THERMAL ENERGY Heat and Temperature – What is the Difference?

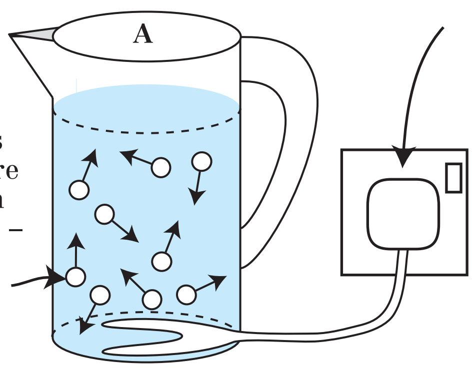
All energy ultimately ends up as heat. In most energy transfers, a proportion ends up as heat energy, and often this is not useful. Sometimes we want to encourage heat transfers, in cooking for example, and sometimes discourage them, in preventing heat losses from your home for example. Therefore, understanding heat energy and how it is transferred is important.

Are heat and temperature the same thing?

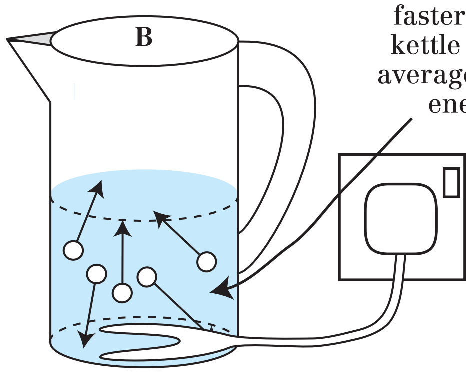
> We define heat energy as the total kinetic energy of the particles in a substance (in Joules).

Identical kettles, both switched on for the same time.

Particles move more slowly in this kettle – lower average kinetic energy.



Same electrical energy supplied to both. Therefore, the water gains the same amount of heat energy. Therefore, the total kinetic energy of the particles in both kettles will be the same.



Particles move faster in this kettle – large average kinetic energy.

This kettle has half the number of particles so to make a fair comparison we measure the average energy per particle.

We have a special name for this average; we call it *temperature*.

> Temperature (in Kelvin) is proportional to the average kinetic energy of the particles.

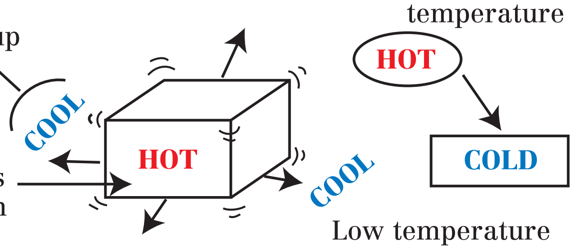
Experience tells us that kettle B is hotter than A. This means that the particles in B have a higher average kinetic energy than those in A. This is reasonable because the same amount of energy is spread over fewer particles in B than in A.

Temperature differences tell us how easily heat is transferred. The bigger the temperature *difference* between an object and its surroundings the more easily heat will be transferred.

Heat always flows from hot to cold

Heats up

High temperature



Cools down

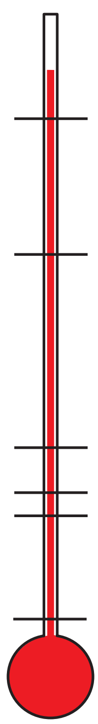
Low temperature

Questions

1. Explain how a bath of water at 37°C can have more heat energy than an electric iron at 150°C.
2. A red-hot poker placed in a small beaker of water will make the water boil, but placed in a large bucket of water the temperature of the water only rises a few degrees, why?
3. Which should lose heat faster, a mug of tea at 80°C in a fridge at 5°C, or the same mug of tea at 40°C, placed in a freezer at –10°C?

Temperature Scales

> Kelvin → °C = (Temperature/K) –273
>
> °C → Kelvin = (Temperature/°C) + 273



°C	Kelvin
2727	3000K Tungsten light bulb filament (glowing)
1197	1470K Earth's core
100	373 Boiling point of water
37	310 Normal human body temperature
0	273 Melting point of water
–273	0 Absolute zero – coldest possible temperature

Two commonly used temperature scales are Celsius, °C and Kelvin, K.
1°C is equal in size to 1K

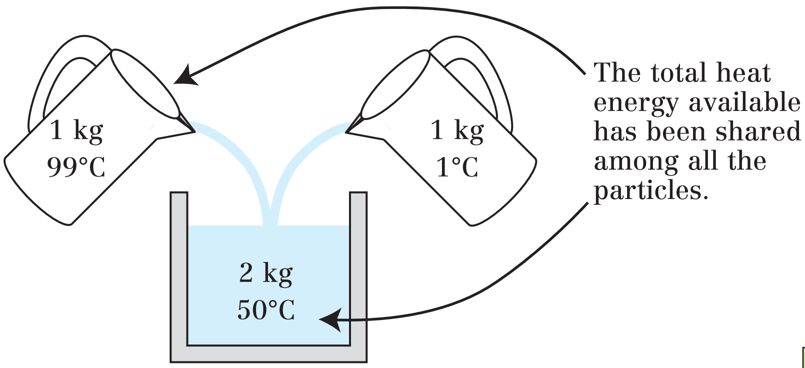
Questions

1. Convert the following into Kelvin: 42°C, 101°C, –78°C, –259°C.
2. Convert the following into °C: 373K, 670K, 54K, 4K.

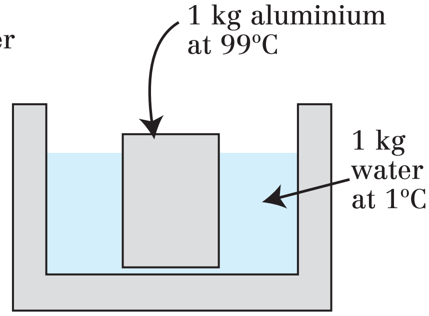
THERMAL ENERGY Specific and Latent Heat

When an object cools, it transfers heat to its surroundings.

Consider



However



Temperature of water / aluminium when they come to equilibrium <50°C (and no heat has been lost from the container).

This tells us that 1 kg of aluminium has less heat energy stored in it than 1 kg of water, so the average kinetic energy (temperature) of the particles when mixed is less. We say aluminium has a lower specific heat capacity than water.

Since temperature is proportional to the average kinetic energy of the particles we are actually measuring the energy needed to increase the average kinetic energy of the particles by a set amount. This will depend on the structure of the material, i.e. what it is made of and whether it is a solid, liquid, or gas. Therefore, *all materials have their own specific heat capacities.*

Specific heat capacity is a measure of how much heat energy 1 kg of a material can hold, defined as:

The energy needed to be supplied to raise the temperature of 1 kg of a material by 1K.

Units J/kgK

Energy supplied (J) = mass (kg) × specific heat capacity (J/kgK) × temperature change (K).

$\Delta E = m \times shc \times \Delta T$

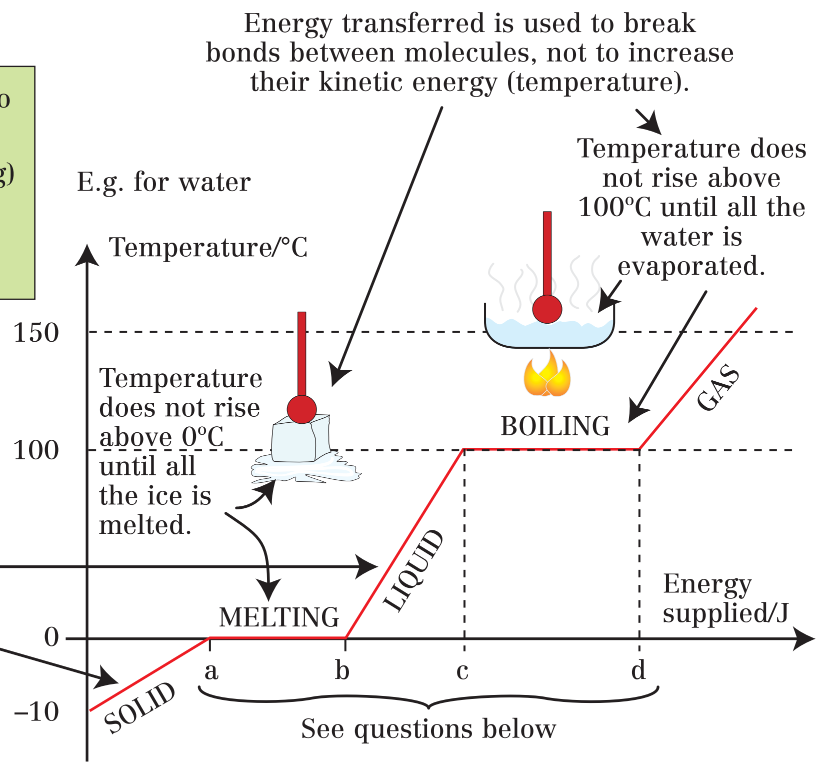
Latent heat is a measure of the energy needed to completely melt or boil 1 kg of a material.

Energy (J) = mass (kg) × specific latent heat (J/kg)

$\Delta E = m \times slh$

Units J/kg

Specific latent heat depends on the strength and number of intermolecular bonds between molecules, so depends on the material and its state.

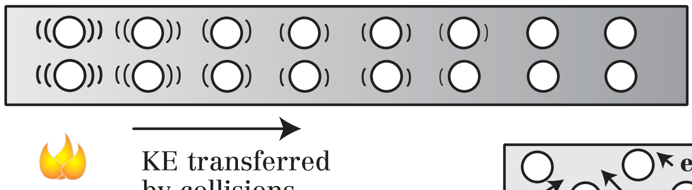


Questions

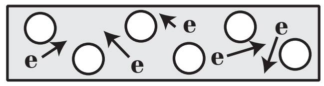
1. What happens to the average kinetic energy of the particles in material when the temperature rises?
2. A pan of boiling water stays at 100°C until all the water has evaporated. Why?
3. Explain why adding ice to a drink cools it down.
4. Given that specific heat capacity of water = 4200 J/kgK and of steam = 1400 J/kgK and that the specific latent heat for melting ice is 334 000 J/kg and for boiling water = 2 260 000 J/kg show that if the graph in the text above represents 2.5 kg of water:
   a. The energy supplied between a and b is 835 000 J.
   b. The energy supplied between b and c is 1 050 000 J.
   c. The energy supplied between c and d is 5 650 000 J.
5. A student finds that it takes 31 500 J to heat a 1.5 kg block of aluminium from 21°C to 44°C. Show that the specific heat capacity of aluminium is about 900 J/kgK.

THERMAL ENERGY Heat Transfer 1 – Conduction

Conduction is the transfer of thermal energy from a high temperature region to low temperature region by the transfer of kinetic energy between particles in a material.

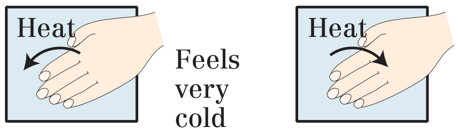


This is especially effective in solids where the particles are firmly bonded together.

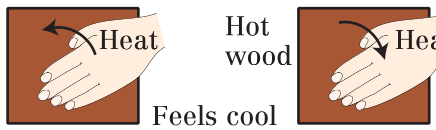


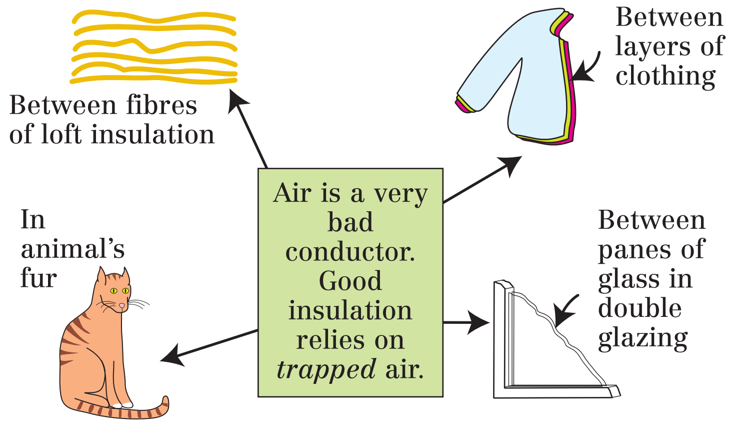
Metals and graphite have free electrons, which can move and carry heat energy. They are very good conductors.

Good conductors transfer heat energy well.



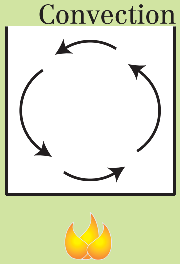
Insulators do not transfer heat well.

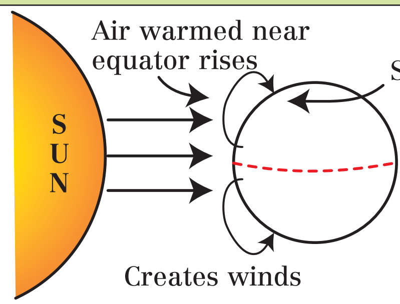


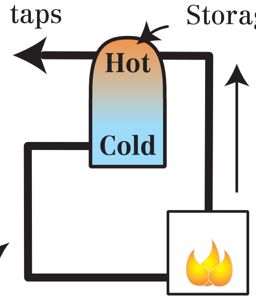


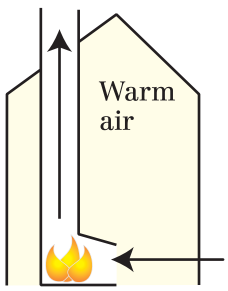
Heat Transfer 2 – Convection

Convection happens in *fluids* because the particles can move and carry heat energy away from the source. Hot fluids have a lower density than cool fluids.

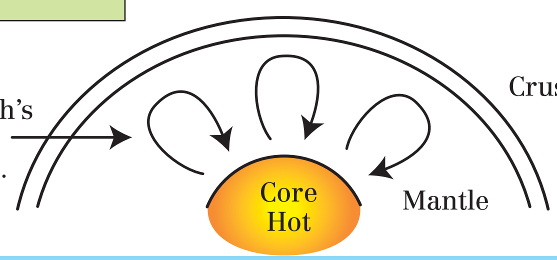








Examples of convection

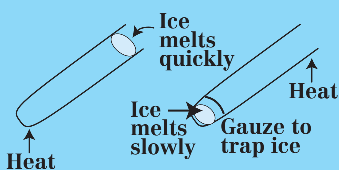


Questions – conduction

1. Using the idea of particles explain why metals are such good conductors of heat and why air is a bad conductor.
2. Air is often trapped, for example between layers of clothing, to reduce conduction. Make a list of five places where air is trapped to prevent conduction.
3. Stuntmen can walk (quickly) across a bed of burning coals without injury, yet briefly touching a hot iron causes a painful burn, why?

Questions – convection

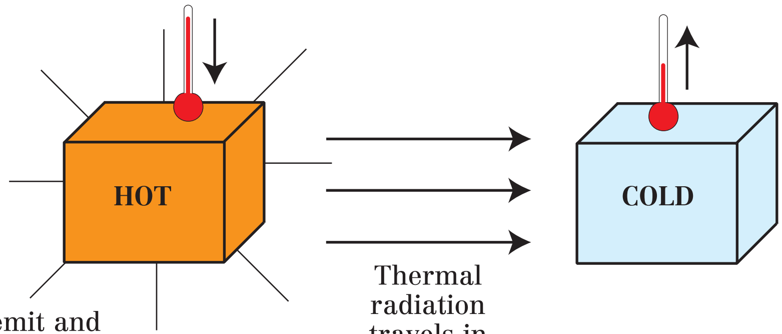
1. Explain the result opposite using the ideas of conduction and convection:



2. Why is the heating element at the bottom of a kettle?
3. Suggest what causes currents in the oceans (in detail).

THERMAL ENERGY Heat Transfer 3 – Radiation

Thermal radiation is the transfer of heat energy by (infrared) electromagnetic waves (see p30 and 32).

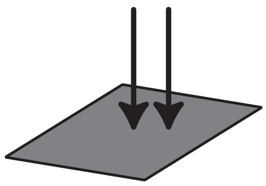


Whenever thermal radiation is absorbed, the energy it carries makes the substance that absorbs it hotter.

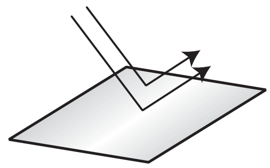
Thermal radiation does not need a medium, it can travel across a vacuum.

All bodies emit and absorb thermal radiation, the hotter they are the more energy they radiate.

Thermal radiation travels in straight lines.

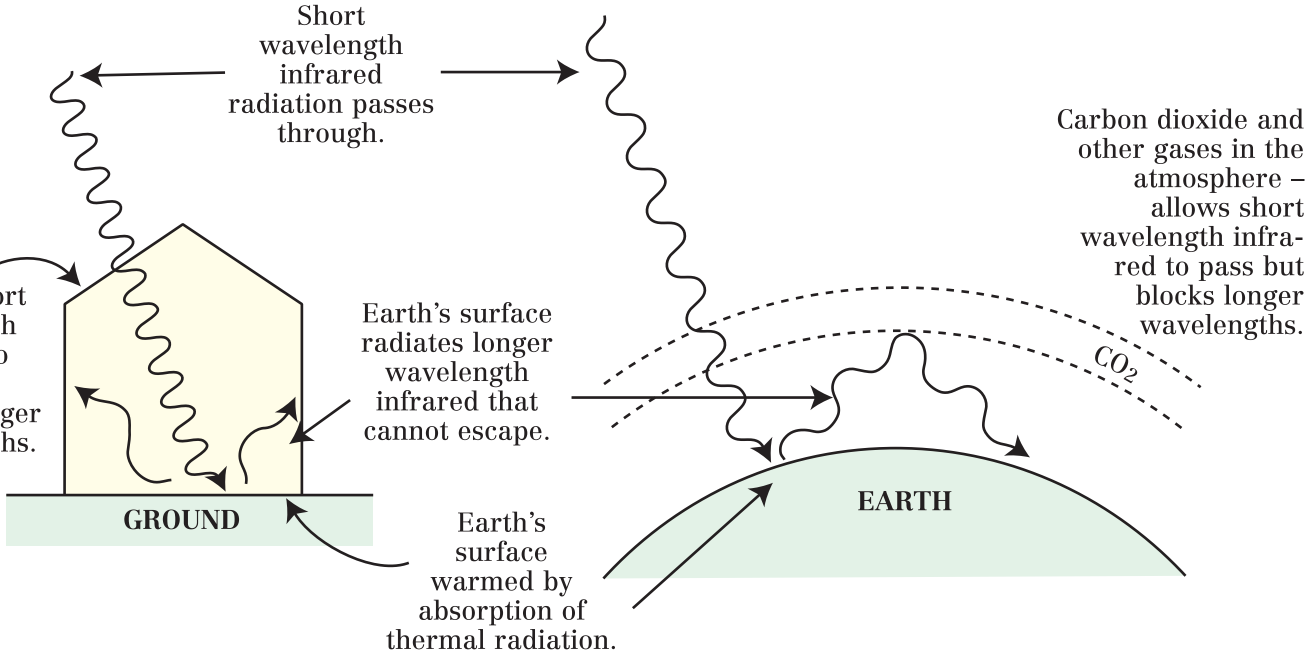


Dark, matt surfaces are good absorbers and emitters of thermal radiation.



Light, shiny surfaces are poor absorbers and emitters of thermal radiation.

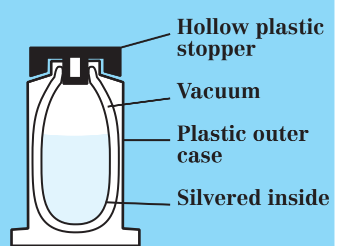
The greenhouse effect



Temperature rises due to the reabsorption of the trapped heat radiation. This leads to global warming.

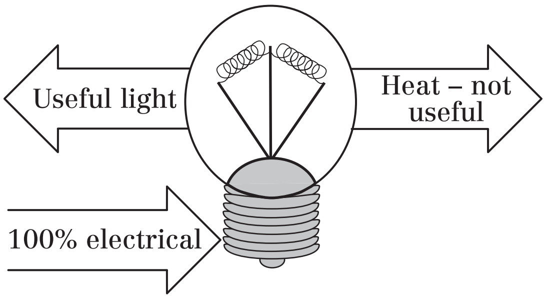
Questions

1. By which method of heat transfer does the heat from Sun reach Earth? How can you tell?
2. Why are solar panels fixed to roofs and designed to heat water painted black?
3. Why are many teapots made of shiny steel?
4. Explain why it is important to reduce the amount of carbon dioxide we pump into the atmosphere.
5. Look at the following diagram of a thermos flask and explain why:
   a. There is a vacuum between the walls of the flask.
   b. The walls of the flask are shiny.
   c. The drink stays hotter longer if the stopper is put in.
   d. Liquid nitrogen (boiling point 77K, –196°C) stays as a liquid in the flask for a long time, but rapidly boils and evaporates if poured out.



THERMAL ENERGY Reducing Energy Wastage in Our Homes

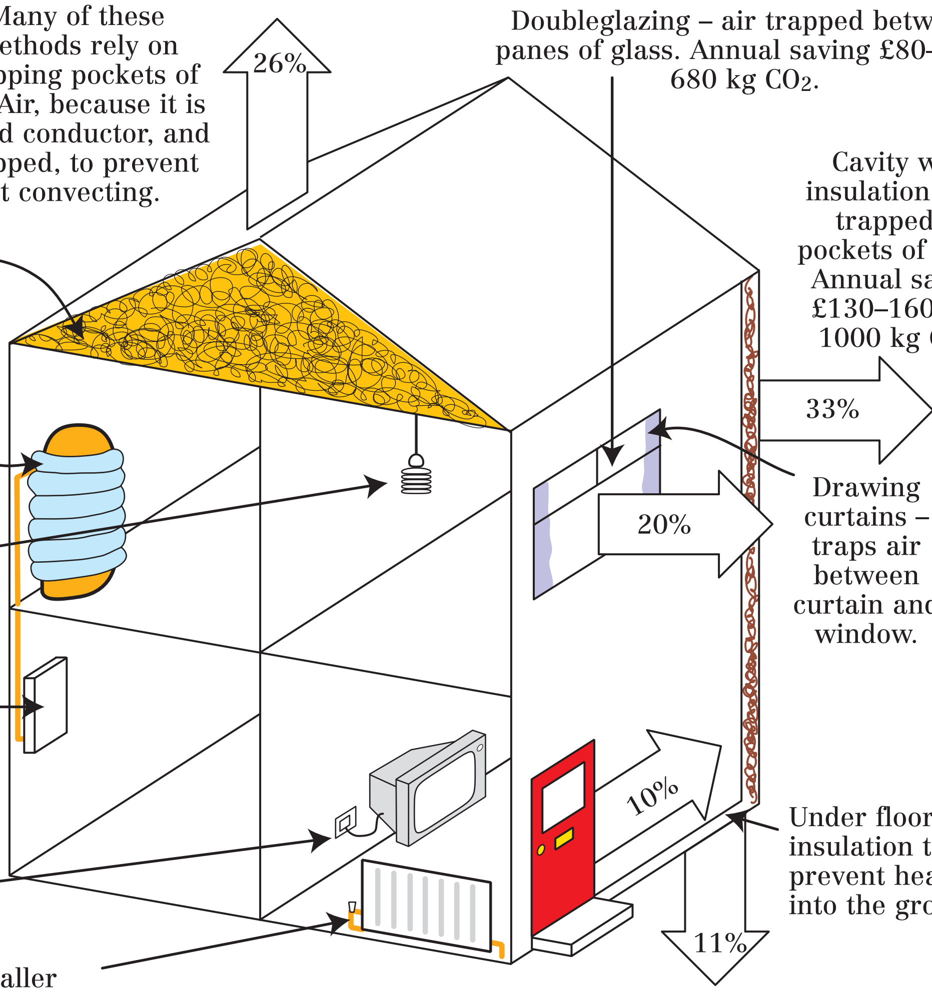
Reducing our demand for energy is as important in reducing greenhouse gas emissions as finding renewable energy resources. Although energy is conserved, we often convert it to forms that are not useful. For example:



To reduce our demand for energy there are many practical steps we can take, many involving the reduction of heat transfer. However, householders must also consider payback time.

$$\frac{\text{Cost of installing}}{\text{annual saving}} = \text{payback time in years.}$$

Many of these methods rely on trapping pockets of air. Air, because it is a bad conductor, and trapped, to prevent it convecting.



Loft insulation made of fibreglass or mineral wool. Annual saving £180–220 and 1500 kg CO_2.

Hot water tank jackets – air trapped in fibres. Annual saving £10–20, 50 kg CO_2.

Energy saving light bulb. Annual saving £9, 40 kg CO_2. Produces much less waste heat.

A condensing boiler condenses hot waste gas from the burnt fuel making it give up its latent heat rather than pumping it straight into the atmosphere.

Not leaving appliances on standby. Annual saving £20, 40 kg CO_2.

Turn down thermostats – the smaller the temperature difference between inside and outside the slower the rate of loss of thermal energy. 1°C reduction has an annual saving of £50 and 300 kg CO_2.

Doubleglazing – air trapped between panes of glass. Annual saving £80–100, 680 kg CO_2.

Cavity wall insulation – air trapped in pockets of foam. Annual saving £130–160 and 1000 kg CO_2.

Drawing curtains – traps air between curtain and window.

Under floor insulation to prevent heat loss into the ground.

Draught proofing – prevents warm air convecting from a warm room into a colder one through gaps in doors and windows. Annual saving £10–20, 120 kg CO_2.

Saving energy also reduces carbon dioxide emissions because carbon dioxide is a waste product of burning any fossil fuel, either directly such as gas in a boiler, or indirectly to generate electricity in a power station.

(Data correct (2006) Energy Saving Trust www.est.org.uk.)

Questions

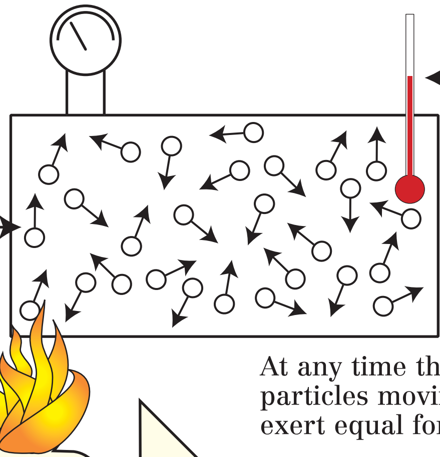
1. A householder could spend £230 on loft insulation that would save £180 in fuel bills each year, or they could spend £75 on draughtproofing and save £20 each year. Which would you recommend they do and why?
2. Why do we talk about wasting energy when physics tells us energy is conserved?
3. Which of the energy saving measures above are free?
4. The annual savings quoted above are both in terms of money and CO_2 saved. Which do you consider to be more important and why?

THERMAL ENERGY Kinetic Model of Gases

The kinetic model of gases is the name we give to the idea that a gas is made up of microscopic particles moving randomly, colliding with each other and the walls of the container.

The pressure is a measure of the rate and force of the collision of the gas molecules with the sides of the container.

The volume of the particles is insignificant compared to the volume of the container.



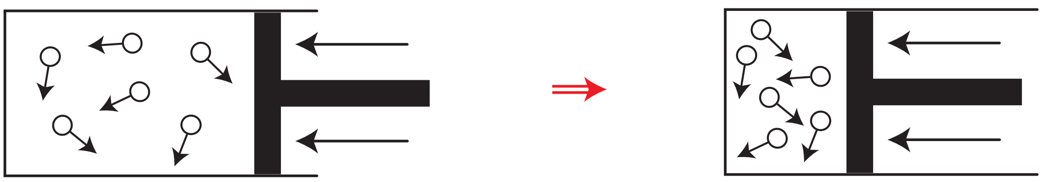
The temperature (in Kelvin) is *directly proportional* to the average kinetic energy of the molecules.

As the temperature rises, so does the average kinetic energy and, therefore, speed of the gas particles.

At any time there are on average equal numbers of gas particles moving in any direction. This explains why gases exert equal forces in all directions.

Heating the gas increases the average kinetic energy of the molecules, i.e. raises the temperature.

The gas particles travel faster and hit the sides of the container faster, and more often. Therefore, the pressure rises. We assume the particles do not lose any kinetic energy during collisions.

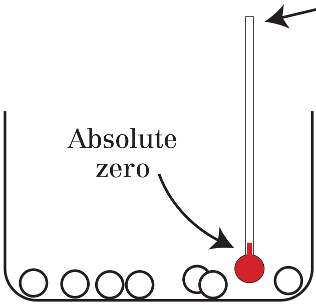


Gas pressure increases.

Gases are very compressible because there are large spaces between the molecules.

Reducing the volume of a container means that the molecules collide with the sides more often as they do not have so far to travel.

No pressure exerted at absolute zero, as there are no collisions.



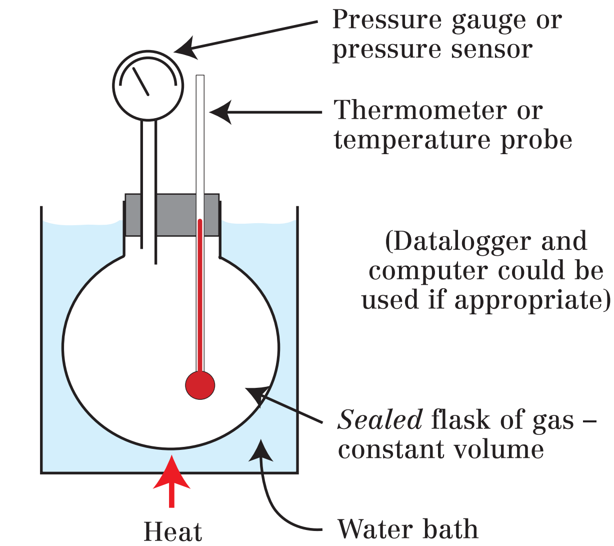
Thermometers read a temperature because gas particles collide with it and transfer kinetic energy to the material of the thermometer.

If the molecules stopped moving, then they would have no kinetic energy – therefore, we would say they had no temperature. This is called *absolute zero* because you cannot get any colder.

Questions

1. Explain carefully why heating a gas in a sealed container raises the pressure. Why might this not be very safe?
2. A motorist checks his tyre pressures before a long journey. At the end of the journey, he notices his tyres are warm and that their pressure has risen, why?
3. A toy balloon containing helium is released accidentally by a child. The balloon rises high into the atmosphere where the air pressure is a lot lower. Eventually it bursts. Why?
4. When you breathe in your lung volume increases. What happens to the air pressure in your lungs, and why does air rush in through your nose?
5. When petrol burns in a car engine it gets very hot very quickly. Why does this force the cylinder out?
6. When carbon dioxide is released rapidly from a fire extinguisher, it makes the nozzle get very cold, why?

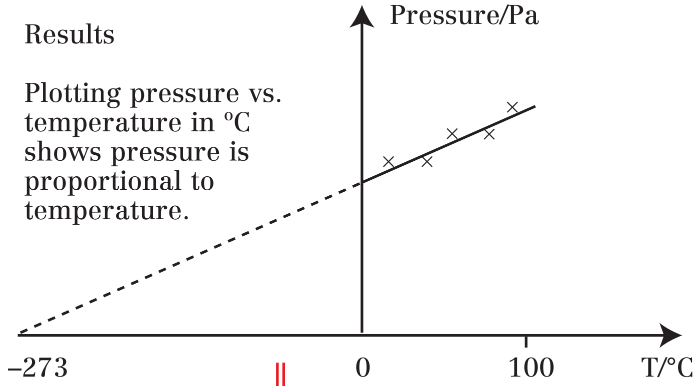
Measuring the variation of gas pressure with temperature:



Pressure is measured in Pascals, Pa. 1 Pa = 1 N/m^2.

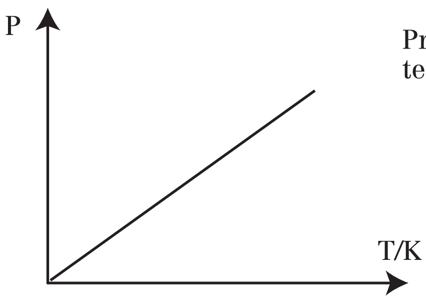
Results

Plotting pressure vs. temperature in °C shows pressure is proportional to temperature.



Extrapolating the line back, we see that the pressure would be zero when the temperature is –273°C. This is absolute zero, because all the gas particles would have stopped moving (see p65).

It would make sense to start a temperature scale here – we call this the Kelvin scale.

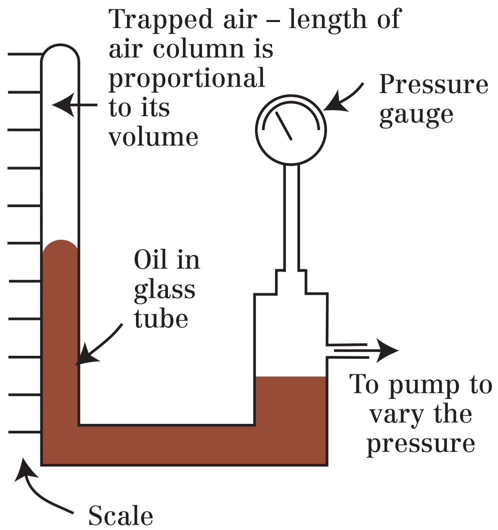


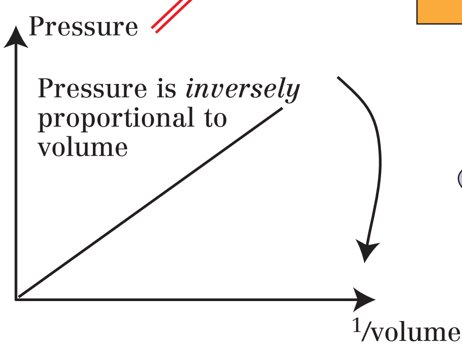
Pressure is *directly* proportional to temperature (measured in Kelvin) i.e.

$$\frac{\text{Pressure}}{\text{temperature (Kelvin)}} = \text{constant}$$

$$\frac{P}{T} = \text{constant}$$

Measuring the variation of gas pressure with volume:





Pressure × volume = constant

P × V = constant

Hence combining the two equations

$$\frac{P_1V_1}{T_1} = \frac{P_2V_2}{T_2}$$

N.B.
All gas law calculations must be carried out with Kelvin temperatures.

Questions

1. The pressure of air in a sealed container at 22°C is 105 000 Pa. The temperature is raised to 85°C. Show that the new pressure is about 130 000 Pa assuming that the volume of the container remains constant.
2. A bubble of air of volume 2 cm^3 is released by a deep-sea diver at a depth where the pressure is 420 000 Pa. Assuming the temperature remains constant show that its volume is 8 cm^3 just before it reaches the surface where the pressure is 105 000 Pa.
3. A sealed syringe contains 60 cm^3 of air at a pressure of 105 000 Pa and at 22°C. The piston is pushed in rapidly until the volume is 25 cm^3 and the pressure is 315 000 Pa. Show that the temperature of the gas rises to about 95°C.
4. When a star forms a gas cloud in space is attracted together by gravity compressing it. As the volume of the gas reduces what happens to its pressure and hence temperature?