

Specific Heat Capacity

Specific heat capacity is really just a sciencey way of saying how hard it is to heat something up...

Different Materials Have Different Specific Heat Capacities

1) More energy needs to be transferred to the thermal energy store of some materials to increase their temperature than others.

2) For example:

You need 4200 J to warm 1 kg of water by 1 °C,
but only 139 J to warm 1 kg of mercury by 1 °C.

3) Materials that need to gain lots of energy in their thermal energy stores to warm up also transfer loads of energy when they cool down again. They can 'store' a lot of energy.

4) The measure of how much energy a substance can store is called its specific heat capacity.

Specific heat capacity is the amount of energy needed to raise the temperature of 1 kg of a substance by 1 °C.

There's a Helpful Formula Involving Specific Heat Capacity

Below is the equation that links energy transferred to specific heat capacity (the Δ 's just mean "change in"):

$$\Delta E = mc\Delta\theta$$

Change in thermal energy (J) — ΔE — Specific heat capacity (J/kg°C) — c — Temperature change (°C) — $\Delta\theta$ — Mass (kg) — m

EXAMPLE:

How much energy is needed to heat 2.00 kg of water from 10 °C to 100 °C?
The specific heat capacity of water is 4200 J/kg°C.

1) First find the change in temperature ($\Delta\theta$) in °C.

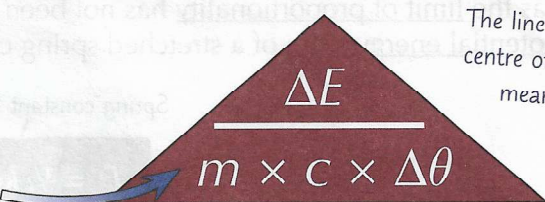
$$\Delta\theta = 100 - 10 = 90 \text{ °C}$$

2) Now substitute this value, along with the values for mass and specific heat capacity, into the formula.

$$\begin{aligned}\Delta E &= mc\Delta\theta \\ &= 2.00 \times 4200 \times 90 \\ &= 756\,000 \text{ J}\end{aligned}$$

If you're not working out the energy, you'll have to rearrange the equation, so a formula triangle will come in dead handy. To use them, cover up the thing you want to find and write down what's left showing.

You write the bits of the formula in the triangle like this:



The line through the centre of the triangle means divide.

Some substances can store more energy than others...

Water is a substance that can store a lot of energy in its thermal stores — it has a high specific heat capacity. This is lucky for us as our bodies are mostly water. It'd be unfortunate if we started boiling on a hot day. Learn the definition of specific heat capacity and make sure you know how to use the formula involving it.

Investigating Specific Heat Capacity

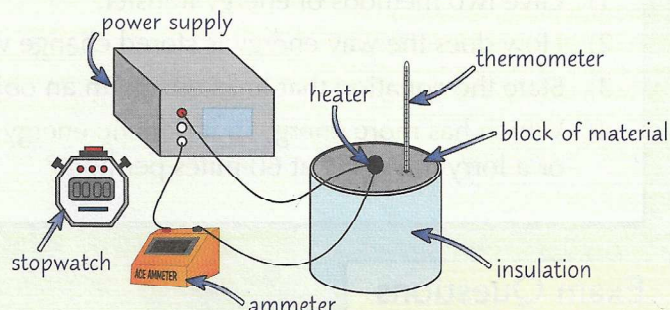
PRACTICAL

This fun practical can be used to find out the specific heat capacity of a material.

You Can Investigate Specific Heat Capacities

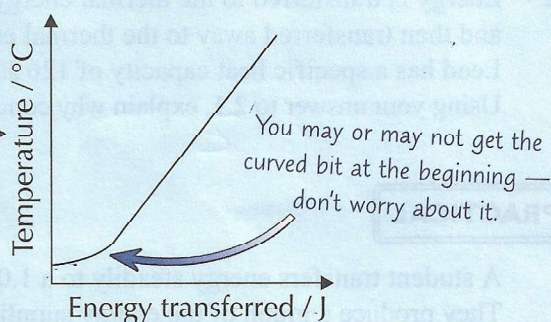
1) To investigate a solid material (e.g. copper), you'll need a block of the material with two holes in it (for the heater and thermometer to go into, see the image on the right).

2) Measure the mass of the block, then wrap it in an insulating layer (e.g. a thick layer of newspaper) to reduce the energy transferred from the block to the surroundings. Insert the thermometer and heater as shown on the right.



- 3) Measure the initial temperature of the block and set the potential difference, V , of the power supply to be 10 V. Turn on the power supply and start a stopwatch.
- 4) When you turn on the power, the current in the circuit (i.e. the moving charges) does work on the heater, transferring energy electrically from the power supply to the heater's thermal energy store. This energy is then transferred to the material's thermal energy store by heating, causing the material's temperature to increase.
- 5) As the block heats up, use the thermometer to measure its temperature e.g. every minute. Keep an eye on the ammeter — the current through the circuit, I , shouldn't change.
- 6) When you've collected enough readings (10 should do it), turn off the power supply.
- 7) Now you have to do some calculations to find the material's specific heat capacity:

- Using your measurement of the current and the potential difference of the power supply, you can calculate the power supplied to the heater, using $P = VI$ (p.54). You can use this to calculate how much energy, E , has been transferred to the heater at the time of each temperature reading using the formula $E = Pt$, where t is the time in seconds since the experiment began.
- If you assume all the energy supplied to the heater has been transferred to the block, you can plot a graph of energy transferred to the thermal energy store of the block against temperature. It should look something like this: ➡
- Find the gradient of the straight part of the graph. This is $\Delta\theta \div \Delta E$. You know from the equation on the last page that $\Delta E = mc\Delta\theta$. So the specific heat capacity of the material of the block is: $1 \div (\text{gradient} \times \text{the mass of the block})$.



- 8) You can repeat this experiment with different materials to see how their specific heat capacities compare.

You can also investigate the specific heat capacity of liquids — just place the heater and thermometer in an insulated beaker filled with a known mass of the liquid.



Think about how you could improve your experiments...

If the hole in your material is bigger than your thermometer, you could put a small amount of water in the hole with the thermometer. This helps the thermometer to measure the temperature of the block more accurately, as water is a better thermal conductor than air (see page 24).

Warm-Up & Exam Questions

These questions give you chance to use your knowledge about energy transfers and specific heat capacity.

Warm-Up Questions

- 1) Give two methods of energy transfer.
- 2) How does the way energy is stored change when someone throws a ball upwards?
- 3) State the equation that links energy in an object's kinetic energy store with mass and speed.
- 4) Which has more energy in its kinetic energy store: a person walking at 3 miles per hour, or a lorry travelling at 60 miles per hour?

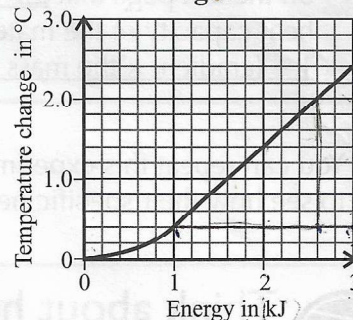
Exam Questions

- 1** A motor lifts a load of mass 20 kg.
The load gains 137.2 J of energy in its gravitational potential energy store. Grade 4-6
- 1.1** State the equation that links gravitational potential energy, mass, gravitational field strength and height.
Use this equation to calculate the height through which the motor lifts the load.
Assume the gravitational field strength = 9.8 N/kg 0.7 m [4 marks]
- 1.2** The motor releases the load and the load falls.
Ignoring air resistance, describe the changes in the way energy is stored that take place as the load falls. [2 marks]
- 1.3** Describe how your answer to 1.2 would differ if air resistance was not ignored. [1 mark]
- 2** 36 000 J of energy is transferred to heat a 0.5 kg concrete block from 20 °C to 100 °C. Grade 6-7
- 2.1** Calculate the specific heat capacity of the concrete block.
Use the correct equation from the Physics Equation Sheet on the inside back cover. 900 J/kg°C [4 marks]
- 2.2** Energy is transferred to the thermal energy store of an electric storage heater at night, and then transferred away to the thermal energy stores of the surroundings during the day.
Lead has a specific heat capacity of 126 J/kg°C.
Using your answer to 2.1, explain why concrete blocks are used in storage heaters rather than lead blocks. [2 marks]

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- 3** A student transfers energy steadily to a 1.0 kg aluminium block.
They produce a graph of the energy supplied against the increase in temperature of the block, shown in **Figure 1**. Grade 6-7
- 3.1** Use **Figure 1** to find a value for the specific heat capacity of aluminium in J/kg°C. Use the correct equation from the Physics Equation Sheet on the inside back cover. 1000 J/kg°C [4 marks]
- 3.2** Would you expect the true value for the specific heat capacity of aluminium to be higher or lower than the value found in this experiment? Explain your answer. [3 marks]

Figure 1



Conservation of Energy and Power

Repeat after me: energy is NEVER destroyed. Make sure you learn that fact, it's really important.

You Need to Know the Conservation of Energy Principle

- 1) The conservation of energy principle is that energy is always conserved:

Energy can be transferred usefully, stored or dissipated, but can never be created or destroyed.

- 2) When energy is transferred between stores, not all of the energy is transferred usefully into the store that you want it to go to. Some energy is always dissipated when an energy transfer takes place.
 3) Dissipated energy is sometimes called 'wasted energy' because the energy is being stored in a way that is not useful (usually energy has been transferred into thermal energy stores).

A mobile phone is a system. When you use the phone, energy is usefully transferred from the chemical energy store of the battery in the phone. But some of this energy is dissipated in this transfer to the thermal energy store of the phone (you may have noticed your phone feels warm if you've been using it for a while).



- 4) You also need to be able to describe energy transfers for closed systems:

A cold spoon is dropped into an insulated flask of hot soup, which is then sealed. You can assume that the flask is a perfect thermal insulator so the spoon and the soup form a closed system. Energy is transferred from the thermal energy store of the soup to the useless thermal energy store of the spoon (causing the soup to cool down slightly). Energy transfers have occurred within the system, but no energy has left the system — so the net change in energy is zero.

Power is the 'Rate of Doing Work' — i.e. How Much per Second

- 1) Power is the rate of energy transfer, or the rate of doing work.
 2) Power is measured in watts. One watt = 1 joule of energy transferred per second.
 3) You can calculate power using these equations:

$$\text{Power (W)} = \frac{P}{t} = \frac{E}{t}$$

Energy transferred (J)
Time (s)

$$\text{Power (W)} = \frac{P}{t} = \frac{W}{t}$$

Work done (J)
Time (s)

- 4) A powerful machine is not necessarily one which can exert a strong force (although it usually ends up that way). A powerful machine is one which transfers a lot of energy in a short space of time.

Take two cars that are identical in every way apart from the power of their engines. Both cars race the same distance along a straight track to a finish line. The car with the more powerful engine will reach the finish line faster than the other car (it will transfer the same amount of energy but over less time).

EXAMPLE:

It takes 8000 J of work to lift a stunt performer to the top of a building. Motor A can lift the stunt performer to the correct height in 50 s. Motor B would take 300 s to lift the performer to the same height. Which motor is most powerful? Calculate the power of this motor.

- 1) Both motors transfer the same amount of energy, but motor A would do it quicker than motor B.
 2) Plug the time taken and work done for motor A into the equation $P = W \div t$ and find the power.

So motor A is the most powerful motor.

$$P = W \div t$$

$$= 8000 \div 50 = 160 \text{ W}$$

Conduction

You're probably familiar with the idea that metals are good thermal conductors but wood isn't, and so on. This page is about how conduction actually happens and about the energy transfers that take place.

Conduction Occurs Mainly in Solids

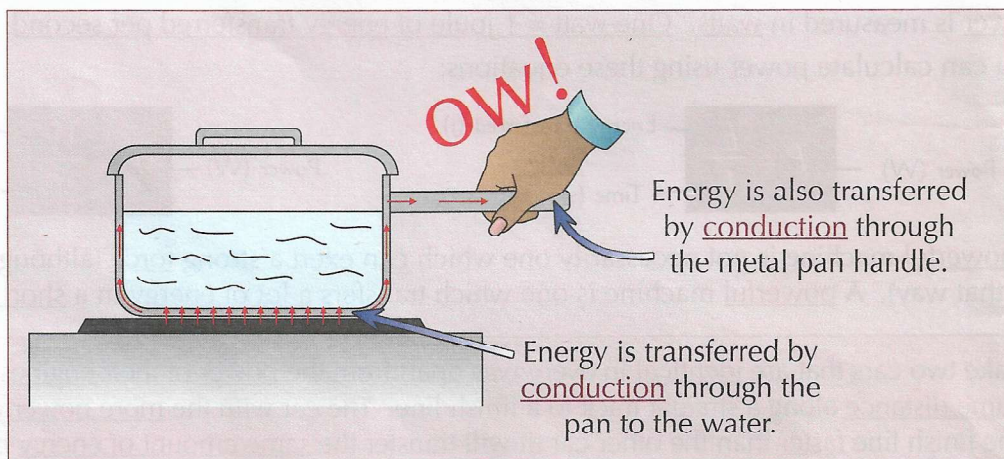
Conduction is the process where vibrating particles transfer energy to neighbouring particles.

- 1) Energy transferred to an object by heating is transferred to the thermal store of the object. This energy is shared across the kinetic energy stores of the particles in the object.
- 2) The particles in the part of the object being heated vibrate more and collide with each other. These collisions cause energy to be transferred between particles' kinetic energy stores. This is conduction.



- 3) This process continues throughout the object until the energy is transferred to the other side of the object. It's then usually transferred to the thermal energy store of the surroundings (or anything else touching the object).

Particles in liquids and gases are much more free to move around, which is why they usually transfer energy by convection (see the next page) instead of conduction.



- 4) Thermal conductivity is a measure of how quickly energy is transferred through a material in this way. Materials with a high thermal conductivity transfer energy between their particles quickly.

Some substances are better thermal conductors than others...

Denser materials (see page 64) are usually better conductors than less dense materials. It's easy to see why — particles that are right next to each other will pass energy between their kinetic energy stores far more effectively than particles that are far apart. For example, water is a much better thermal conductor than air.

Convection

You'll have heard it said that hot air rises. Well, it does (assuming the air above it is cooler).

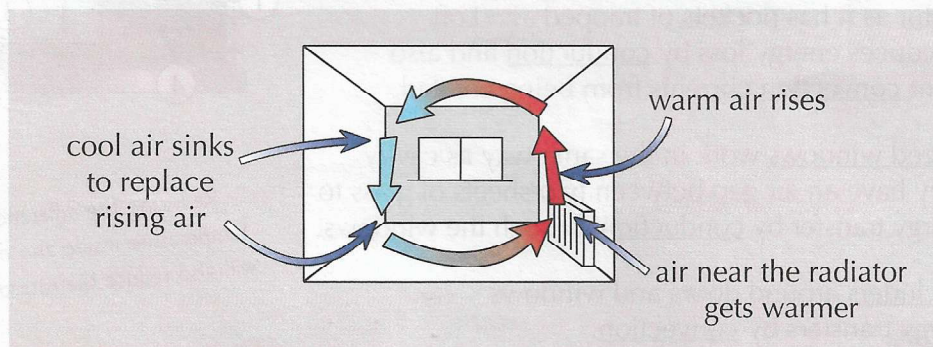
Convection Occurs Only in Liquids and Gases

Convection is where energetic particles move away from hotter to cooler regions.

- 1) Convection can happen in gases and liquids. Energy is transferred by heating to the thermal store of the liquid or gas. As with conduction, this energy is shared across the kinetic energy stores of the gas or liquid's particles.
- 2) Unlike in solids, the particles in liquids and gases are able to move. When you heat a region of a gas or liquid, the particles move faster and the space between individual particles increases. This causes the density (p.64) of the region being heated to decrease.
- 3) Because liquids and gases can flow, the warmer and less dense region will rise above denser, cooler regions. If there is a constant heat source, a convection current can be created.

Radiators Create Convection Currents

- 1) Heating a room with a radiator relies on creating convection currents in the air of the room.
- 2) Energy is transferred from the radiator to the nearby air particles by conduction (the air particles collide with the radiator surface).
- 3) The air by the radiator becomes warmer and less dense (as the particles move quicker).
- 4) This warm air rises and is replaced by cooler air. The cooler air is then heated by the radiator.
- 5) At the same time, the previously heated air transfers energy to the surroundings (e.g. the walls and contents of the room). It cools, becomes denser and sinks.
- 6) This cycle repeats, causing a flow of air to circulate around the room — this is a convection current.



In convection, particles move from hotter regions to cooler regions...

So in convection, the particles move taking their energy with them. Don't get this confused with conduction though. Conduction is the process where vibrating particles transfer energy to neighbouring particles. Have a flick back to the last page if you need to remind yourself about this.

Reducing Unwanted Energy Transfers

There are a few ways you can reduce the amount of energy scampering off to a completely useless store — lubrication and thermal insulation are the ones you need to know about. Read on to find out more...

Lubrication Reduces Frictional Forces

1) Whenever something moves, there's usually at least one frictional force acting against it (p.108). This causes some energy in the system to be dissipated (p.23), e.g. air resistance can transfer energy from a falling object's kinetic energy store to its thermal energy store.

2) For objects that are being rubbed together, lubricants can be used to reduce the friction between the objects' surfaces when they move. Lubricants are usually liquids (like oil), so they can flow easily between objects and coat them.

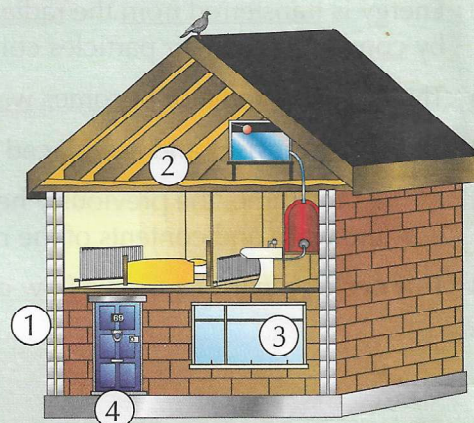
Streamlining reduces air resistance too, see page 108.

Insulation Reduces the Rate of Energy Transfer by Heating

The last thing you want when you've made your house nice and toasty is for that energy to escape outside. There are a few things you can do to prevent energy losses through heating:

- Have thick walls that are made from a material with a low thermal conductivity. The thicker the walls and the lower their thermal conductivity, the slower the rate of energy transfer will be (so the building will cool more slowly).
- Use thermal insulation. Here are some examples:

- 1) Some houses have cavity walls, made up of an inner and an outer wall with an air gap in the middle. The air gap reduces the amount of energy transferred by conduction through the walls. Cavity wall insulation, where the cavity wall air gap is filled with a foam, can also reduce energy transfer by convection in the wall cavity.
- 2) Loft insulation can be laid out across the loft floor and ceiling. Fibreglass wool is often used which is a good insulator as it has pockets of trapped air. Loft insulation reduces energy loss by conduction and also helps prevent convection currents from being created.
- 3) Double-glazed windows work in the same way as cavity walls — they have an air gap between two sheets of glass to prevent energy transfer by conduction through the windows.
- 4) Draught excluders around doors and windows reduce energy transfers by convection.



Reducing the difference between the temperature inside and outside the house will also reduce the rate of energy transfer.

Having a well-insulated house can reduce your heating bills...

When people talk of energy loss, it's not that the energy has disappeared. It still exists (see page 23), just not necessarily in the store we want. For example, in a car, you want the energy to transfer to the kinetic energy store of the wheels, and not to the thermal energy stores of the moving components.

Investigating Energy Transfers

PRACTICAL

Now it's time to get practical. This investigation isn't too complicated, but there are several variables that it's really important to keep constant. So make sure you follow the method carefully.

You can Investigate the Effectiveness of Different Insulators...

Here's the method for how you can do this:

1) Boil water in a kettle. Pour some of the water into a sealable container (e.g. a beaker and lid) to a safe level. Measure the mass of water in the container (p.182).

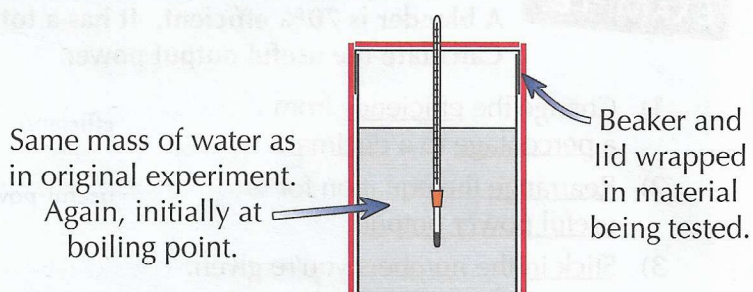
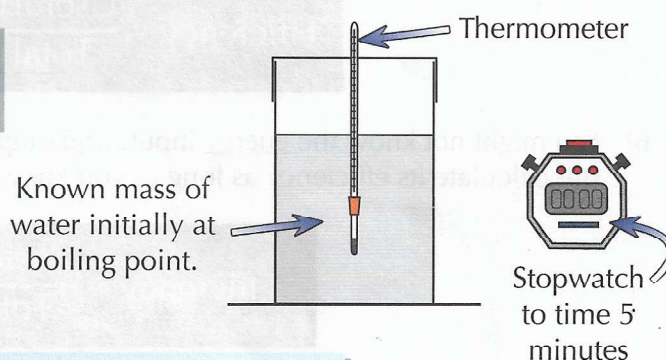
2) Use a thermometer to measure the initial temperature of the water (p.182).

3) Seal the container and leave it for five minutes. Measure this time using a stopwatch.

4) Remove the lid and measure the final temperature of the water.

5) Pour away the water and allow the container to cool to room temperature.

6) Repeat this experiment, but wrap the container in a different material (e.g. foil, newspaper) once it has been sealed. Make sure you use the same mass of water each time.



You should find that the temperature difference (and so the energy transferred) is reduced by wrapping the container in thermally insulating materials like bubble wrap or newspaper.

... and Factors that Affect how Good a Material is at Insulating

- 1) You could, for example, also investigate how the thickness of the material affects the temperature change of the water.
- 2) You should find that the thicker the insulating layer, the less energy is transferred and the smaller the temperature change of the water.



It's tricky to keep the variables constant in this experiment...

For example, it's unlikely that the foil you have available will be exactly the same thickness as newspaper. These are all things you should mention in your conclusion. It's a good idea to repeat your investigation too — you don't want errors creeping in without you noticing.

Efficiency

Devices have energy transferred to them, but only transfer some of that energy to useful energy stores. Wouldn't it be great if we could tell how much it usefully transfers? That's where efficiency comes in.

Most Energy Transfers Involve Some Waste Energy

- 1) Useful devices are only useful because they can transfer energy from one store to another.
- 2) As you'll probably have gathered by now, some of the input energy is usually wasted by being transferred to a useless energy store — usually a thermal energy store.
- 3) The less energy that is 'wasted' in this energy store, the more efficient the device is said to be.
- 4) You can improve the efficiency of energy transfers by insulating objects, lubricating them or making them more streamlined (see pages 26 and 108).
- 5) The efficiency for any energy transfer can be worked out using this equation:

$$\text{Efficiency} = \frac{\text{Useful output energy transfer}}{\text{Total input energy transfer}}$$

You can give efficiency as a decimal or you can multiply your answer by 100 to get a percentage, i.e. 0.75 or 75%.

- 6) You might not know the energy inputs and outputs of a device, but you can still calculate its efficiency as long as you know the power input and output:

$$\text{Efficiency} = \frac{\text{Useful power output}}{\text{Total power input}}$$

EXAMPLE:

A blender is 70% efficient. It has a total input power of 600 W. Calculate the useful output power.

- 1) Change the efficiency from a percentage to a decimal.
- 2) Rearrange the equation for useful power output.
- 3) Stick in the numbers you're given.

$$\text{efficiency} = 70\% = 0.70$$

$$\begin{aligned} \text{useful power output} &= \text{efficiency} \times \text{total power input} \\ &= 0.70 \times 600 \\ &= 420 \text{ W} \end{aligned}$$

Useful Energy Input Isn't Usually Equal to Total Energy Output

- 1) For any given example you can talk about the types of energy being input and output, but remember — NO device is 100% efficient and the wasted energy is usually transferred to useless thermal energy stores.

- 2) Electric heaters are the exception to this. They're usually 100% efficient because all the energy in the electrostatic energy store is transferred to "useful" thermal energy stores.

- 3) Ultimately, all energy ends up transferred to thermal energy stores. For example, if you use an electric drill, its energy is transferred to lots of different energy stores, but quickly ends up all in thermal energy stores.