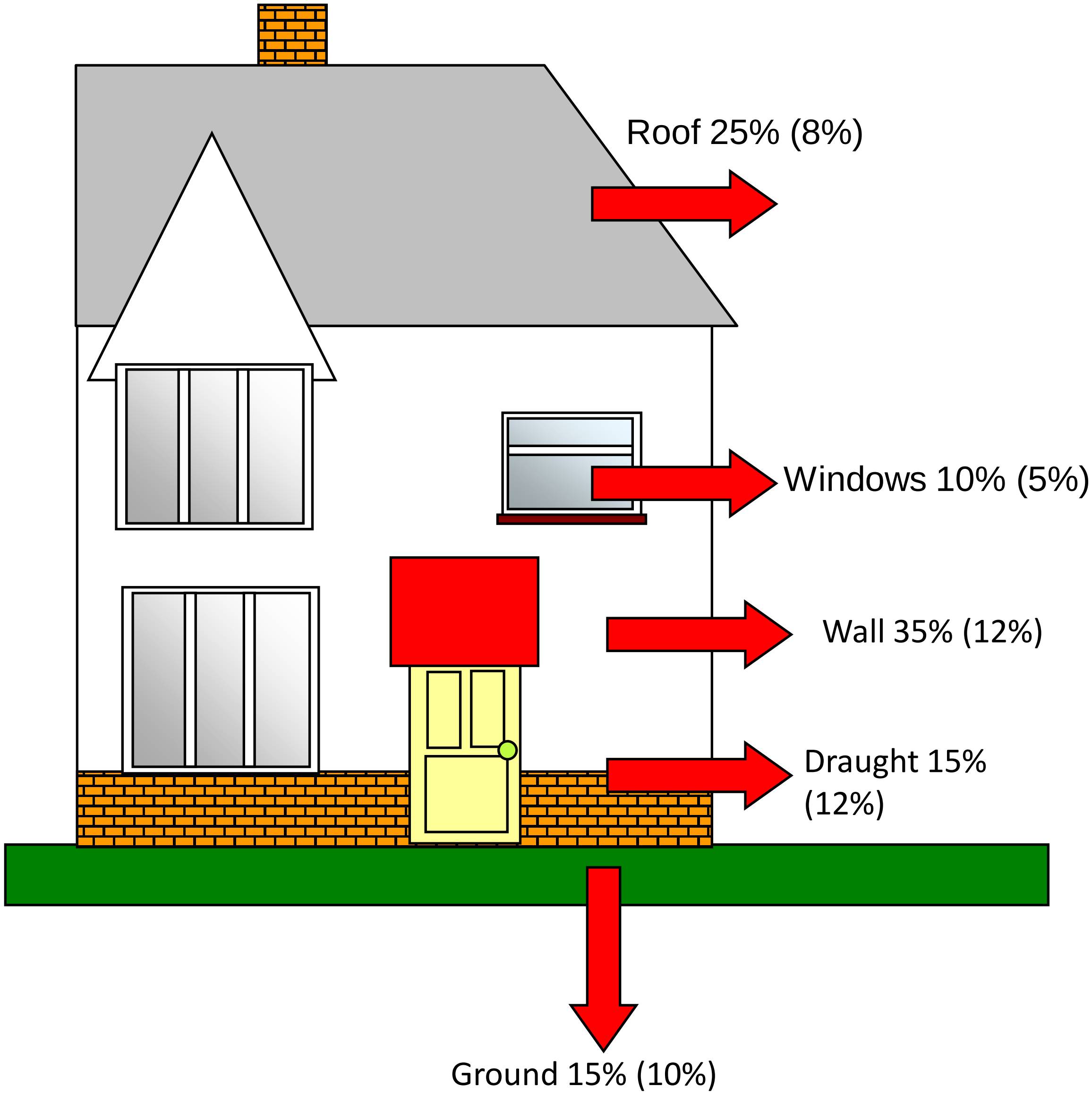
Notice the indirectly heated hot water cylinder. Hot water from the boiler flows through a coil in the cylinder and heat from this is transferred to the rest of the cylinder. There will also usually be an electric immersion heater which you can use to heat the water when the boiler is off.

There are also header or expansion tanks. These collect excess water due to expansion in the pipes.

Heat loss from a house

The heat loss from a house can be reduced in the following ways (bracketed in the diagram). It is much greater when it is cold outside and especially if it is windy as well.

1. Loft insulation – glass fibre and/or layers on insulation
2. Double glazing
3. Cavity wall insulation
4. Curtains, blinds, shutters
5. Carpets
6. Draught excluders



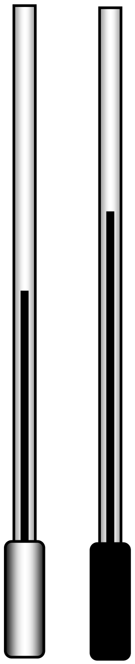
Heat radiation (1)

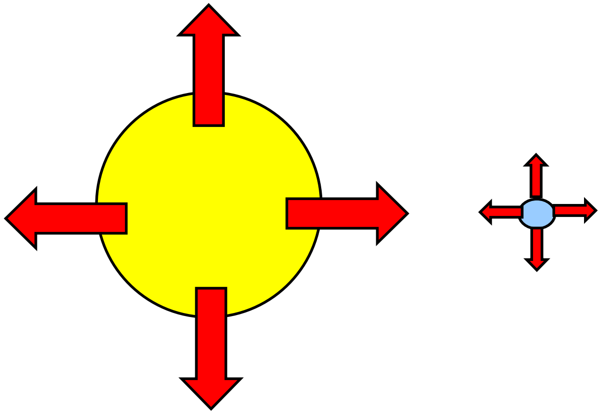
All objects emit heat radiation. This radiation is invisible to the human eye but the radiation from hot bodies can be felt by your hand.

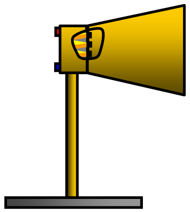
The proper name for heat radiation is infra red radiation.

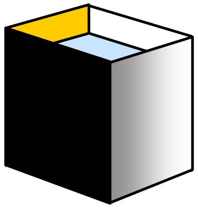
Two objects of the same material and the same size but at different temperatures will emit different amounts of radiation, the hotter one emitting more radiation. Two objects of the same material and the same temperature but of different sizes also emit different amounts of heat radiation – the bigger one emitting more radiation than the smaller one.

Thermometers with blackened or silvered bulbs

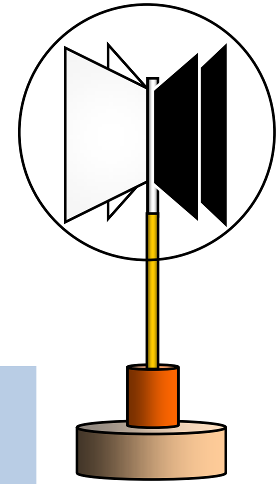








Heat radiation (2)



Some surfaces emit heat better than others.

Black surfaces are the best emitters of heat radiation.
Black surfaces are the best absorbers of heat radiation.
Shiny surfaces are the best reflectors of heat radiation.
Shiny surfaces are poor absorbers of heat radiation
Glass will not transmit heat radiation.

1. Radiators in houses do not radiate very well; they ought to be painted black. Car radiators usually are a dark colour so that they can get rid of the heat efficiently.
2. Aluminium foil is sometimes put behind radiators to reflect the heat out into the room
3. A vacuum flask has shiny surfaces on the vacuum side to prevent heat loss
4. White clothes are worn in summer as they reflect the heat better than dark ones
5. The reflector behind an electric fire should be kept clean to reflect the heat well
6. A greenhouse keeps warm inside because of the properties of the glass.
7. Spacecraft have shiny surfaces to reflect the radiation from the Sun
8. Highly polished teapots will keep hot longer as their surfaces do not give out heat so well
9. White washed buildings will keep cooler in hot weather than darker ones