Y8 PHYSICS

In Year 8 we cover three main topics; **Energy**, **Waves** and **Radioactivity**.

All three represent really important ideas in Physics which Physicists did not really get to grips with until the later nineteenth and early twentieth centuries. Energy owes its current structure to the Scotsmen James Watt, James Joule and William, Lord Kelvin, along with Ludwig Boltzmann and Nicholas Carnot. Kelvin has the scientific temperature scale named after him and also worked on waves, but most famously another Scotsman, James Clerk Maxwell, worked out the equations which describe light as a wave.

Kelvin was known for speaking his mind, even if that meant he was later proved wrong. One of his scientific failures was that he could not correctly calculate the Earth's age from its current temperature and from understanding how it had cooled. This was because he did not know to take into account heating by radioactive decay. Understanding that nuclear radiation was the cause of Kelvin's problem and the naming of the three types of radiation was by kiwi, working in Manchester, Ernest Rutherford, but the term radioactivity was first applied by Marie Curie. She is still the only person to win a Nobel Prize in both Physics and Chemistry, as well as being the mother of a Nobel winning daughter.

> "No balloon and no aeroplane will ever be practically successful."
> Lord Kelvin, 1902

THINGS YOU NEED TO HAVE REMEMBERED FROM Y7

In Y7 we covered:

- **Measurement and Units:**

  You are required to know the following units:

Quantity	Symbols Commonly Used in a Formula	SI base unit	Symbol for base unit
Length or distance	*l*,*d* or *s*	metres	m
Area	*A*	metres squared	m^2
Volume	*V*	metres cubed	m^3
Mass	*m*	kilograms	kg
Time	*t* or *T*	seconds	s
Temperature	*T* or *Θ*	degrees Celsius	^oC
Speed or Velocity	*v*	metres per second	m/s
Density	*ρ*	kilograms per metre cubed	kg/m^3
Force	*F*	newtons	N
Pressure	*P*	pascals	Pa

  You are also required to remember the meaning of common unit multipliers:

  Larger: Mega, M, one million times & kilo, k, one thousand times
  Smaller: milli, m, one thousandth & centi, c, one hundredth (centimetres is a very common unit, but where possible using centi should be avoided)

- **Material Properties:**

You are required to remember that metals are good conductors of electricity and that elastic materials change their shape when a force is applied.

You should also remember that objects float when their density is lower than the density of the fluid they are in, and that the upwards force experienced by an object in a fluid is called upthrust or buoyancy.

You should also remember that the formula for density is given by $\rho = \frac{m}{V}$

- **Forces and Motion:**

You are required to remember that:

Weight is the force due to gravity which is measured in newtons and on Earth always acts towards the Earth's centre
Objects accelerate in the direction of the *resultant* force acting on them
Friction is a force which always acts in the opposite direction to motion
Mean or average speed is given by the formula $v = \frac{s}{t}$

You should also remember that the formula for pressure is given by the formula $P = \frac{F}{A}$

- **Space:**

You should remember that:

The sun is a fairly ordinary star which glows hot because nuclear fusion is occurring in its core
The planets in our solar system orbit the sun because of the sun's large gravity
The earth orbits the sun in a year and rotates around its axis in a day
The earth's axis of rotation is at an angle to its orbit which creates the seasons by changing the day length and by changing the area that the incoming light from the sun is spread over.
One gravitational effect of the Moon's orbit is to create two bulges in the oceans, one roughly facing the Moon and one on the opposite side. When the Earth's rotation takes us through those bulges we get high tides.

- **Practical Work:**

You are required to remember that:

A well designed experiment has an independent variable, a dependent variable and that as far as possible all other variables are kept the same (controlled).
A well designed Physics experiment will produce a line graph which can be interpreted to tell us about the Physics of the process being investigated.
All the data from an experiment should be recorded. Usually this is done in a table with the independent variable in the leftmost column (units should be in the column headings and not with the data)
It is important to record the precision of the instruments used, as this gives an estimate of uncertainty. All values should be recorded to the full precision of the instrument even if this means that zeroes follow a decimal place, e.g. 2 metres measured with a tape marked with millimetre divisions would be recorded as 2.000m.
When calculating values from experimental data it is the significant figures, and not the decimal places, that matter. Calculated values should be rounded to the same number of significant figures as the data.

Physics write ups have a set pattern which may differ from Chemistry's or Biology's. This structure is laid out in the same "Writing up a Practical" document as you used last year.

- **Maths:**
  You are required to be able to rearrange formulas to make any term in the formula the subject.
  This is a tough skill and is one you will work on in Maths lessons all the way through to A level, but please try to change the subject of the formula without just guessing and without resorting to formula triangles.
  As in Year 7, most Y8 formulae are of the form:

$$A = BC \quad \leftrightarrow \quad C = \frac{A}{B} \; or \; B = \frac{A}{C}$$

  Where the lack of mathematical symbol between the *B* and *C* means they are being multiplied.

  You are required to remember that the number of significant figures is more important in Physics than the number of decimal places:

  0.08 and 3.08 are both to two decimal places, but the 1st only has one significant figure, the second has three.

  You should remember that we introduced the idea of powers of 10 last year, i.e. ×1,000 = $\times 10^3$ and , $\frac{1}{1000}$th = $\times 10^{-3}$. Your calculator is likely to give you answers using this notation and so being aware of it will be useful in Year 8 and will become very important as you pursue Physics further.

1 Energy

1.1 Energy Defined

In day to day language *energy* is something that you must have in order do anything, and is used up as you work or play.

In Physics the use of the word "Energy" is similar; Wikipedia describes it as "the property that must be transferred to an object in order to perform work on – or to heat – the object".

There are, however, three big differences between the Physics definition and our casual use:

- The term "work" has a strict meaning, usually, but not always, connected to mechanical motion. In Physics "work" is not the thinking involved in writing your homework, but the mechanical movement of your pen.
- In Physics heating and doing work are both ways of transferring energy and are both measured in joules.

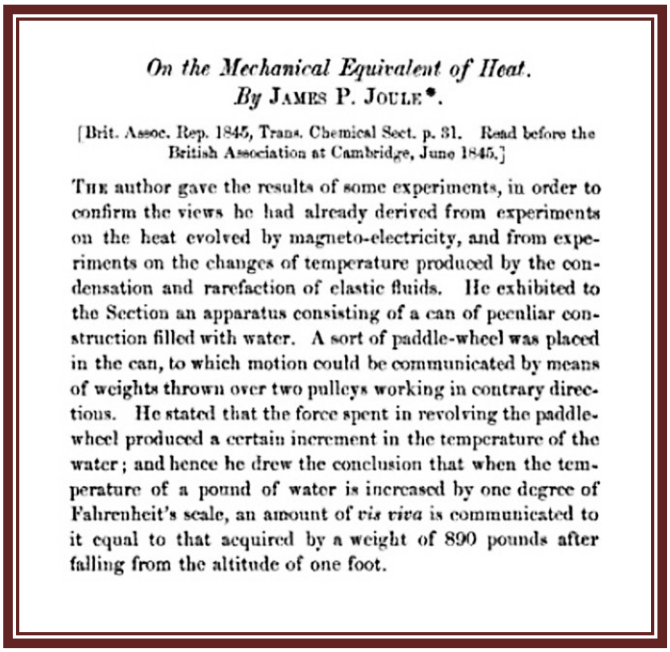
Energy cannot be used up, just changed (see 1.2 Energy Laws

- 1.2.1 The Law of Conservation of Energy).

The equivalence between mechanical work and heat was conclusively shown by James Joule. He performed experiments using electric motors, and using fine sieves through which he squeezed viscous liquids, in both cases he found close agreement between the amount of mechanical work and the resulting heating. In his most famous experiment - reported to the British Association of Science in 1845 (see the red box) he used falling weights to spin paddle wheels in water and thus heat the water.

Joule's measurements give us the modern definition of the unit of energy, which is named after him:

- One joule (1J) is the work done in pushing or pulling something with a force of one newton for the distance of one metre.
- 4.18 joules (4.18J) is required to heat up one gram of pure water by one degree Celsius.



On the Mechanical Equivalent of Heat.
By JAMES P. JOULE*.

[Brit. Assoc. Rep. 1845, Trans. Chemical Sect. p. 31. Read before the British Association at Cambridge, June 1845.]

THE author gave the results of some experiments, in order to confirm the views he had already derived from experiments on the heat evolved by magneto-electricity, and from experiments on the changes of temperature produced by the condensation and rarefaction of elastic fluids. He exhibited to the Section an apparatus consisting of a can of peculiar construction filled with water. A sort of paddle-wheel was placed in the can, to which motion could be communicated by means of weights thrown over two pulleys working in contrary directions. He stated that the force spent in revolving the paddle-wheel produced a certain increment in the temperature of the water; and hence he drew the conclusion that when the temperature of a pound of water is increased by one degree of Fahrenheit's scale, an amount of *vis viva* is communicated to it equal to that acquired by a weight of 890 pounds after falling from the altitude of one foot.

These definitions will be used at GCSE, but are not required in Y8. However, you are required to know that the unit of energy is the joule. Its symbol is a capital **J**, nothing that looks like a small **j** will be accepted.

The fact that work and heat are the same leads to an incredibly important result in Physics which is known as the *1st Law of Thermodynamics*, or more generally *The Law of Conservation of Energy* and **understanding and applying the Law of Conservation of Energy is required in Y8**.

1.2 ENERGY LAWS

1.2.1 The Law of Conservation of Energy

The Law of Conservation of Energy states that Energy cannot be created or destroyed it can only be transformed from one form into another.

Energy is transformed from one type into another when work is done.

For example if you drag a weight along a table for one metre with a force of one newton then by the definition above one joule of mechanical work is done. When you stop dragging the weight stops, so the question is, given the Law of Conservation of Energy, where did that one joule of energy come from and where did it end up?

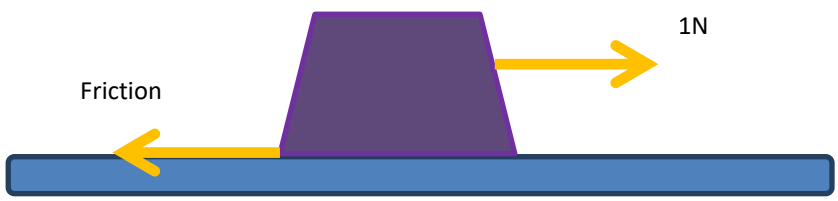


Figure 1.2.1 The horizontal forces acting on a block being dragged along a table.

The force applied to pull the weight along will have been opposed by friction. Wherever two surfaces slide across each other (dynamic friction) both surfaces heat up. So the 1J expended will end up heating the table and the weight. **We say that the Thermal Energy (or the Internal Energy) of the weight and of the surface has been increased by 1J**. You might expect to be able to feel a temperature increase, but 1J is nothing like enough to make a noticeable difference to the temperature of a table or a metal weight. You would need very

sensitive kit to prove the temperature rise. The fact that he was able to demonstrate a consistent temperature rise in a similar situation is why Joule's experiment is famous.

This answers where the energy went to, but where did it come from? Well it came from you and you are powered by a set of chemical reactions which ultimately derive from respiration; the reaction of sugars acquired from your food with oxygen. You can therefore be regarded as a store of chemical energy. You are of course inefficient (see later) so more than one joule will have been expended by you to achieve one joule of work, **we say that your chemical energy store has been depleted by at least 1J**. The extra has not disappeared; it has warmed up your muscles, or rather 'increased their Thermal Energy'.

1.2.2 Energy Types

There are a number of ways that energy can be stored within an object. Some are obvious:

- **Thermal Energy** (Thermal Energy forms part of an object's Internal Energy, to a scientist the two are different, but up to GCSE are used interchangeably – try to avoid saying or writing "Heat Energy" because technically it is incorrect). Thermal Energy increases with temperature and can only approach zero at -273°C (absolute zero). You have to be careful however, an iceberg, because of its size, will have more thermal energy than a kettle full of boiling water.
- **Chemical Energy**. You should understand from your Chemistry that some chemicals are likely to go through chemical reactions which release energy while forming more stable compounds. Burning is a good example of such a reaction. We say that chemicals that are likely to react in this way are a store of Chemical Energy.
- **Kinetic Energy**. Any object in motion can be regarded as storing Kinetic Energy, the faster it is going or the more mass it has, the more Kinetic Energy it has.
- **Nuclear Energy**. Some atoms have unstable nuclei (see Nuclear Radiation) and naturally decay (their nuclei change to a more stable form, releasing energy in the process), others can be made to change their nuclei by Nuclear Fission (nuclear power stations) or Nuclear Fusion (the sun and other stars). These atoms are regarded as stores of nuclear energy.

Other energy stores are a consequence of position, and are therefore less obvious:

- **Gravitational Potential Energy (GPE)**. An object above a surface will fall when released because of gravity. Energy must be expended to get that object to its higher position and energy will be released when it falls. Therefore, while in position the object must have a store of Gravitational Potential Energy. The higher it is with respect to the surface, and the more mass it has, the more GPE it has.
- **Electrical Potential Energy**. Charged particles experience forces attracting or repelling them from other charged particles. By the same reasoning as for gravity where the position above a surface gave rise to GPE, the position of a charged object with respect to other charges gives rise to Electrical Potential Energy.
- **Magnetic Potential Energy**. Magnets and Magnetic Materials are attracted and repelled by other magnets. The position of a magnetic object with respect to other magnets gives rise to Magnetic Potential Energy.
- **Elastic Potential Energy**. Stretching or compressing an object requires work and therefore energy, and when the object is released there is a release of energy. Elastic Potential Energy is the energy stored and depends on the amount of stretch or compression and the stiffness of the object.

There are also ways of moving energy from one place to another via waves, two of which are often recognised as distinct energy types:

- **Light**. For example, the sun's thermal energy is radiated out into space and some arrives at the earth's surface via light waves. While traveling in between the sun and us it can be regarded as Light Energy. The same process is occurring in Thermal Energy transfer via Radiation (****).
- **Sound**. Sound relies on the movement of particles and so could be regarded as some combination of kinetic and potential energies, but it is often easier to regard it as a single energy type, although not an energy store.

Finally, probably the most important method in our modern world for converting one form of energy to another is via electricity.

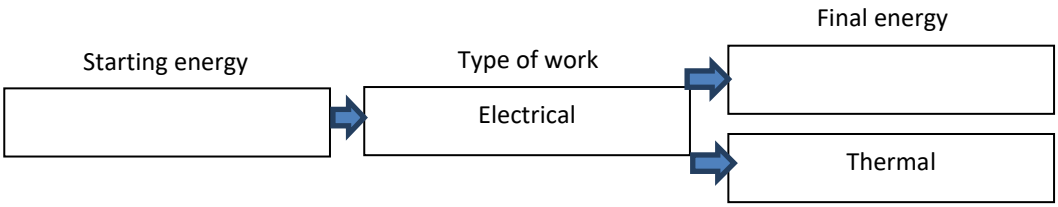
- **Electrical Energy** (this is not the same as, although it is related to, Electrical Potential Energy). Electrical Energy can be regarded as the method of transfer of energy in, for example, changing the Chemical Energy in a cell into the Kinetic Energy of an Electric Motor. It is very difficult to store Electrical Energy without first turning it into some other form, and so like Light and Sound, Electrical Energy is a transfer not a store.

In Year 8, and all the way up to GCSE, a common exam question is to ask you to identify the forms that energy is being stored in before and after work has been done, and to identify the methods of transfer.

Examples of Naming Energies During Transfers:

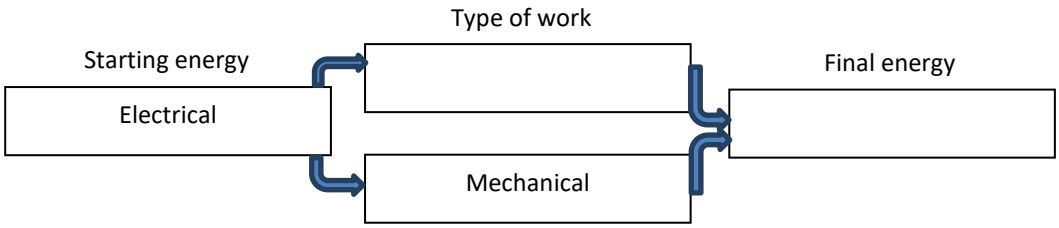
1. **A simple circuit**

   Complete the flow diagram showing the energy transformation occurring in a circuit with a cell and an electric motor:



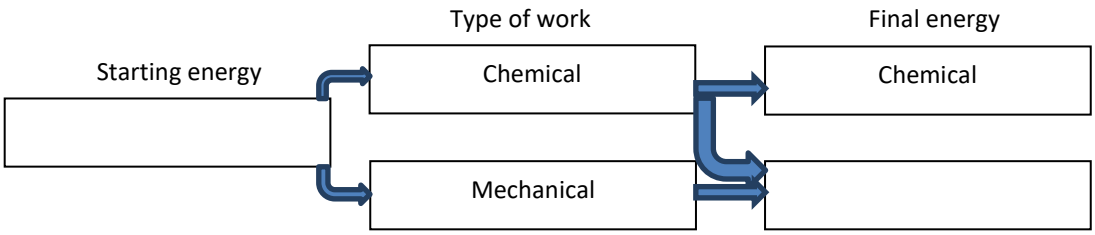
   The answers for the blank boxes are obviously "Chemical", which is how energy is stored in a cell or battery, and "Kinetic", because creating motion is the whole point of electrical motors, but there will be some heating as well hence the "Thermal" box.

2. **A loudspeaker running on mains electricity:**



   Here, even though Electrical Energy is not a store, we do not know what transfers took place in the mains system and so accept Electrical Energy as the starting point. The missing boxes are Sound which seems like it should be the final energy, but is really only a step in the transformation, and Thermal – the electrical work, mechanical work and the sound all eventually just slightly heat up the surroundings.

3. **Eating breakfast**



Here the first box is Chemical. Your breakfast will be a chemical energy store that your body performs more chemistry upon to convert it into a form that your body can use or store. Your body's chemical energy store will also have to provide a little energy for your body's movements (mechanical) and to start the biochemistry. Finally the chemical processing and mechanical work performed by your body will produce heat and so Thermal Energy increases – the right hand empty box.

As you get to GCSE, and definitely at A level, the questions will be less about filling in the blanks and more about using formulas for the different energies to put numbers on the transfers.

1.2.3 Efficiency

It is complicated, but at its simplest the 2nd Law of Thermodynamics says that systems tend towards disorder. That is energy which is organized and concentrated ends up being spread out, the proper word is dissipated. The dissipated energy usually ends up just heating the environment up by a tiny bit (you will have noticed that Thermal was a final form in all three examples above).

The first and second laws together give probably the most important rule for Engineers:

You can never convert all of the starting energy into just the final energy form that you want.

In other words any natural or man-made system or device which converts energy will waste some of that energy.

Efficiency (symbol η – the lower case greek letter eta) is the measure of how good a system is at converting its starting energy into the desired, useful final energy.

$$Efficiency\ as\ a\ decimal\ = \frac{Useful\ Output\ Energy}{Total\ Input\ Energy}$$

$$Efficiency\ as\ a\ percentage = \frac{Useful\ Output\ Energy}{Total\ Input\ Energy} \times 100$$

Or in symbol form:

$$\eta = \frac{E_o}{E_i} \qquad \text{or} \quad \eta\% = \frac{E_o}{E_i} \times 100$$

The Law of Conservation of Energy says that the theoretical maximum value that efficiency could have is 100%, because we cannot make energy. The fact that in a device some energy is always wasted, however, means that in reality **efficiency must always be less than 100%**.

Examples of Efficiency Calculations:

1. **For every 100J of electrical energy input an electric motor produces 77J of Thermal Energy, the rest is Kinetic. What is the motor's percentage efficiency?**

   Kinetic Energy is the useful output, E_o, of a motor, which is given by the difference between the input and the waste:
   E_o = 100-77 = 23J
   Use:

$$\eta\% = \frac{E_o}{E_i} \times 100$$

$$\eta\% = \frac{23}{100} \times 100 = 23\%$$

Motor Efficiency = 23%

2. **An old fashioned light bulb transfers only 1% of its input energy as visible light. If a bulb receives 180J of electrical energy, how much energy is emitted as light?**

Use:

$$\eta\% = \frac{E_o}{E_i} \times 100$$

We want E_o so rearrange:

$$E_o = \frac{\eta\%}{100} \times E_i$$

$$E_o = \frac{1}{100} \times 180 = 1.8\text{J}$$

1.8J is produced as visible light

3. **A modern LED light bulb has an efficiency of 12%, how much input electrical energy is necessary for an LED to produce 1.8J of light?**

Use:

$\eta\% = \frac{E_o}{E_i} \times 100$ and rearrange to make E_i the subject $E_i = \frac{E_o}{\eta\%} \times 100$

Gives:

$$E_i = \frac{1.8}{12} \times 100 = 15\text{J}$$

An LED light requires 15J of input energy to produce 1.8J of visible light.

4. **A power station needs to produce enough electricity for 150,000 LED bulbs in Jersey (4 per household) to produce 1.8J of visible light energy each.**
   a. **If the power station has an efficiency of 0.32 how much input chemical energy is needed to make enough electrical energy?**

   From question 3 the necessary electrical energy for one bulb to make 1.8J of light is 15J, therefore for all of Jersey:

   = 15×150,000 = 2,250,000J

Carnot worked out that for what is known as a Heat Engine, (a device that transforms Thermal Energy) the maximum possible efficiency is given by:

$$Efficiency = \eta = \frac{T_s - T_e}{T_s}$$

Where T_s is the starting temperature and T_e is the output, or exhaust, temperature.

For example, if a coal-fired power station uses steam to spin its turbines and the steam enters the turbines under pressure at 300°C and leaves at 100°C then you might think that the Carnot Efficiency is:

$$= \frac{300 - 100}{300} \times 100 = 67\%$$

Unfortunately, as we will see at A level, these calculations must be done using the Kelvin Temperature Scale. To convert degrees Celsius into Kelvin we have to add 273 (absolute zero being -273°C). Hence the maximum possible efficiency is really only:

$$= \frac{573 - 373}{573} \times 100 = 35\%$$

That is, even if there were no friction in the turbines, no electrical heating of the generators and no heat lost up the boiler's chimney, only 35% of the chemical energy released by burning the coal could leave the power station as electricity.

Therefore 2,250,000J is the electrical energy that the power station must output, E_o.

This time the efficiency is a decimal not a percentage therefore to find the input energy, E_i, to the power station, use:

$$\eta = \frac{E_o}{E_i}$$

and rearrange to make E_i the subject

$$E_i = \frac{E_o}{\eta}$$

Gives:

$$E_i = \frac{2250000}{0.32} = 7031250\text{J}$$

The power station requires an input of 7.0MJ (million joules) of chemical energy.

You will remember from Y7 that rounding your answer to the same number of significant figures as in the question is correct, BUT you should make sure that you have written down the answer to more significant figures in your workings.

b. **Jersey's power station uses diesel as its fuel. One kilogram of diesel releases 48MJ when completely burnt, what mass of diesel is needed to provide the energy calculated in part a.?**

If one kilogram produces 48 million joules, *x* kilograms produces *x* × 48 million joules. So to find *x:*

$$E = x \times 48000000 \qquad \text{which rearranges to} \qquad x = \frac{E}{48000000}$$

Which gives:

$$x = \frac{7031250}{48000000} = 0.14648\text{kg}$$

Therefore just under 150g of diesel must be burnt to provide 1.8J of light energy from each of 150,000 LEDs in Jersey.

(1.8J by the way would be about 3 seconds worth of light from a normal lamp, so six hours of lighting would require over 1000kg of diesel and that is assuming that we are all using super-efficient LED lights!)

1.2.4 Sankey Diagrams

The information necessary to perform an efficiency calculation can be difficult to extract from a written question. This difficulty is addressed by using a form of energy flow diagram where the width of the arrows indicates the amount of each energy type. This is called a Sankey Diagram.

Sankey Diagram Examples

1. **Work out the percentage efficiency of the device whose Sankey Diagram is shown in Figure 1.5.1**

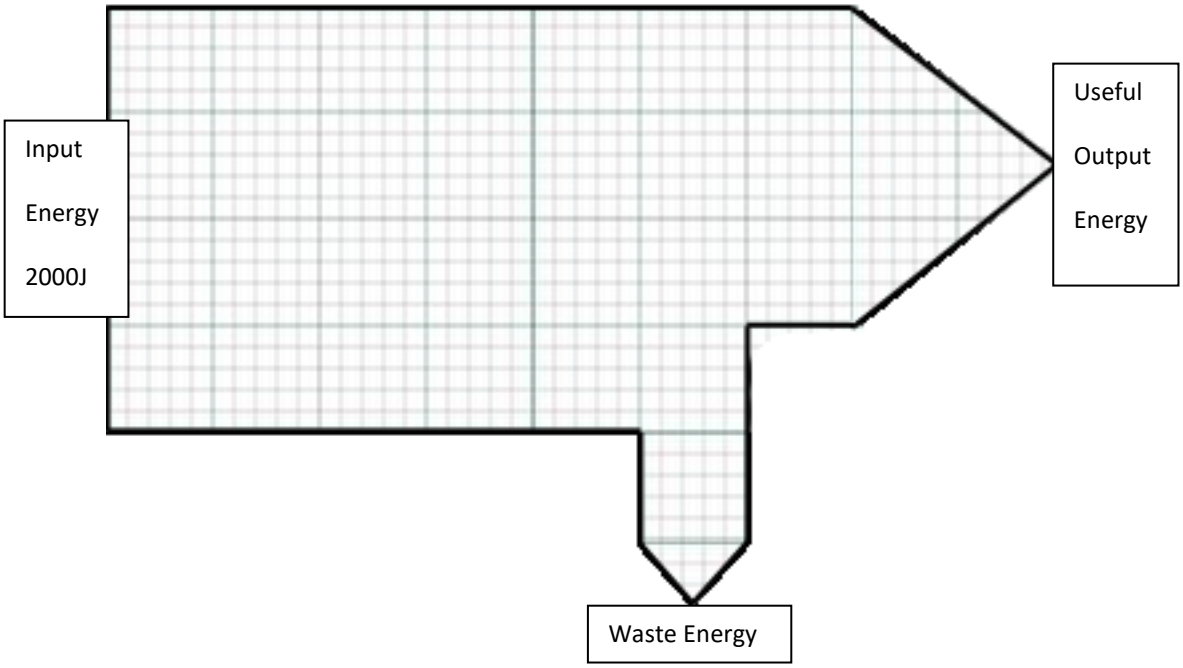


Figure 1.5.1 A basic Sankey Diagram

Looking at Figure 1.51 you can see that it shows the energy flow for some device which converts most of its input energy into a useful output, but that some energy is wasted. Because we know that the arrow thickness is proportional to the amount of energy, and because a grid has been added to the diagram, we can work out the amounts for each energy arrow.

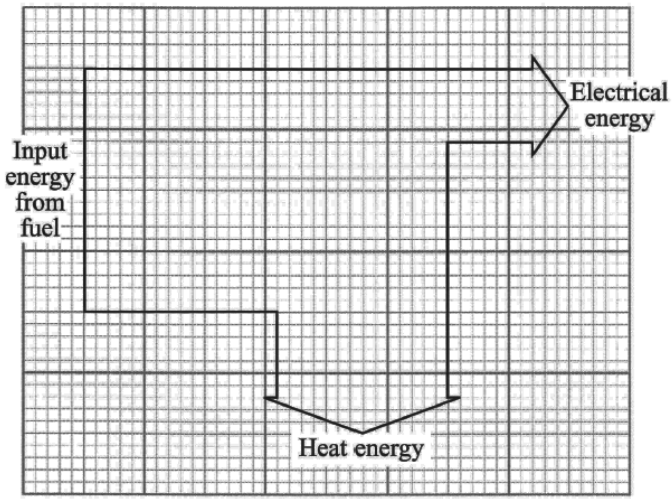
Input Energy, E_i = 2000J and is represented by 4 large squares
Therefore 1 large square is equivalent to 500J. The Waste Energy is 1 large square or 500J.
The useful output energy, E_o, is 3 large squares so:
E_o=1500J
Use:

$$\eta\% = \frac{E_o}{E_i} \times 100 = \frac{1500}{2000} \times 100 = 75\%$$

The efficiency of the device is 75%.

2. A 2008 GCSE Question:

(a) The diagram shows the energy transformations in a fuel burning power station.



(i) Name **one** fuel that is burned to provide the energy source for a power station.

.....

(1 mark)

The answers to a(i) could be *coal, oil or natural gas*

(ii) Use the diagram and the equation in the box to calculate the efficiency of the power station.

$$\text{efficiency} = \frac{\text{useful energy transferred by the device}}{\text{total energy supplied to the device}}$$

Show clearly how you work out your answer.

.....

.....

Efficiency = ...

(2 marks)

Note that GCSEs no longer give you the equations the way that they did in 2008, you have to memorise all the equations.

This question is interesting because it does not give you any values, therefore you have to work out the energies in terms of grid squares. This does not matter because efficiency is a **ratio**. (In Physics a ratio is a value arising from the two things being compared by division having the same unit – the ratio itself, therefore, does not have a unit. Although related, this is different to how the word ratio is used in Maths)

The input energy, E_i, is represented by 20 small squares.

The Useful Output Energy, E_o, is the Electrical Energy which is represented by 6 small squares.

So using:

$$\eta = \frac{E_o}{E_i} = \frac{6}{20} = 0.3$$

The answer to a(ii) is that the ***Power Station Efficiency is 0.3.***

1.2.5 Calculations for the Winch Efficiency Experiment

Most groups will carry out an experiment to test the Efficiency of a Model Winch.

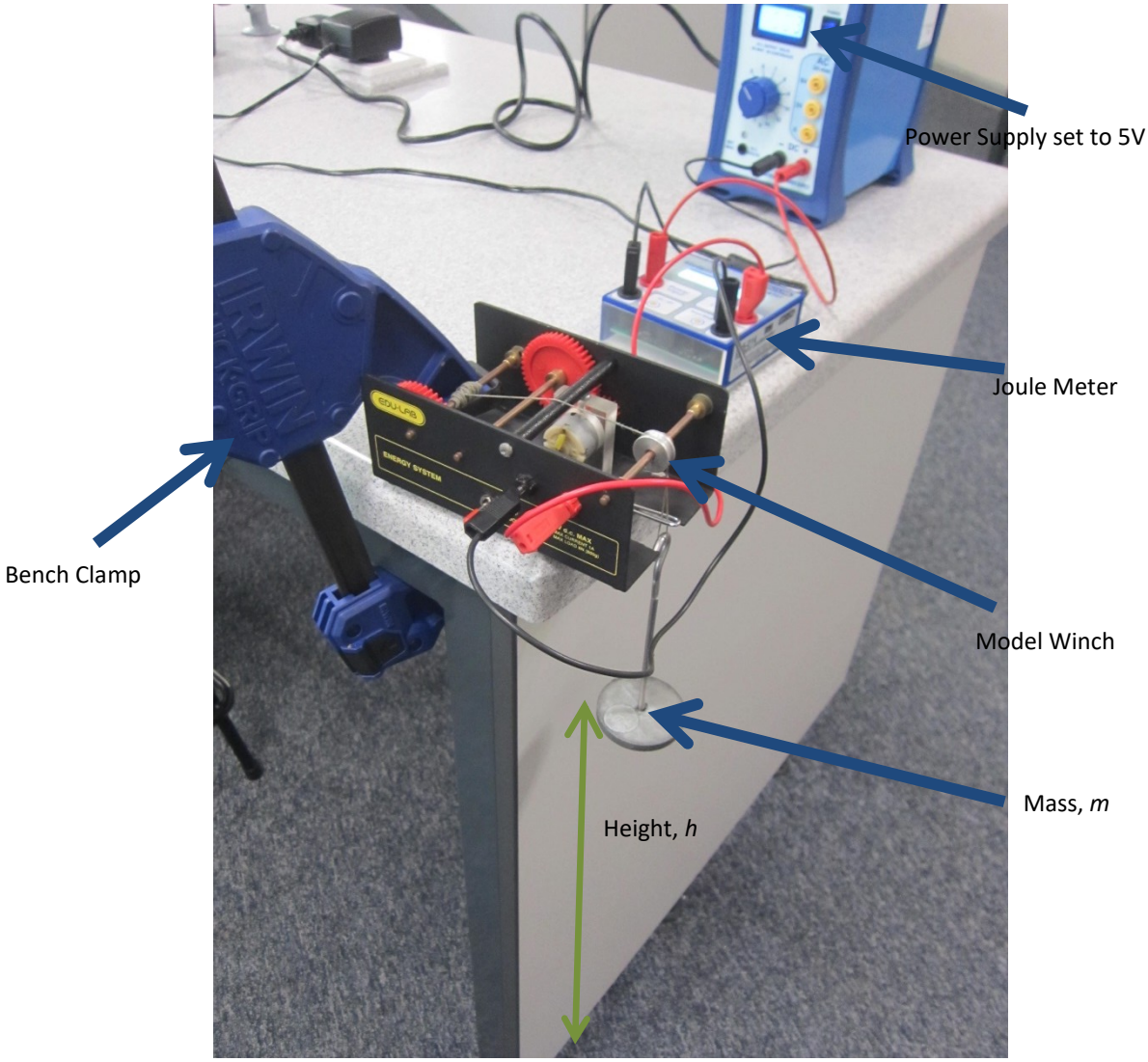


Figure 1.2.5 Experimental set-up for testing the efficiency of a model winch using a joule meter

In this experiment the independent variable is the mass lifted, the dependent variable is efficiency which is calculated from several variables recorded in the experiment, and the important control variable is the height the mass is lifted through.

Calculating the efficiency requires the total input energy from the power supply to be recorded for each test. This is done using the joule meter which records the electrical energy that passes through it from Input to Load. The useful output energy for a winch is the Gravitational Potential Energy gain. Although the equation for this is ***not*** required in the Y8 exams you must use it for this experiment:

$$GPE = mgh$$

m is the mass lifted in kg, *h* the height the mass is lifted through in m and *g* is known as the gravitational field strength and which on earth is 10N/kg.

So if in one test you lifted 150g through 77cm the calculation for useful output energy would be:

m=0.150kg
h=0.77m
g=10N/kg

$$E_o = 0.150 \times 10 \times 0.77 = 1.155\text{J}$$

Since the best experimental data you have here is only two significant figures this would be rounded to 1.2J in your table.

If, for example, the input electrical energy, E_i, recorded on the joule meter for this test was 8J then the efficiency for this test is:

$$\eta = \frac{E_o}{E_i} = \frac{1.2}{8} = 0.15$$

You will need to perform these two calculations using your numbers for each test you did. There is no need to write out workings for every one.

A table for this experiment – assuming you did three repeats and went up in 50g steps might look like the one below **(The results in this example table are made up. Make sure you use your own**).

Lift height, *h* /m	0.77 – control variable, same for all					
Mass, *m* /kg	Total Input Energy recorded on joule meter, E_i /J				Calculated GPE, E_o /J	Calculated Efficiency, η
	Repeat 1	Repeat 2	Repeat 2	Average		
0.050	7	6	6	6.3	0.49	0.08
0.100	8	7	7	7.7	0.77	0.10
0.150	8	8	8	8	1.2	0.15
etc……..						

Your graph will then be a plot of Mass on the *x*-axis and Efficiency on the *y*-axis. This experiment does not usually produce a straight line, so you will need to think about how to draw your line of best fit.

1.2.6 Power

When work is being done and energy is being transformed, or when heating and cooling is occurring so that thermal energy is moving from one object to another, it often makes more sense to talk about the energy moved per second than the total amount of energy. For example it makes no real sense to talk about a nuclear power station having an output of 500MJ of electrical energy, because it will output that in half a second, and will continue to output twice that every second for the whole time it is running. Instead we talk about the power station producing 1000MJ per second.

Energy per second is the quantity **Power**. Although the unit joules per second would be correct, power has its own unit name **watts** (symbol **W**) named after James Watt who invented the concept of "Horse Power" to help sell his steam engines. So a nuclear power station produces 1000MW of electricity, that is one billion joules of electrical energy every second.

The formula for power, *P*, is:

$$Power = P = \frac{Work\ Done\ (Energy\ Transfered)}{Time\ Taken} = \frac{E}{t}$$

Although often, the rearranged form with Energy Transferred, *E*, as the subject, is more useful:

$$E = Pt$$

Remember that Time Taken, *t*, in this formula must be in seconds.

Power Examples

1. **If the input to an electric motor is 40W, a) how much energy will be converted if the motor runs for 10 minutes, and b) if the motor efficiency is 22% how much energy is dissipated as heat in that 10 minutes?**

   a) Use:

   $$E = Pt$$

   But remember that *t* must be in seconds so:

   $$t = 60\times10$$

   $$E = 40 \times 60 \times 10 = 24000\text{J}$$

   The energy converted will be 24,000J or 24kJ

   b) We know E_i = 24000, η%=22, we can therefore find the useful output, E_o:

   $$\eta\% = \frac{E_o}{E_i} \times 100 \quad \rightarrow \quad E_o = \frac{\eta\%}{100} \times E_i = \frac{22}{100} \times 24000 = 5280\text{J}$$

   However, the question asked for the heat dissipated, that is the Thermal Energy lost to the surroundings. This will definitely not be the useful output from the electric motor. The heat dissipated must be the waste energy. The wasted energy is given by the difference between the Total Input and the Useful Output:

   $$E_w = E_i - E_o = 24000 - 5280 = 18720\text{J}$$

   The energy dissipated as heat will be just under 19,000J or 19kJ.

2. **If an electric heater uses 78kJ of electrical energy in 2 minutes what is the heater's power rating?**

Note that the question is in kilojoules (kJ), one kilojoule is 1000 joules so:

$$E = 78 \times 1000 = 78000\text{J}$$

Remember that time must be in seconds and use:

$$P = \frac{E}{t} = \frac{78000}{120} = 650\text{W}$$

The power rating of the heater is 650W

3. **If a television has a power rating of 33.5W how many hours must it be turned on for for 1MJ of electrical energy to have been used?**

Note that 1MJ is one million joules.
Use:

$$E = Pt$$

And rearrange to make time the subject:

$$t = \frac{E}{P} = \frac{1000000}{33.5} = 29850.7\text{s}$$

However, the question asks for the answer in hours, not seconds, so we need to divide by 60 and 60 again.

$$= \frac{29850.7}{60 \times 60} = 8.2919 \text{ hours}$$

You could leave the answer like that, but your calculator has a useful button:

Figure 1.2.6 The degrees (or hours), minutes and seconds button on a calculator

If you can find and press this button your calculator will tell you that 8.2919 hours is 8 hours 17 minutes and 30.75 seconds.

For the TV to use 1MJ of electricity will require it to run for just under 8 hours 20 minutes.

1.2.7 Power in Sankey Diagrams and Efficiency Calculations

Because efficiency is a ratio it does not matter if the efficiency is calculated using Total Input Energy, E_i, and Useful Output Energy, E_o, or Total Input Power, P_i, and Useful Output Power, P_o. Just make sure both terms are power, or both terms are energy, you cannot have a mix of the two in an efficiency calculation.

Just as Energy flow through a device can be illustrated with a Sankey Diagram so can the Power flow, remember Power is just Energy per second.

Sankey Diagram problems and Efficiency problems are as likely to be in terms of Power as Energy. It does not alter the maths, just the units involved.

Power Examples Continued

4. An Electric motor has a 40W input and a 22% efficiency. a) What is its useful output power, b) How much power is dissipated as heat, c) How much Thermal Energy will have been dissipated in 10 minutes?

a) Use:

$$\eta\% = \frac{P_o}{P_i} \times 100$$

And rearrange to make P_o the subject:

$$\frac{\eta\% \times P_i}{100} = \frac{22 \times 40}{100} = 8.8\text{W}$$

The Useful Output power is 8.8W

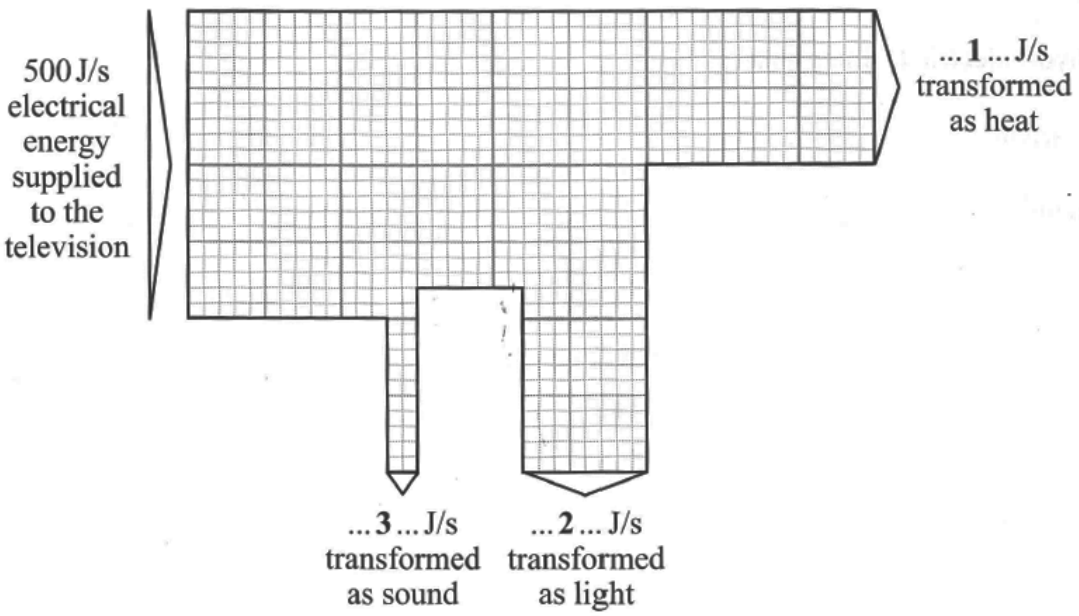
b) The Heat dissipated = Waste = $P_i - P_o$ = ***31.2W***

10 minutes is 600 seconds so to find Thermal Energy Dissipated use:

$$E = Pt = 600 \times 31.2 = 18720\text{J}$$

The Thermal Energy dissipated in 10 minutes is just under 19kJ (i.e. exactly the same as in example 1)

5. A 2007 GCSE Question. Find the values 1, 2, 3 and 4



The efficiency of the television is ...4...

Notice that the Examiners have tried to make this question easier by using J/s as the units instead of W, that way you do not have to understand power to do this question – we will use watts.

500W is shown by 20 small squares therefore one small square represents 25W.

1) Transformed as heat and wasted is 10 small squares, 10×25= ***250W***
2) Transformed as light; 8 small squares, 8×25 = ***200W***
3) Transformed as sound; 2 small squares, 2×25 = ***50W***
4) Light and sound are the useful outputs from a TV so the Useful Power Output, P_o = 200+50 = 250W

   Use:

$$\eta = \frac{P_o}{P_i} = \frac{250}{500} = 0.50$$

The efficiency of the TV is 0.5

1.3 Summary for Energy Laws

You need to know that:

- In Science the words **energy** and **work** have particular meanings.
- Energy is a quantity that is always conserved – it is never created or destroyed.
- It is a quantity that exists because of rules for how the universe behaves, the Laws of Thermodynamics, rather than being a physical thing like a liquid.
- Energy is transferred by doing work or by heating.
- Energy can be referred to as taking different types or forms. Different types have different equations which you will learn as you carry on through Physics.
- Energy tends to become spread out – **dissipated**.
- Energy has the unit joules, J.
- You can never transfer all of your input energy into the form of output energy that you want.
- **Efficiency**, η, measures how good the energy transfer, from total input energy to useful output energy, is.
- Efficiency is a ratio – it does not have a unit.
- Efficiency is always less than 1 (or as a percentage, less than 100%).
- **Power** is the energy transferred per second.
- Power has the unit watts, W.

$$P = \frac{E}{t} \qquad or \qquad E = Pt$$

- Efficiency can be calculated using Power as well as Energy.

$$\eta = \frac{E_o}{E_i} \qquad or \qquad \eta = \frac{P_o}{P_i}$$

- **Sankey Diagrams** are a way of showing the flow of energy or power through a device.

1.4 Heat

In Physics the term **Heat** may only be used to describe thermal energy that is being transferred. It can be a noun: heat; the thermal energy being transferred, or a verb, to heat; the process of transferring thermal

energy into an object. To cool; is the process of transferring thermal energy out of an object, and when we say "keep cool" we mean preventing thermal energy from transferring into an object.

As with "energy" this is similar to the everyday, casual usage of "heat", but not exactly the same. You have to be careful to use the Physics language correctly.

Controlling the movement of heat is incredibly important; from keeping our houses and ourselves warm in winter to keeping vaccines cool when they are being distributed in hot third world countries.

You will know from Chemistry that everything is made from particles such as atoms or molecules, and that on a microscopic scale those particles are always randomly moving.

In Year 8 Physics you are required to be able to understand and describe the three main physical processes that allow heat to move. You should also understand that if an object increases its temperature the object it now has more thermal energy and the particles that make up the object are moving faster.

1.4.1 Temperature

Temperature is a familiar idea, we all recognise a hotter day or a cooler day and know that the hotter day will have a higher temperature. We also all know that certain physical processes, like the freezing of water, happen at certain temperatures. Being familiar with something, and being able to define it to the satisfaction of a physicist are different things however.

Physicists define an object as being at a higher temperature than another if, when the two are put in contact, heat moves from the hotter one to the cooler one.

So if you took a block of ice out of the freezer at -18°C and placed it into liquid nitrogen at -196°C thermal energy would move from the cold ice into the very cold liquid nitrogen. The ice would get colder, and the ice would heat the liquid nitrogen causing it to boil. This is because -18°C is a higher temperature than -196°C.

On the scientific, or Kelvin, temperature scale temperature is proportional to the average kinetic energy of the individual particles in the object. That KE, on a microscopic scale, is particle vibrations in a solid, and random particle movement about in a liquid or a gas.

Temperature on any scale is a measure of how fast the particles that make up an object are moving microscopically.

Two objects have the same temperature if, when in contact, there is no overall movement of heat from one to the other. The average kinetic energies of their particles will be the same. Two objects at the same temperature will probably *not* have the same total thermal energies, because they are probably made from very different numbers of particles.

Temperature scales are defined by taking two physical processes that occur at different temperatures and using them as your fixed points, you can then decide how many divisions to chop the gap up into. This makes sense if you think about the degrees Celsius scale. Anders Celsius chose the freezing of water and the boiling of water at normal atmospheric pressure to be his two physical processes. He then decided that there should be one hundred divisions between them, and that the freezing off water would be the zero point on his scale. So the freezing point of water is 0°C and the boiling point is 100°C because of decisions that Celsius made 250 year ago, not because there is anything especially important about those numbers or the behavior of water.

Temperatures are measured by calibrating something that physically changes when the temperature changes. Calibrating means setting a scale against known values.

The physical change that we most often use is the expansion of alcohol. As the alcohol, coloured with a dye, in the bottom of a thermometer heats up it expands. As the alcohol expands it is squeezed up a narrow tube. The higher up the tube the alcohol reaches, the higher the temperature. We read the temperature by comparing the alcohol in the tube with the scale which was calibrated and marked on at the factory.

Hot and cold are not things, they are relative. Most things are hot compared to the surface of Pluto and most things are cold compared to the interior of the sun.

Temperatures are changed by there being an overall movement of thermal energy into or out of an object.

1.4.2 Thermal Expansion

You will remember from your chemistry that solids, liquids and gases are different from one another in two key aspects:

- The spacing between particles. Compared to the particle sizes the spacings are huge for gases, and small for liquids and solids
- The organisation of the particles. The average positions of each particle are unchanging and usually have a repeating pattern for solids, but are random and moving for liquids and gases.

Usually increasing the thermal energy within an object will increase the kinetic energy of its particles, whether they are moving randomly or held in place and just vibrating. The faster moving particles then spread out a little to allow for that movement and the exterior dimensions of the object expand.

A well-known exception to the "things expand as they get hotter" rule is water at close to its freezing point:

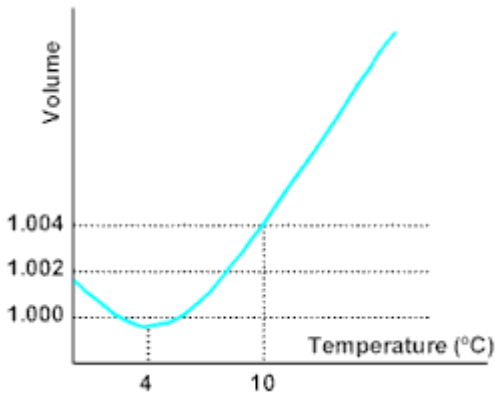


Figure 1.4.2 The change in liquid water's volume at close to its freezing point[1]

The particular bonding between water molecules, and the shape of the water molecules, means that the best arrangement of water molecules to form ice crystals is really unusual in having more space between the molecules than liquid water does. Ice therefore takes up more volume, has a lower density, than water. In changing from ice to water (melting) the gap between water molecules falls. As the temperature rises the spacing continues to fall a little, and then increases, giving the smallest spaces between molecules and the smallest volume at 4°C. Above 4°C water's expansion is similar to other liquids.

Objects usually expand as their thermal energy rises, as their temperature rises.

The particles that make up the object do not expand – it is the spacing between them that changes.

- A gas going from about room temperature to 100 degrees hotter will increase in volume by about a third (33%).
- A liquid doing the same temperature change will increase in volume by between 2 and 10%.
- A solid will increase in volume by somewhere between 0.01 and 1%[1]

In general metals increase in length by only ten millionths of their original length for every ^{o}C temperature rise. However, if you think about a train track that is 200km long (London to Bristol maybe), a one degree temperature change will cause the length to increase by 10 millionths, so the increase is given by:

$$200 \times 1000 \times \frac{10}{1000000} = 2\text{m}$$

A temperature rise of just 1°C will cause the track to get two metres longer, which would be enough to cause the track to bend, and might endanger the train, if the track were a single piece of metal.

1.5 Heat Transfer

1.5.1 Heat Transfer in Non-metallic Solids - Conduction

Heat transfer in solids is via a process called Thermal **Conduction**.

A method of visualising the structure of solids is to imagine each atom as a small heavy ball joined to its neighbours by springs, where the springs are the bonds. Now imagine a Bunsen burner being applied to one end of your solid. Those atoms at that end will have more thermal energy and will vibrate very much faster. The strongly vibrating atoms are attached to all of the rest by the springs and so the vibrations get transferred along the solid.

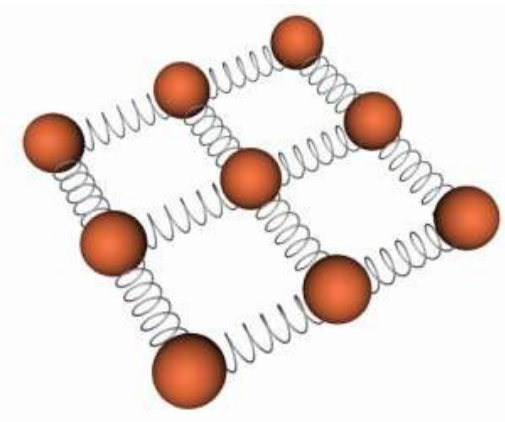


Figure 1.5.1 An atomic lattice represented by a series of spheres connected by springs[2]

Conduction in non-metallic solids works by passing thermal energy through the solid by vibrational energy being passed from atom to atom.

[1] http://cnx.org/contents/C20NI-lv@5/Thermal-Expansion-of-Solids-an
[2] http://www.sr.bham.ac.uk/xmm/structures2.html

The molecules within plastics are huge in comparison with most molecules, but the bonds that hold the molecules together to form a solid are weak and irregular compared with many other non-metals. This means that the vibrations are not easily passed from one molecule to the next. Plastics are poor conductors of heat.

Conduction occurs in liquids and gases as well. However, the lack of a regular arrangement of bonds in liquids and the lack of any bonding at all between the particles in gases mean that thermal energy cannot be passed between particles efficiently. Where the fluid is free to move, convection (see below) will dominate over conduction in a liquid or a gas.

1.5.2 Heat Transfer in Metals – Conduction

As with non-metals the transfer of heat through a solid piece of metal is called **Conduction** and some thermal energy is moved by vibration just like above. There is, however, a second process in metals which is more important.

Metals bond by sharing their outer electrons across the whole crystal. This means that metals have huge numbers of electrons available to move around. The proper term is that the electrons in a metal are **delocalised**. In fact the electrons can be regarded as a liquid or a gas surrounding the metal ions, this liquid is referred to as the "sea of electrons".

When a metal is heated not only do the ions vibrate faster, the delocalised electrons also bounce around faster. Where they are free to move, the fast moving "hot" electrons quickly spread throughout the metal taking their heat energy with them. Each electron moves only a tiny amount of energy, but there are so many electrons available to move, 10^{22} or 1 followed by 22 zeros of them in one gram of copper, that they have a large effect.

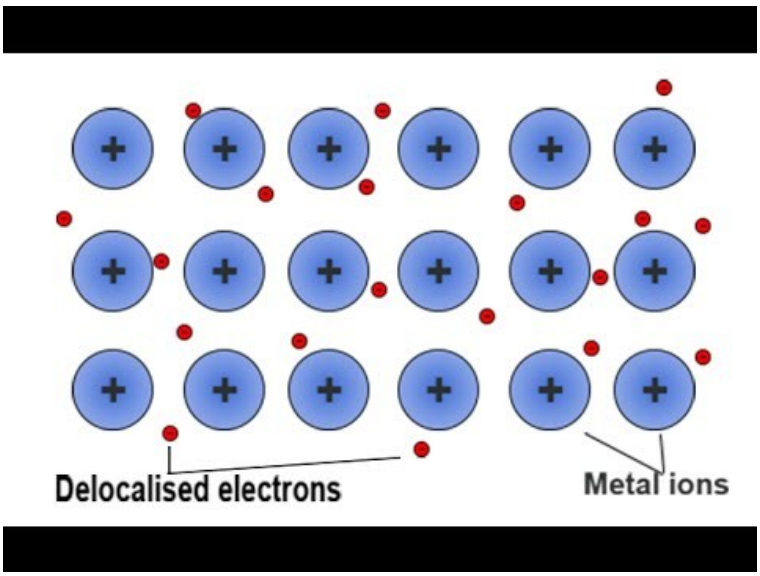


Figure 1.4.2 A visualisation of the "sea of electrons" surrounding the ions in a metal[3]

The hot electrons spread through the cold electrons to even out their concentration in the same way that solutes diffuse through a liquid to even out a concentration gradient. Diffusion in liquids is a topic you will cover in Biology.

[3] https://www.youtube.com/watch?v=ZNTEKYRvlco

Metals are therefore excellent conductors of heat. **The rapid diffusion of hot, delocalised electrons allows thermal energy to quickly spread through a piece of metal**.

1.5.3 Heat Transfer in Gases and Liquids - Convection

In Physics liquids and gases are both referred to as fluids; both flow to take the shape of their container. In day to day language only liquids tend to be described as fluids.

Liquids and gases can conduct heat, but only slowly. That is kinetic energy can be passed from one particle to another as the particles collide. However, particularly in gases, this is a rare event – **so liquids are poor conductors of heat, and gases are very poor conductors of heat**.

Providing they have the space to move around, liquids and gases will instead quickly transfer heat via a process called **convection**. **Convection is a very effective way to transfer heat energy**.

Convection operates because, as you learnt in Year 7, less dense things will float in more dense fluids because of a force known as buoyancy or upthrust.

Buoyancy can operate on different parts of the same fluid if those different parts have different densities because they have different temperatures.

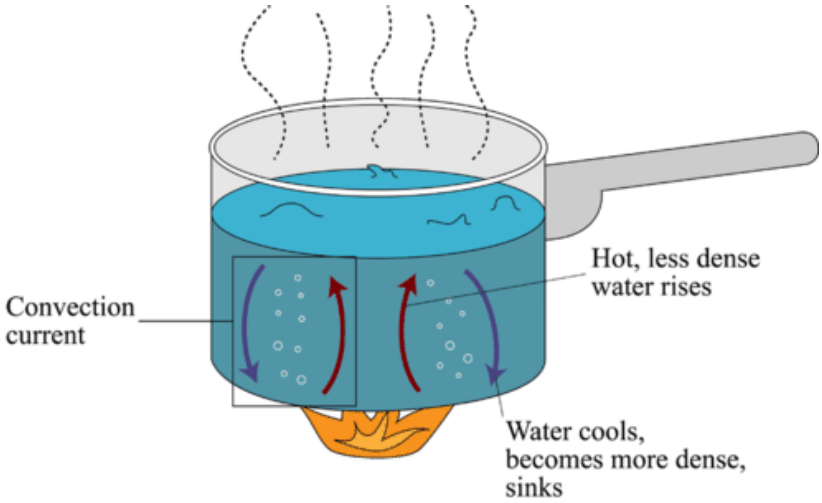


Figure 1.5.3 Convection in water being heated at the centre of the base[4]

The steps in the convection process are:

1. Fluid close to a heat source gains thermal energy and expands
2. This hotter fluid is now less dense than the cooler surrounding fluid
3. Buoyancy means that the less dense, hot fluid floats upwards
4. Cooler fluid is drawn towards the heat source from the sides to replace the rising hot fluid
5. That cooler fluid is heated and the process repeats.

Note that the thermal energy is moved upwards because the warmer fluid moves upwards. The hot particles are moving rather than "heat" itself moving. Also, because the buoyancy force comes from gravity, convection has a direction where the other two heat transfer methods do not – "Hotter air rises" it doesn't naturally fall or go sideways.

[4] https://www.ck12.org/physical-science/Convection-in-Physical-Science/lesson/Convection-MS-PS/

In a closed system, like the saucepan of water being heated in figure 1.4.3, convection is not only effective in moving the thermal energy upwards, but also mixes the fluid. This isecause the rising fluid above the heat source must be matched by descending fluid at the sides and roughly circular flows called "**convection currents**" are set up.

Convection currents are important ideas for Geography; weather and plate tectonics are both processes that happen because of convection currents.

1.5.4 Heat Transfer by Radiation

Radiation is a problematic word in Physics. When you read it you probably think of Nuclear Radiation and its dangers, but it has a wider meaning. In Physics the word tends to used where there is a transfer of energy over a distance, but the method of that transfer is not obvious. So Nuclear Radiation is an example; energy is being moved, possibly causing damage, but we can't see how. When we talk about Radiation as a Heat Transfer process it is usually Infra-red light that we are talking about. This is an energy transfer via waves, just like visible light, but we can't see infra-red light, so it is referred to as "radiation". We could call visible light "radiation", but we can see it, so usually we don't.

Infra-red Radiation, infra-red light, is not dangerous and is definitely not Nuclear Radiation.

It turns out that everything hotter than absolute zero, which is of course everything, radiates light just because of its temperature. It is just that most of that light is outside of the visible spectrum. At normal, day to day temperatures, everything, including us, radiates infra-red light. Very much hotter things, like the sun, radiate visible and ultraviolet light as well.

(Infra-red light is often referred to as "heat"; physiotherapists use "heat lamps" which emit Infra-red, and when we say "I can feel the heat coming off that bonfire" what we mean is we can feel the infra-red being produced by the bonfire being absorbed by our skin.)

Light is energy and so to be radiating light is to be losing energy. However we can also absorb light, and so "Radiation" as a process works in both directions, as a way of losing or gaining thermal energy.

An object at the same temperature as its surroundings must be absorbing as much energy from its surroundings as it is radiating. This is because our definition of temperature says that there is no overall transfer of thermal energy between objects at the same temperature. Hotter objects will, however, be radiating more energy than they receive and cooler objects will be absorbing more than they radiate.

Figure 1.4.4 Pictures of a boiling kettle taken with a visible light camera (right) and a thermal infra-red camera (left)[5]

Radiation is usually the least effective heat transfer mechanism of the three. However, it has a massive advantage; the other two processes rely on particles, Radiation, being light, does not. This means Radiation

[5] https://www.youtube.com/watch?v=ClRrU6JuBOc

can transfer heat through a vacuum. This is lucky for us because without this characteristic of Radiation we would receive little energy from the sun through the vacuum of space.

1.5.5 Heat Transfer by Radiation – Surfaces

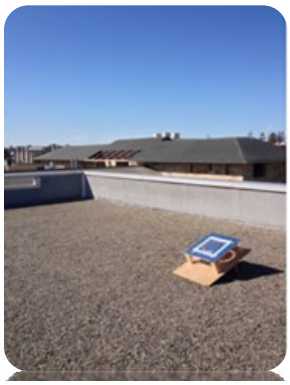
The fact that everything is radiating and absorbing heat does not mean that everything is radiating the same amount. Even objects at the same temperature do not necessarily radiate and absorb thermal energy at the same rates, it depends on their surfaces.

Radiation from and absorption by an object occurs at its surface. Therefore a bigger surface area means that the Radiation process is more effective.

Bigger surface area being better for Radiation is true even on the microscopic scale. Matte surfaces are rough on a microscopic scale giving them a high surface area, shiny surfaces are smooth, even on a microscopic scale and so by comparison have a low surface area. Matte surfaces are good for the Radiation process, shiny surfaces are poor.

The rule that a surface good at absorbing will also be good at emitting thermal energy by radiation is a frustrating one for engineers. Think how long coffee would stay hot if it were in a cup with a surface that absorbed any light energy around, but emitted very little.

In 2014 a group of engineers from Stanford University devised a surface that sidestepped the rule. They made a surface that was an extremely poor emitter and absorber in the part of the spectrum where the sun's light energy is found, but was also a very good emitter and absorber in a narrow portion of the spectrum where almost no light comes from the sky, but a part of the spectrum where light is made by warm objects. When put onto their roof in the California sun their device cooled down by 5 degrees, because it was r ılight, but was still emitting



The "Passive Cooling" Device on a Stanford Roof

Other surface characteristics can also have an effect; in the visible spectrum something is black because it is absorbing much of the light falling on it, something is white or silver because it is reflecting most of the light falling on it (we will cover this more when we do Colour in Y9). This means that for Radiation, a black surface is good, white or silver surfaces are poor.

The most important idea to understand about Heat Transfer by Radiation is that a surface that is good at absorbing heat will also be good at emitting heat. A surface that is poor at absorbing heat will also be poor at emitting heat. Any surface will be both absorbing and radiating all the time, which it is doing the most of will depend on its temperature compared to the radiators (things emitting light – not the white things on a wall) around it.

Large, black, matte surfaces are good at absorbing and radiating heat energy via light. Small, silver, shiny surfaces are poor at absorbing and radiating light.

1.6 Insulation

Insulation is designed to reduce the transfer of thermal energy. It is a common misconception that it keeps things warm, it is just as effective at keeping things cool, its job is to reduce thermal energy transfer in either direction.

A good insulator is going to be a poor conductor of heat and from the discussion above the poorest conductors are gases. However, gases are good at convection so for a gas to become an insulator it must be trapped in

place and it is this technique that most insulators use – trap air (the poor conductor) in place in a matrix of something that is still a pretty poor conductor itself. Wool, hair, foam rubber, expanded polystyrene, glass fibre blankets used in the roof (loft) or around a water tank – all examples of creating insulation by trapping air.

When you go skiing you are advised to wear lots of layers. Each layer of clothing traps a layer of air; it is the air that does the insulating.

Trapped air deals with convection and conduction leaving only radiation, most modern insulation will also have a silvered outside layer to reduce the transfer of heat by radiation.

1.6.1 Insulation and the Home – Air Gaps

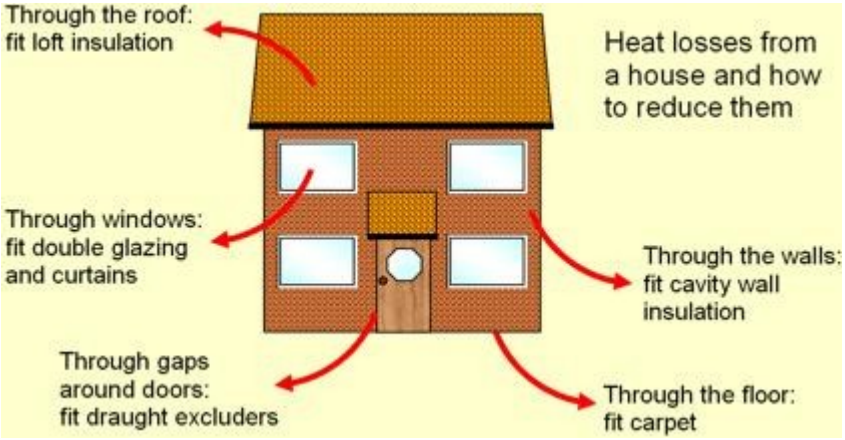


Figure 1.6.1 The sites of heat loss in a house[6]

Once you have appreciated that insulation is about trapped air then the function of the air gap between two panes of glass in double glazing is obvious, as is the fact that the air in a window cannot be trapped in smaller spaces as it is in most insulation.

Windows also do something more complex, they allow in visible light – which is a form of energy. During the day there is more visible light outside of a house than inside so a room with a window has a overall energy gain in the visible light region. This energy gain contributes to the warming of the room. The warm room emits infrared light. Infrared light does not go through glass as easily as visible and it is possible to add coatings that further reduce the infrared loss. Thus where there is a window by day – light energy enters, infra red light energy does not leave – the room warms up. This is called a **greenhouse effect**. The fact that the atmosphere does something similar on a bigger scale and that us adding CO_2 is altering the atmosphere's greenhouse effect is why you have heard the term in connection with global warming, but any window, particularly a sunny one, will have a greenhouse effect. By night of course a window is just a conduit for the loss of thermal energy. Curtains, or shutters in France, trap a layer of air between themselves and the window so reducing this loss.

In older houses the walls also often have an air gap between the inner and outer layers of bricks that form the walls. These are known as Cavity Walls – a cavity is an empty space inside an object – and are obviously better at insulating the house than just a single layer of bricks. However the air gap is usually wide enough for convection to occur and so it would be better if the air were properly trapped. This is what "**cavity wall insulation**" does – it is foam or some kind of air trapping fluff pumped into the cavity to trap the air in the cavity in place. New houses will tend to have only one layer of bricks with a layer of strongly insulating solid foam sheet screwed to the walls, old Jersey farm houses will probably only have one layer of granite – insulation will need to be retro-fitted.

[6] http://www.home-heating-systems-and-solutions.com/thermal-heat-loss.html

1.6.2 Vacuum Flasks

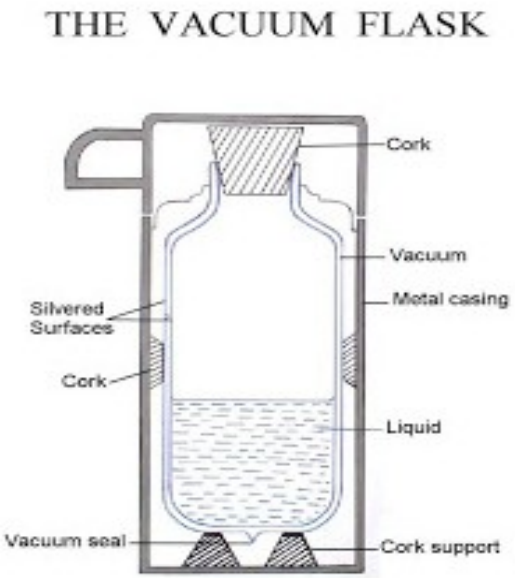


Figure 1.5.2 The structure of a traditional vacuum flask[7]

Vacuum flasks are often known by a brand name – Thermos flasks. In a laboratory, especially when they are being used to keep things very cold, they are often referred to as dewars because they were invented by Sir James Dewar. The flask has a double layered wall which has been evacuated; this means that the air between the two layers has been pumped out to create a vacuum.

The processes of convection and conduction both require particles, in a vacuum there are very, very few particles meaning that the wall of a dewar are very good insulators – in fact only radiation can move thermal energy across the gap and this is minimized by coating both walls with a very shiny, silvered, surface. Heat energy can therefore only really be transferred in or out of a vacuum flask at the neck. The best dewars have glass walls and so the cork supports shown in the diagram offer protection to the delicate structure as well as providing an extra layer of insulation.

[7] http://viviankueh-physicsproject2009.blogspot.com/2009/07/3-application-of-radiation-in-real-life.html

1.6.3 Hot water systems

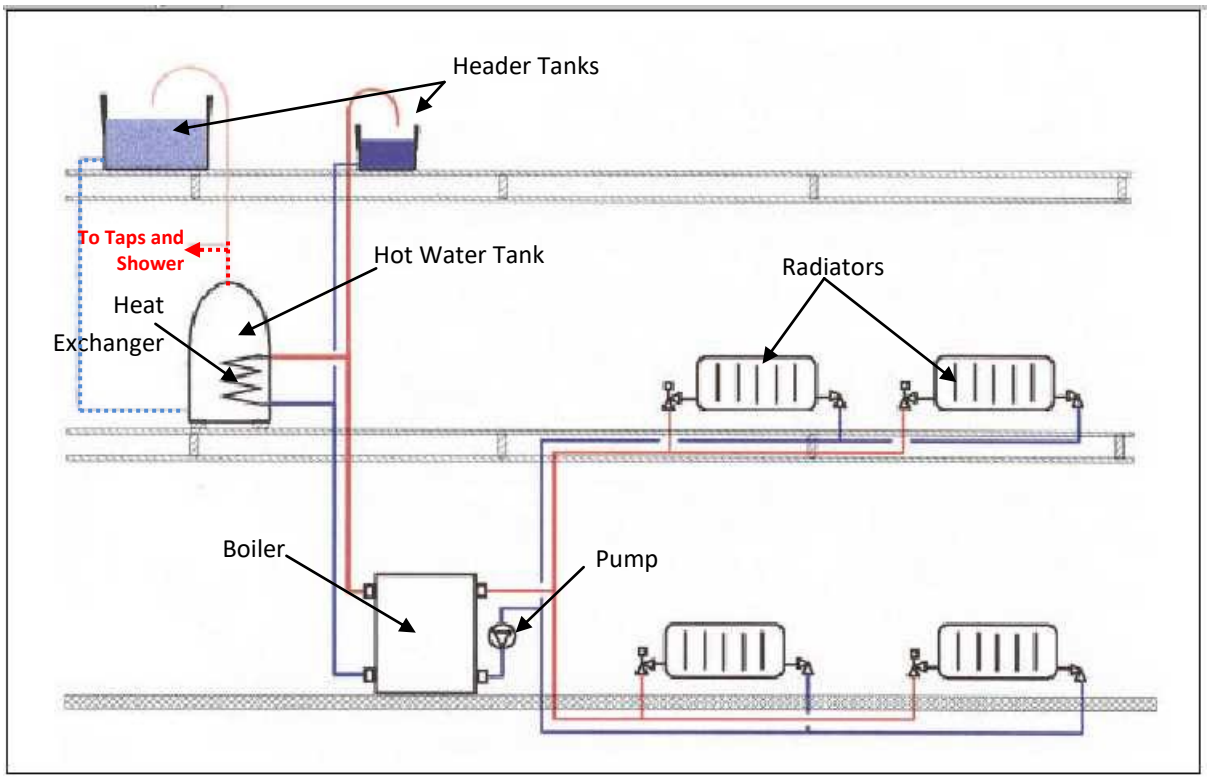


Figure 1.5.3 The basic layout of a household hot water system[8]

Hot water systems in homes often have one boiler but two functions; to provide heating and to provide hot water at the taps.

Providing heating is done by pumping water heated up in the boiler around the (misnamed) radiators or possibly underfloor heating, this is controlled by turning the pump on and off.

The hot water is provided by keeping the hot water tank hot via a heat exchanger. Hot water from the boiler passes through copper pipes in the tank meaning that the water from the boiler heats the tank, but it and the water we might drink do not mix. Obviously the hot water tank needs very good **insulation** so that thermal energy is not lost from the tank. Neither the loop between boiler and heat exchanger nor the supply to the taps needs a pump. In both cases the hot water comes from the top and the cold enters at the bottom meaning that gravity acting on the density differences between the hot and cold water can move them around – this is another example of **convection**.

1.7 What Not to Say

It is incredibly easy to mix up the ideas about temperature, and heat and thermal energy that you had before coming to Physics lessons with what you have learnt in Physics. Doing this can end up with some messy thing that is really not Physics in your head. It is even easier in a Physics exam to panic and to start to use your everyday language to answer questions and not the Physics terminology you have learnt – we see this in Thermal Physics more than any other topic.

[8] http://www.miketheboilerman.com/pipeworklayouts.htm

Insulation:

because the heat particles can not get throug the paper as it is not a conductor like wood.

This comes from a question about using layers of paper as an insulator.

Where to start? Well the common misconception here is that heat is a substance; that heat is formed of particles. Heat is thermal energy being transferred. Physically thermal energy is the random motion of microscopic particles, not a substance.

But clearly this student also does not know that paper is largely made from wood so their thermal properties are similar or that wood is really not a good conductor!

heat molecules take longer to geth trough air than solids

Having identified air as the insulator our students now have no idea how to explain why. Ignoring the "heat molecules" - heat as a substance again; thermal energy can be transferred through air by convection or radiation, but air trapped in place cannot convect and is a very very poor conductor.

because heat struggles to go throu air it is almost impossible.

stopping the cold escaping

This is a really common misconception in answers about insulation. This is no surprise, it is exactly what we say; "wrap up warm, keep the cold out." We often imagine insulation as stopping the movement of "cold", but this is incorrect Physics. Our definition of temperature tells us that heat flows from hot to cold; it is thermal energy that is being moved. Cold is not a thing; it is the relative lack of thermal energy. So in this case—a question about keeping an object cool– the answer needs to be about reducing the thermal energy entering, not about preventing the cold from escaping.

attarcts heat to it

Another idea that is surprisingly common is that insulators have some special properties that give them an affinity for thermal energy; as this student misspells "attracting" thermal energy to them. They don't.

This student not only has the direction of heat movement incorrect but thinks that aluminium is an insulator—it is a metal, no metal is an insulator

The ice cream would heat up because the aluminium foil would trap the heat in.

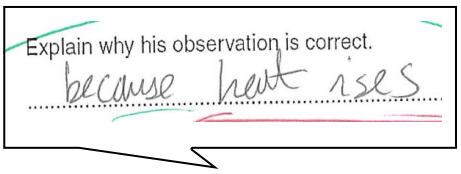
It is better because the cold reflects back onto the Ice cream and keeps it colder for longer.

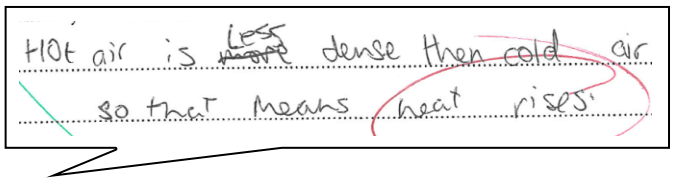
Here again we have the idea of cold in motion, this time as a form of radiation

Finally a student who understands the function of the aluminium foil—to reduce heat transfer by radiation—but they are so casual in their language that they lose the mark, sunshine reflects off shiny surfaces—the sun does not!

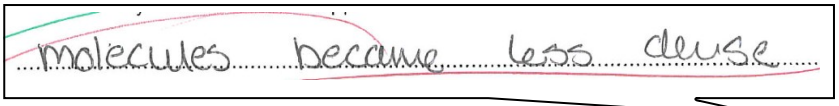
which makes the sun bounce off them.

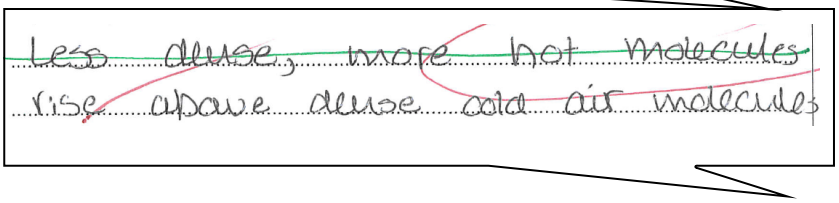
Convection:



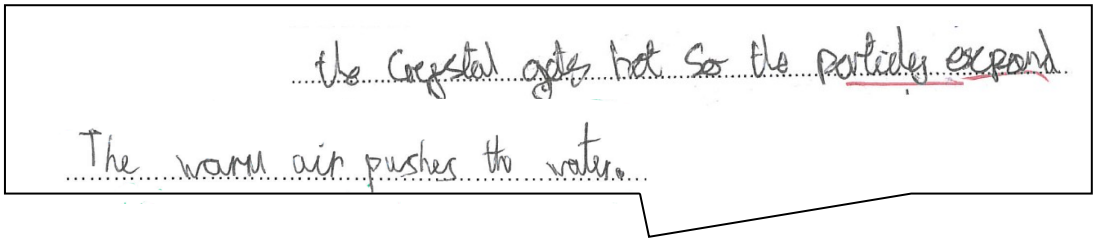


We frequently see this as an answer to convection questions but the mark schemes usually specifically say "Do not allow 'Heat rises'." This is because the key idea in convection is that it is the fluid itself that moves, the thermal energy is moved because the air (in this case) moves.





Much worse from a scientific point of view is to suggest that the particles themselves expand or become less dense. It is the fluid as a whole that has become less dense because the spacing between particles has increased



These two are in answer to a question about hot water systems. In the top one the student remembers seeing potassium permanganate crystals in a convection experiment, in the second the student remembers that air moving has something to do with convection—oh dear!

1.8 Summary for Heat and Temperature

You need to know that:

- **Temperature scales** use two fixed points with the space between divided up into a certain number of divisions. For Celsius this is the freezing and boiling points of water and 100.
- Temperatures tell us which direction thermal energy will move, i.e. from hotter to colder.
- **Thermal Energy** (internal energy) on a microscopic scale is the random movement or vibration of particles.
- Thermal energy in the process of being transferred is called **heat**.
- Thermal energy is transferred in three ways, **Conduction** (two different processes), **Convection** and **Radiation**. You must be able to describe the physical process of each.
- Radiation is enhanced with matte black surfaces and reduced by shiny silver surfaces.
- **Insulators** are materials which slow down the transfer of thermal energy.
- Most common insulators rely on trapping air (a very poor conductor).
- The structure of vacuum flasks hugely reduces the transfer of thermal energy.
- Insulation is important in the home to prevent wasting energy.