Energy Transfer Unit

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Science Enhancement Programme

ENERGY TRANSFER UNIT

The Science Enhancement Programme is a part of Gatsby Technical Education Projects. It is developing curriculum resources to support effective learning in science, and providing courses and professional development opportunities for science teachers.

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HEALTH AND SAFETY

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Energy transfer unit

Introduction

Energy is a particularly difficult concept to explain. This resource has been developed to introduce clear and consistent ways of talking about energy transfers and transformations. The booklet aims to cut through the confusion that often surrounds the energy concept, and examines some of the key teaching and learning issues. It relates practical tasks to the approaches to energy transfer and transformation taken in the QCA KS3 Scheme of Work for science, and can be used at KS4 as a way of comparing in a simple way the relative sizes of various energy changes.

There is no shortage of different approaches to the teaching of energy and this has resulted in much confusion and conflicting advice. Sometimes the advice is negative – for example, “avoid the expression heat energy” – though without giving simple positive ways of talking about these things. Textbooks too are often confusing, or just wrong, in the way they develop the concept, and even syllabuses can be unhelpful in the language that they use.

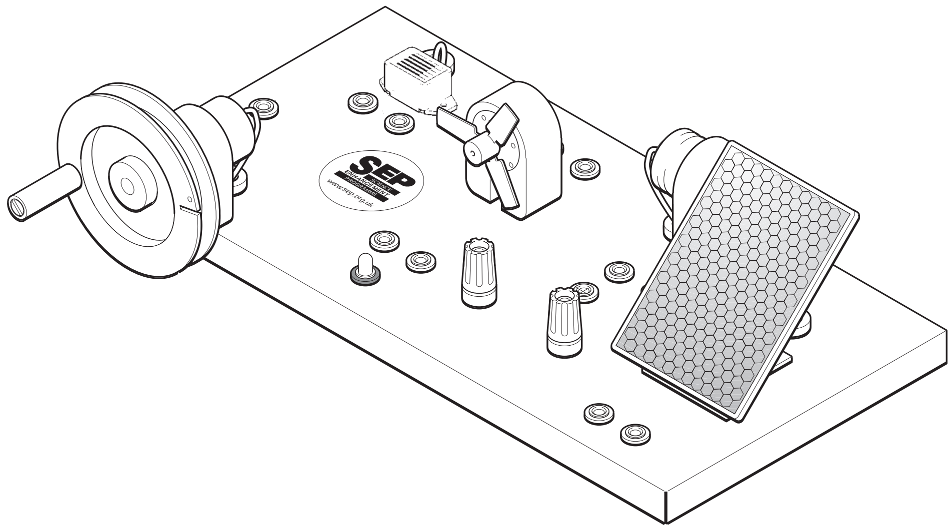
Because there are so many different ways of approaching the teaching of energy, this booklet does not aim to provide a sequence of activities that can be used directly with pupils – this would have simply added an additional set of terms and ways of talking to your existing approach. Instead, the booklet provides a set of practical activities intended for teachers, using the unit to illustrate key ideas about energy. However, as you work through the activities, you will hopefully find ways in which the unit and these ideas about energy can be used to support in your own particular teaching context. So, you could then ‘lift out’ these activities and integrate them into your existing approaches.

The unit

The energy transfer unit consists of a number of different devices mounted on a substantial steel base:

- Dynamo (can be turned by hand or by falling masses on a thread)
- Solar cell (also called a photovoltaic cell)
- Capacitor
- Electric motor
- Buzzer
- Lamp (a light emitting diode or LED)

In addition, the unit includes two electrical leads to connect the devices, two crocodile clips, a length of nichrome resistance wire, a thermocolour sheet (which changes colours at different temperatures) and a battery holder.



Using the unit

The energy transfer board is fully-assembled and almost ready to use. The only thing you need to do is to push the green dynamo handle/pulley onto the spindle of the dynamo, and secure it in place by turning the screw with the Allen key provided.

The devices can be connected to each other in a variety of combinations. For example, turning the dynamo by hand can drive a choice of output devices such as the lamp (LED), audible buzzer or a miniature motor. The capacitor can be used to store sufficient energy to drive any of the outputs. The solar cell, when lit by direct sunlight or a desk lamp, will also drive any of the outputs or charge the capacitor. The pair of uncommitted terminals enables connection to external apparatus or an alternative output, for example, to the length of nichrome wire placed on the thermocolour sheet to demonstrate how it becomes warm when a current passes.

The booklet

This booklet begins by looking at qualitative aspects of energy and provides a background to the science related to KS3 work. These ways of talking about energy also provide the foundation for work at KS4. The booklet then goes on to look at quantitative ideas about energy that are relevant to KS4.

The practical activities are contained in double boxes. The left hand box is about the practical work itself – what to do and what to observe. The right hand box is about the explanations in terms of energy using language appropriate for pupils. Following the double boxes, the text in small font provides more detailed scientific explanations, and includes further discussion of teaching and learning issues (with references where appropriate to the QCA Scheme of Work for KS3).

Important Operational Notes

1. When charging the capacitor using the dynamo, please ensure that the connections are in accordance with the colour coding of the sockets (i.e. red to red) and that the dynamo is turned **clockwise**. Attempts to charge the capacitor using reverse polarity can lead to damage. The solar panel must also be connected to the capacitor using the correct polarity.

2. The colour-change response of the thermochromic film is critically dependent on the temperature of the film itself which, ideally, is just on the threshold of changing colour. Only attempt the experiment with the dynamo and nichrome wire in a warm room. In a cooler environment, first charge the capacitor and then discharge it through the nichrome wire.

Introduction to teaching about energy

Before going on to the practical activities, it is useful to make a few brief points here about the nature of energy and how it is dealt with in the curriculum. This provides the background to the key points made in the practical activities, where the ideas will also be expanded and discussed in more detail. However, within the scope of this booklet, the treatment has to be fairly limited. If you want to read more about energy and these ideas, Robin Millar has written a useful chapter on energy in the ASE book 'Teaching Secondary Physics' (Editor: David Sang, Publisher John Murray).

What is energy?

Many school textbooks introduce energy by stating that it is difficult to say exactly what it is. This is a very reasonable place to start, since there is no easy answer to the question 'What is energy?'. There are formal definitions, but these don't really help pupils to understand what it is. It may be better to think of understanding energy as coming to know the character in a drama or a novel – getting to know the concept bit by bit as more of the story about its characteristics unfold. However, there are at least three broad ways to think about the nature of energy.

Energy as a value

One way of thinking of energy is simply as a *value* that can be calculated. Many different kinds of change take place - a candle burning, a ball rolling downhill, an electric kettle boiling some water - but for each of these you can calculate the total energy before and find that it is the same as the total energy after. We could think of this as a 'book-keeping' approach.

It is interesting to note that many chemists in the 19th century viewed the concept of an atom simply as a 'book-keeping' device to make calculations on reacting quantities. It was only in the 20th century that atoms came to be seen as entities with some kind of independent existence rather than as a convenient fiction.

Energy in many guises

Another approach sees energy not as an abstract value, but as more 'entity-like'. However, it manifests itself in many ways – hot things are seen as having 'heat energy', moving things as having 'kinetic energy', and so on. Though these manifestations appear to be very different, energy can change itself from one 'guise' to another – for example, when a fuel burns, 'chemical energy' is changed into 'heat energy'.

Energy is energy

A third approach is to think of energy as 'fluid-like' – and the same kind of thing whether it is in a hot object or a moving one. It doesn't change its *nature* – energy is energy is energy – but *where it is* does change. So, we can talk of energy as being in a certain region, moving from one place to another, having a lot of it or a little of it, making it concentrated in one region or letting it spread out. For example, temperature can be seen as being a measure of the 'concentration of energy', and energy is what flows from hot to cold as temperature differences disappear.

Energy transformation and energy transfer

A very common way to introduce energy in KS3 has been the 'forms of energy' approach. A central feature of this approach has usually been the 'energy circus', in which a wide variety of phenomena are used to illustrate the many different kinds of 'energy transformation'. However, the first version of the National Curriculum, and every version since, omitted any references to 'forms of energy' or 'energy transformation' and instead focused on the processes of 'energy transfer'. The implication was that there should be a move away from thinking about energy as 'changing from one form to another' and to think of it as staying 'the same kind of thing', with the focus on where it is stored and how it goes from one place to another.

For example, the 2000 version states that in KS3, pupils should be taught:

- 5d the distinction between temperature and heat, and that differences in temperature can lead to transfer of energy
- 5e ways in which energy can be usefully transferred and stored

At KS4, pupils should be taught, for example:

- 5a how insulation is used to reduce transfer of energy from hotter to colder objects
- 5d to calculate power in terms of the rate of working or of transferring energy

Why not teach about forms of energy? There is a concern that much of the talk involving forms of energy is just adding 'verbal ornamentation' to descriptions of changes. When you switch on a light in a room, the electrical current makes the lamp produce light. What deeper understanding is gained by calling this a change of electrical energy to light energy? In addition, pupils do not always find it easy to find the correct labels to attach to these energy changes and often invent their own. So, a child taking part in a race might be seen as converting 'food energy to running energy'. Textbooks, as well as children, also show variations in the terms used for 'forms of energy', which complicates things further.

It was these difficulties that led the National Curriculum to refer throughout to 'energy transfers'. While the change in terminology from 'transformation' to 'transfer' seems slight, it actually signifies a fundamental change. Talking about energy transfer stresses the importance of thinking about energy as staying the same kind of thing but in going from place to place.

Often, however, the significance of the new terminology has gone unnoticed, with the term 'transfer' substituted for 'transformation'. It is common to see phrases such as 'chemical energy transferred to heat energy'. When you think about it the word 'transfer' makes no sense in this context. It is consistent to talk about energy being '*transformed'* or '*changed'* from one form to another, even though some people would prefer not to talk about forms at all. But energy cannot be '*transferred'* from one form to another. It is this kind of confusion that this booklet aims to address. In particular it focuses on these key ideas about energy:

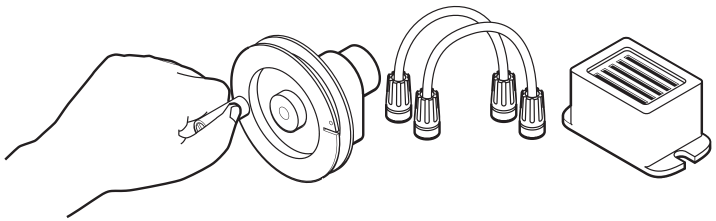
- how energy is *transferred*
- how energy is *stored*
- *conservation* of energy
- *dissipation* of energy

Energy and fuels

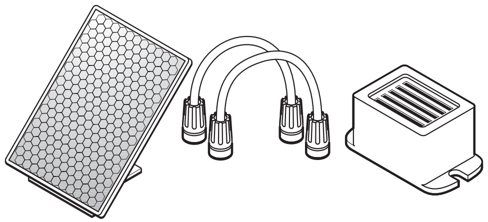
In everyday language, the term 'energy' is often used to mean 'fuel'. For example, we talk of the world's energy running out, and the need to save fuel. This is very different from the scientific concept of energy, which is a conserved quantity. In textbooks, the use of the term 'energy' often slides between two contradictory meanings - as something which is used up (reinforcing the everyday meaning) and as something conserved (which pupils find difficult to reconcile with their own understanding of energy). The National Curriculum refers to 'energy resources' (renewable and non-renewable, so these includes fossil fuels as well as other resources). This terminology is helpful in clarify the distinction between everyday and scientific meanings – thus, energy resources are used up, energy isn't.

Energy resources

A good starting point in teaching about energy is to focus on using energy resources to do things. A key idea here is to distinguish between the concepts of energy and an energy resource. (See the QCA Scheme of Work, Unit 7I 'Energy resources').



Connect the two terminals of the dynamo to the two terminals of the buzzer using the leads provided. Turn the handle. What happens? (N.B. The buzzer only works when a current is flowing through it in a particular direction, so try turning the handle in each direction.)



Connect the solar cell to the buzzer using the leads provided. If it is a sunny day, put the solar cell in direct sunlight; otherwise shine a desk lamp onto the solar cell. What happens?

In our homes, much of the fuel that we use goes to make things hotter (central heating, water heaters, cookers) or to make things move (washing machines, vacuum cleaners, loudspeakers). So here is the beginning of an understanding of the nature of energy. The difference between something when it is hot compared to when it is cold is that it has more energy. Similarly, the difference between something when it is moving compared to when it is stationary is that it has more energy. To make things hot or to make them move we need something that we can get the energy from – an *energy resource*.

In introducing the notion of an energy resource, there is no need to focus on forms of energy, or on the nature of transfers and stores. The basic questions are: where is the energy and where does it go?

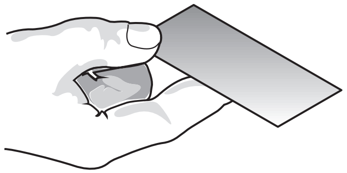
Turning the dynamo to make the buzzer work can be seen as an analogy of a power station and a radio in the home. Here, a *non-renewable* energy resource (food in the body or fuel in the power station) is being used to make something move (buzzer or radio loudspeaker). The use of the sun and the solar cell illustrates a *renewable* energy resource.

The QCA scheme of work (7I) use the term 'fuel' to mean something that burns and releases energy. So, used in this sense, a fuel is an energy resource, though not all energy resources are fuels. Sometimes the meaning of 'fuel' is extended to include all energy resources – so it is important to be clear what is intended when the term is used. The QCA schemes of work also introduce here the ideas of both transforming and transferring energy (for example 'solar cells transform solar energy' and 'solar panels transfer solar energy to water'). Given what was said about the use of these terms in the earlier section in the booklet ('Introduction to teaching about energy'), particular care is needed in this approach in distinguishing changes in form and changes in location.

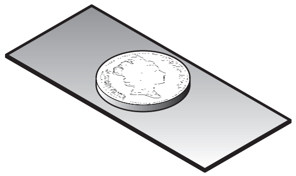
Heating and cooling

Understanding how temperature differences cause objects to become hotter or colder is central to the understanding of energy. The QCA Scheme of Work, Unit 8I 'Heating and cooling' illustrates how the distinction between heat and temperature can be developed. Though this area is not much addressed by the energy transfer unit as such, it does include a small piece of thermocolour sheet and this has many applications.

Rest the piece of thermocolour sheet on your fingertips. Note how the colour changes, starting from black and ending at dark blue, as the sheet warms up. Would you expect the sheet to warm up quicker or slower if you did the same thing with a glove on your hand? Try it.



Hold a coin (e.g. 1p piece) between your fingers for about 10 seconds, put it on the sheet for a few seconds and then remove it. What has happened? Would you expect the sheet to warm up more or less if you did it with a similarly sized piece of plastic (e.g. a plastic counter or 'tiddlywinks'). Try it.



Many pupils believe that if you hold an object in your hands while wearing a pair of gloves it will warm up quicker than without the gloves. Holding thermocolour sheet in a gloved hand therefore provides them with a puzzle, since the warming effect is actually slower. In coming to an understanding of this, they need to move away from intuitive explanations that involve seeing insulation as something that keeps thing warm or makes things warm. They need to see insulation as a barrier to an energy flow between things at different temperatures – and thus can work just as well at keeping things cold as keeping them warm.

Metal objects feel colder to the touch than plastic even when they are at the same temperature. Again, simple experiments with the thermocolour film can challenge pupils' ideas about this. How warm something feels depends not just on its temperature but on its conductivity too.

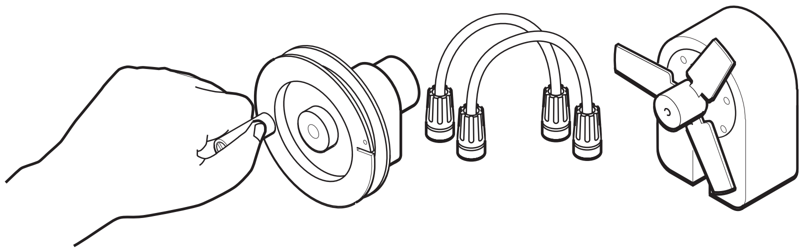
There are lots of other ideas than can be explored using the thermocolour sheet – details will appear on the SEP website.

Heat is a term that causes a lot of argument about the way it is used at school level. Strictly speaking, heat is the energy transferred from one body to another due to a temperature difference. It is not the energy contained in a body. What is usually referred to as the heat energy in a body is more correctly its 'internal energy'. At school level, this is also referred to as thermal energy. However, there is a danger in being too 'purist' about the use of the term 'heat'. Definitions about the term and insistence on its correct use are best left for those students who later study thermodynamics at a more advanced level.

The notion of 'heat flow' is something that pupils have experience of from everyday life, and provides the foundations on which to build important concepts about energy flows that are drawn on later. Thus, a key idea (e.g. QCA scheme of work, 8I) is to distinguish between the concepts of temperature and heat. What is important at this stage is to try to move pupils understanding on from everyday notions of 'heat' to the concept of the energy in objects at different temperatures and how it flows.

Transferring energy: mechanically and electrically

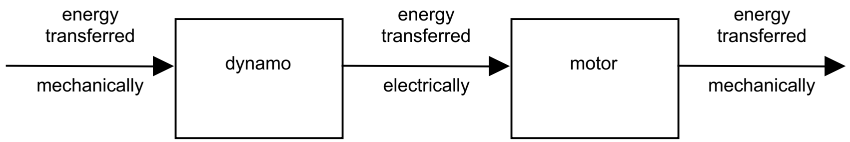
The energy transfer unit is particularly useful in looking at mechanical and electrical transfers of energy. The previous sections introduced the idea that energy can flow from one place to another. The following sections look in more detail at how these transfers of energy can happen. The ideas relate in particular to the QCA Scheme of Work, Unit 9I 'Energy and electricity'.



Connect the dynamo to the motor (make sure you put the red lead into the red terminals and the black one into the black terminals). Turn the dynamo clockwise. What happens to the motor? Turn the dynamo faster and then slower and see what happens.

The dynamo is connected to the motor by electrical leads, but you could almost imagine that they are connected mechanically, like a bicycle wheel is connected to the pedals. Turn the dynamo anti-clockwise and see what happens.

Take one of the leads out of the motor terminal. Turn the handle and feel the difference when there is no load.



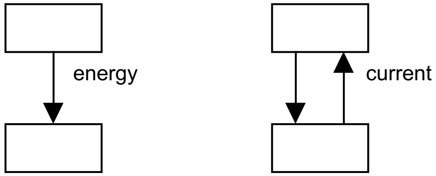
Energy is transferred from your muscles to the motor. Let's not worry where the energy in your muscles originally came from at the moment (we'll come back to that later). After that the energy transferred from your muscles through a series of bones in your arm (acting as levers) to the dynamo. This is a *mechanical transfer* of energy.

From the dynamo to the motor energy is *transferred electrically*. This demonstration draws attention to the similarity between mechanical and electrical transfer of energy (instead of using a dynamo, you could have used a drive belt, or a chain, or a series of gears to produce the same effect of turning the fan on the motor round). Just like these mechanical devices an electrical circuit is just another way of transferring energy from one place to another.

From the motor onwards, the energy is now transferred mechanically – the turning of the fan. The diagram doesn't show where the energy goes after that – again we'll come back to that later.

Turning the dynamo *by hand* gives a very direct 'feel' for the way in which energy is 'pumped' from the dynamo to the motor – and when there is no load, the difference in how easy it is to turn the dynamo is very striking. However, *understanding* where the energy comes from in our bodies would be a rather difficult place to start – our feelings of 'being energetic' and 'having energy' are easily confused with the scientific concept of energy. So, thinking about energy in chemical stores is left until later in this story.

A key idea here is that the electrical current flows *from* the dynamo to the motor and *back* to the dynamo, whereas the energy flow is in *one direction* only. This is summarised in the diagram on the following page. The distinction between current and energy is important since pupils often believe that the current is used up and does not return.



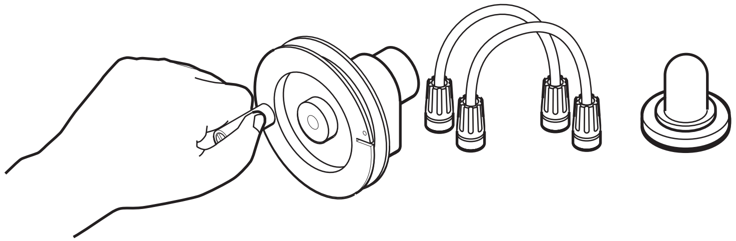
The analogy with a bicycle chain is helpful – the chain keeps on going round and round, though the energy transfer is from the pedals to the wheel. If the chain didn't come back the energy transfer could not take place.

What is important here is establishing the analogy between a drive belt or chain as a mechanical way of transferring energy and an electric current as doing exactly the same thing. Instead of the National Grid, energy could be transferred to our homes mechanically. Why isn't it? A good starting point for discussion.

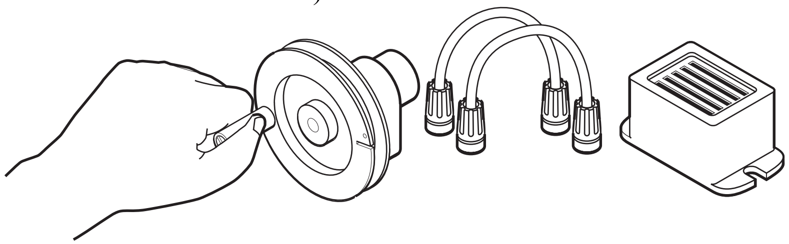
The scientific term for energy transferred mechanically is mechanical work (*Fd*) and the term for energy transferred electrically is electrical work (*VIt*). If there are no energy losses, then these ways of transferring energy do not involve an increase in entropy (in contrast to energy transfer by heating which is dealt with in the next section).

Transferring energy: radiation and heat

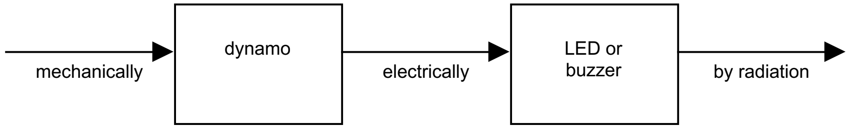
This section looks at two other important ways in which energy moves from one place to another.



Connect the dynamo to the lamp (LED), and turn the handle. (N.B.This only works with current flowing in the correct direction, so try turning the handle in each direction.)

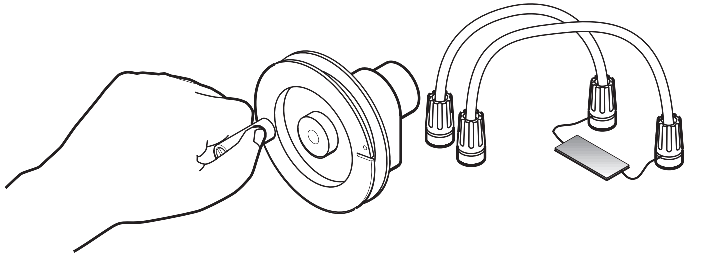


Now connect the dynamo took the buzzer and turned the handle. (Again, note that this only works in one direction.)

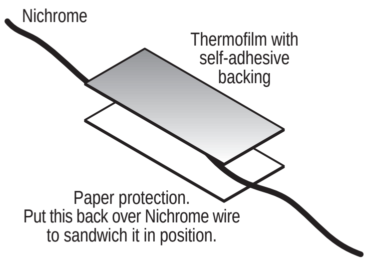


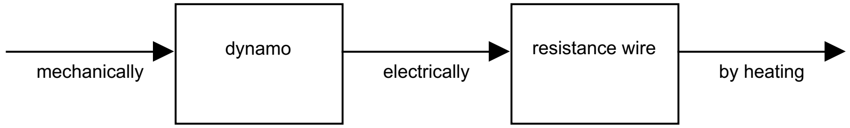
In both of these cases, energy is transferred electrically to the device (buzzer or LED) and in both cases energy spreads out in all directions from the device. For the buzzer, energy is carried away by sound, and for the LED, energy is carried away by light. Sound and light, though very different, are both *wave* phenomena, and so the energy transfers can be seen as rather similar. In both cases, the energy is transferred away from the device by radiation.

There are other kinds of waves that can carry energy in a similar way. In an earthquake, energy is carried away from the epicentre by seismic waves. Tidal waves may be used as a renewable energy resource. Light is just one part of the electromagnetic spectrum, and energy is also transferred by all the other kinds of electromagnetic radiation (X-rays, infra-red radiation, radio waves, and so on).



Connect a short length of nichrome resistance wire (enclosed) to the two spare terminals. Peel away the self-adhesive backing of a small piece of thermochromic film and sandwich the wire between the two layers as in the diagram. Observing the temperature change of the nichrome wire.





This is similar to the examples of the buzzer and the LED, in that energy is transferred electrically to the resistance wire, and then energy spreads out. However, the energy does not spread out by radiation (or at least, most of it does not). It is transferred by *heating* due to the temperature difference between the wire and the surroundings. Energy goes from the hot wire to the cooler surroundings.

Note that strictly speaking, *heating* only applies to transfers in which energy goes from a higher to a lower temperature. When you rub your fingers on the table hard they get warmer, but you are *not* heating them. Energy is being transferred mechanically to your fingers, and this is what makes them hot – not because they are being heated! Similarly, in the above example, the resistance wire gets hot, but it is not being heated – the energy is transferred to it *electrically*.

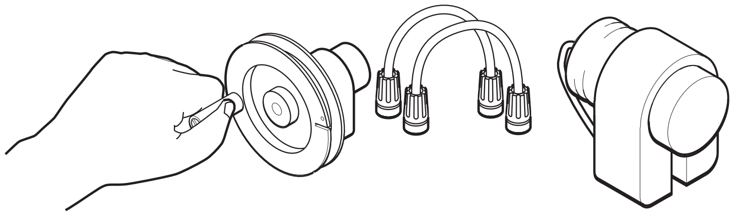
Transferring energy: summary

The previous two sections have described four ways in which energy can be transferred from one place to another:

- mechanically
- electrically
- by radiation
- by heating

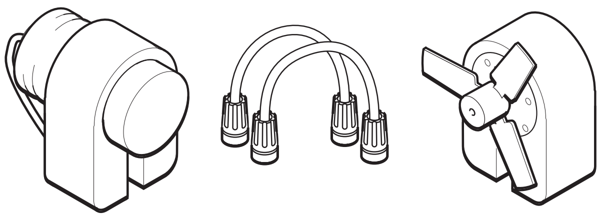
Storing energy: electrical

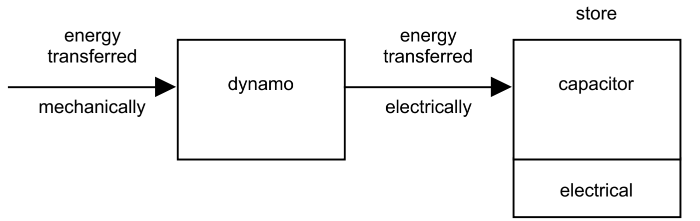
One of the devices in the energy transfer unit is a capacitor – this can store energy.



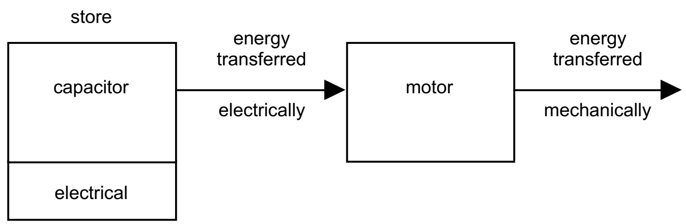
Connect the dynamo to the capacitor, and turn the handle clockwise to ‘charge’ the capacitor. After a few turns, remove the leads from the dynamo and put them into the terminals for the motor. What happens?

Connect the leads back to the dynamo and charge the capacitor again. Can you feel it is getting easier as you turn the handle and the capacitor ‘fills up’ with charge? Release the handle of the dynamo and observe what happens to it. Why does it do this?





The capacitor can store energy in it, and it can later be released. Often, the energy stored is referred to as ‘electrical energy’ – but really it is just the same energy that came from turning the dynamo handle stored in a particular way. So, you can think of the capacitor as an ‘*electrical store of energy’*.



In textbooks, it is common to see the expression ‘electrical energy’, and it is often used to indicate the energy that is transferred from one electrical device to another (for example, a dynamo to a motor) by an electrical current. ‘Electrical energy’ may also be seen in textbooks to refer to stored energy (for example in a capacitor). In the energy transfer approach taken in this booklet, in which energy is seen as the same kind of thing rather than as changing from one form to another, the term ‘electrical energy’ has not been used. Rather the emphasis has been on *how the energy is transferred* and *how the energy is stored*. Thus, the energy that goes from the dynamo to the capacitor is *transferred electrically*, and the energy in the capacitor is in an *electrical store of energy*.

If you think about the transfer and storage of water as an analogy to the transfer and storage of energy, you can see why this way of talking makes sense. Suppose you had poured some water into a cylindrical tank, and you wanted to measure the volume of water that you had. Which of these questions would make more sense?

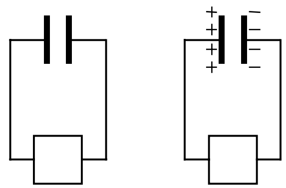
How much water is stored in the cylindrical tank?
How much cylindrical water is stored in the tank?

Clearly, the first question makes more sense, because it is more natural to think of 'cylindrical' as applying to the tank than to the water. Similarly, if you wanted to know how much energy was stored in the capacitor, the first question is better if you want to focus on the nature of the store rather than on the 'form of energy'.

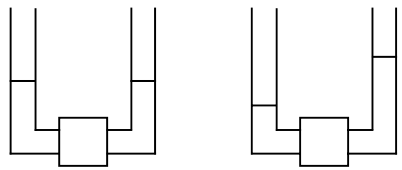
How much electrical energy is stored?
How much energy is in the electrical store?

The point about 'cylindrical' in connection with water storage example is that it gives us a way of calculating the volume of water stored ($\pi r^2 h$, where r is the radius and h is the height). In the same way, the point about 'electrical' in the energy storage example is that it gives a way of calculating the quantity of energy stored ($\frac{1}{2}CV^2$, where C is the capacitance and V is the potential difference across it). So, 'forms of energy' are not so much forms of the energy itself but different ways in which we can calculate the energy.

How is the energy stored in the capacitor? Conceptually, the capacitor is a pair of parallel metal plates (though in the actual capacitor they are rolled around each other). We can think of the dynamo as a 'pump' of electrons – it removes electrons from one side of the capacitor and pushes them to the other. So, a positive charge builds up on one plate and a negative charge on the other. Energy is released when the electrons flow back from the negative plate to the positive.



An analogy would be a U-shaped tube of water and a pump. Energy is stored when water is pumped out on one arm of the tube and into the other. Energy is released when the water flows back.



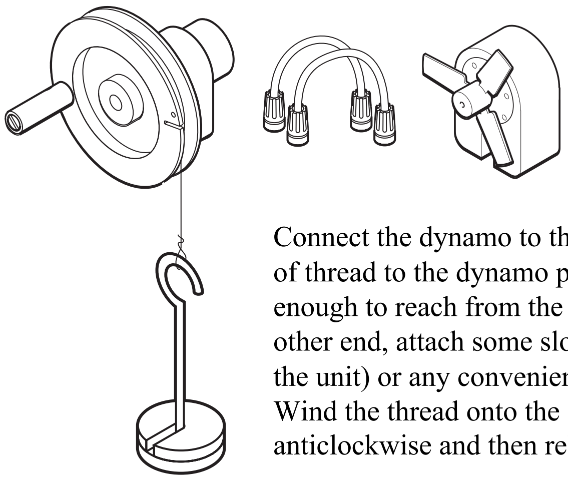
A key point about charging the capacitor is that we cannot say that the energy is stored in the positive plate or in the negative plate – *it is stored in the system as a whole*. The energy is stored because charges have been separated that are attracted to each other. Another analogy is a spring that has been stretched – it does not make sense to say that the energy is stored in one end or the other of the spring – it is stored in the system (i.e. the spring) as a whole. Energy stored in this way is referred to as potential energy – and in the case of the capacitor the full scientific term would be called electrical potential energy (though as before remember that this is really a shorthand way of referring to the way that the energy is stored rather than as a different kind of energy).

Other kinds of potential energy stores are gravitational and chemical, and these will be discussed in the next two sections. Again, the full scientific terms for these are gravitational potential energy and chemical potential energy respectively. Lifting a book off the table is an example of a gravitational energy store – the energy though is not stored in the book. Just as for the capacitor, the energy is stored in the system as a whole – in this case, the book and the Earth are pulled apart against the gravitational forces between them and the energy is stored in the book-Earth system. Similarly, when water is electrolysed to produce hydrogen and oxygen, the energy is stored not in the hydrogen or in the oxygen, but in the hydrogen-oxygen system.

Even though 'forms of energy' are not mentioned in the National Curriculum, they still appear in many textbooks, in KS3 tests, and in GCSE syllabuses and examinations. Pupils therefore need to be taught to use this kind of language, even though it may be better to think of 'forms' as applying to the nature of the stores than to the nature of the energy stored. Unit 9I in the QCA scheme of work suggests a way in which energy transfer and transformation approaches may be combined.

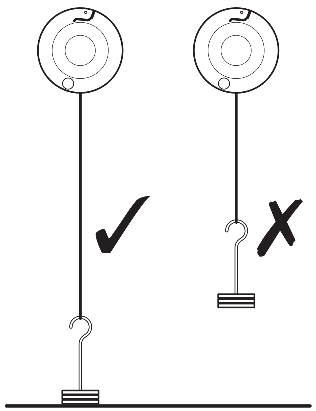
Storing energy: gravitational

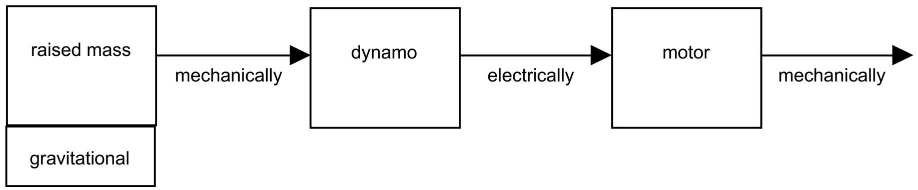
Energy can be stored when masses are lifted, and released when they fall.



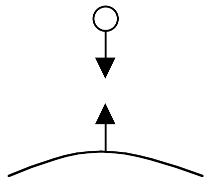
Connect the dynamo to the motor. Then tie a piece of thread to the dynamo pulley (it should be long enough to reach from the table to the floor). To the other end, attach some slotted masses (not included with the unit) or any convenient object (about 100g). Wind the thread onto the dynamo pulley by turning anticlockwise and then release the masses.

N.B. The recommended maximum mass is 250g. Ensure that the falling mass touches the ground before the cord wound around the handle runs out. If the cord suddenly becomes taut, it may damage the dynamo.





Energy is stored when a mass is lifted. This stored energy is really no different from the energy stored in the capacitor in the previous example, *but it is stored in a different way*. So, although it is sometimes referred to as gravitational energy, you can think of this as a shorthand way of saying that it is energy in a *gravitational store*. An important idea here is that when you raise a mass above the earth, it is a bit like pulling a spring – the spring exerts a force at each end pulling them back together.

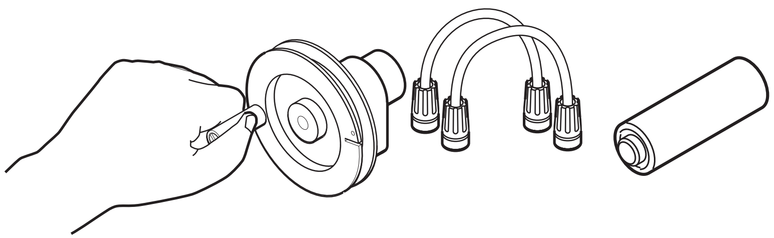


Frequently, it is referred to as 'potential energy', though this is a bit ambiguous as there are different kinds of potential stores – for example, electrical (as in the last section), gravitational and chemical (see the next section). To be more precise, you could talk about 'gravitational potential energy' (remembering that this is a shorthand for talking about energy in a gravitational potential store).

Storing energy: chemical

Energy can be stored and released during the re-arrangements of atoms that occur during chemical reactions.

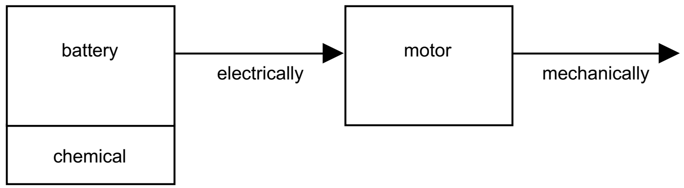
For this experiment, you will need a rechargeable battery that has been completely discharged. (WARNING: Do not short-circuit rechargeable batteries by connecting a lead from one terminal directly to the other – if you need to discharge a battery connect it to the motor until the motor stops running.)



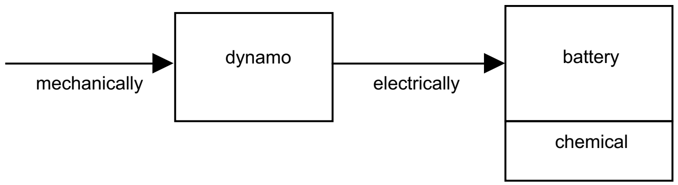
Put the battery into the battery holder. Put the leads into the dynamo terminals and attach a crocodile clip to each of the other ends. Connect the croc-clips to the battery – red to the positive terminal of the battery and black to the negative (you will need to attach one croc-clip to the terminal of the top of the holder and the other to the terminal at the bottom where a second battery would go.)

Turn the handle clockwise to 'charge' the battery. After a couple of turns, remove the leads from the dynamo and put them into the terminals for the motor. What happens?

Try to find out if there is a rough relationship between the number of times you turn the dynamo and how long the motor turns. If you do double the number of turns, does the motor go on for twice as long?



This demonstration gives a very direct 'feel' for the notion of energy as 'fluid-like'. The more you turn the dynamo the more energy is 'pumped' into the battery – and this can be shown by the length of time a motor runs from the energy stored in the battery.



Often, the energy that is stored in a battery is referred to as 'chemical energy' but again this is really just a way of saying that the battery is a *chemical store* of energy.

How is the energy stored chemically? Fundamentally it is rather similar to storing energy by raising a mass above the earth – these are attracted towards each other by a gravitational force, and energy is released when the mass falls. When a battery is charged, a chemical reaction takes place in which atoms are 'pulled apart' – they are attracted towards each other by electrostatic forces.

Storing energy: summary

In the previous three sections, three different kinds of store have been discussed – *electrical*, *gravitational* and *chemical*. These are all examples of potential energy stores – called 'potential' because 'something' has been 'pulled apart' (electric charges, objects, atoms) – when the attractive forces between them pull them back together again then energy is released. There are also other kinds of potential energy stores. Stretched springs or squashed rubber balls are examples of *elastic* stores (with attractive or repulsive forces between the atoms in the objects). Energy may be stored in a system consisting of two bar magnets - depending on which poles are pointing to each other they may move together or apart due to the attractive or repulsive magnetic forces. This is a *magnetic* store of energy. Energy may be released during a nuclear reaction because of the forces between the particles in atomic nuclei – this is a *nuclear* store of energy.

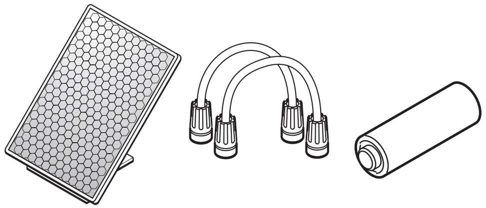
Not all stores of energy are potential energy stores. In the discussion of energy resources earlier, it was noted that energy is in moving things and in hot things. These two examples of energy stores are due to movement of large-scale objects (kinetic) and movement of particles at the molecular level (thermal).

In summary, the kinds of energy store that have been described are:

- gravitational
- elastic
- electrical
- magnetic
- chemical
- nuclear
- kinetic
- thermal

Energy and the Sun

Explaining photosynthesis and respiration draws on all the ideas about energy transfers and stores.



You can use the solar cell to charge the rechargeable battery. Connect the battery to the solar cell in the same way as you did using the dynamo in the previous activity. If the sunlight is not sufficiently strong, shine a desk lamp on the solar cell for a few seconds and then connect the battery to the motor.

As the battery is charged, chemical changes take place within the battery. Similarly, you can also the solar cell to electrolyse a solution. Put a little water into a beaker or glass and add a pinch of salt. Attach the croc-clips to a couple of nails and dip the nails into the solution. Observe the bubbles.

You can use the solar cell with any of the other devices – it will light the LED, sound the buzzer, turn the motor or charge the capacitor. You can also connect it to the dynamo so that it lifts a mass (quite impressive!). Attach some slotted masses by thread to the dynamo pulley, and connect the dynamo to the solar cell. How much mass will it lift?

Charging a battery using a solar cell can be seen as an analogy to photosynthesis. Energy is transferred by radiation from the Sun and is stored chemically. Electrolysis is an even closer analogy as far as the chemistry is concerned, since water is being split into hydrogen and oxygen. In the plant, the oxygen is 'thrown away' into the atmosphere, and the hydrogen is stored by joining it with carbon dioxide to form carbohydrates. The plant does not need to store the oxygen because it is always readily available in the air. When the carbohydrates later combine with oxygen, the stored energy is released. Note that the energy is not stored in the 'fuel' itself, but in the 'fuel-oxygen' system. Without oxygen, the fuel would be no use as a source of energy.

There is a similarity here to what people are calling the 'hydrogen economy' in which energy from the Sun is used to split water into hydrogen and oxygen, and to use hydrogen as a fuel. The technical difficulties with this have been how to store hydrogen cheaply and safely. Nature, through its synthesis of carbohydrates, has found an elegant and efficient way of doing this.

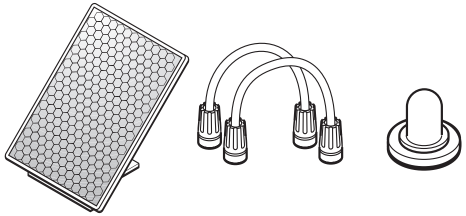
In addition to photosynthesis, the Sun also has other effects on Earth, for example, the solar panel and motor raising masses can be seen as an analogy to the 'engine' which lifts vast quantities of water as clouds.

In everyday talk, we say that we do, or do not, have the energy to do something. Much research into children's ideas about energy indicates that this is their starting point: that energy is associated with activity and being alive, that it represents a power to act, that it is used up. Quite correctly, children see that taking exercise can make one more energetic, not less. This conflicts with the scientific notion of energy as being conserved. This is a difficult part of the energy story - how energy comes from Sun and through photosynthesis becomes part of a store that includes the food in our bodies and the oxygen in the air. So, when textbooks say things like 'it is difficult to say what energy is' this is certainly true. But when some go on to add 'but it is easy to recognise when we have got it', this is potentially very misleading. What is more usually recognised is something closer to the idea of a fuel than to the scientific concept of energy.

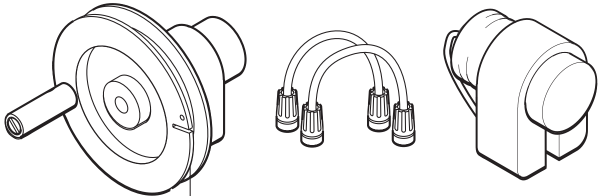
Energy conservation and dissipation

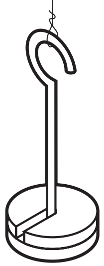
Thinking about energy as being stored and being from one place to another leads naturally into the idea that it is conserved. Historically, it was the realisation that there was a quantity that could be calculated and remained unchanged throughout a change that led to the energy concept.

Connect the solar cell to the LED, and shine a desk lamp on it. What can you say about the brightness of the desk lamp compared with the brightness of the LED?



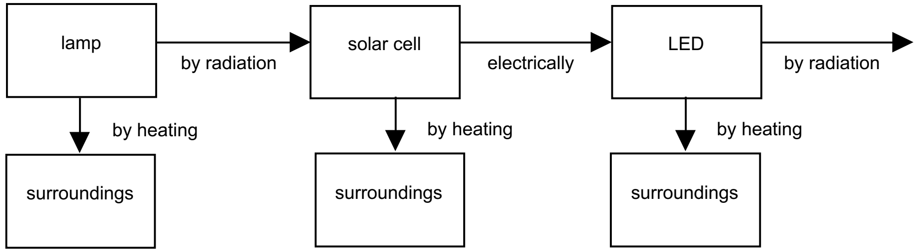
What does this suggest about the energy that goes in compared with the energy that comes out? What has happened to the rest?



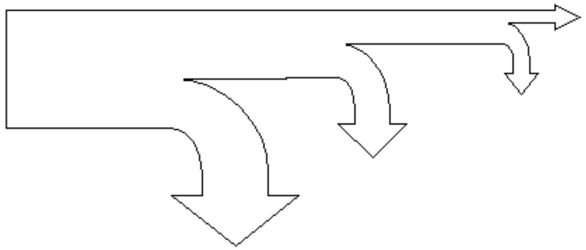


Attach a set of slotted masses with total mass of 100g to the dynamo using a thread, and wind the thread onto the pulley by turning the handle anticlockwise. Connect the dynamo to the capacitor. Allow the masses to fall until they hit the ground and immediately remove the leads to the dynamo. Swap the leads around and connect back to the dynamo (i.e. red to black and black to red). Does the dynamo lift the weights back up? If not, repeat using the same 100g mass when falling, but reducing the mass when lifting.

The demonstrations suggest that the energy going in is greater than the energy going out. However since energy is conserved, the energy must have gone somewhere else. In all of the energy transfers, the devices get warmer and so energy escapes to the surroundings by heating.



Sometimes this is referred to as energy degradation, but a better term is dissipation (‘degradation’ suggests that the energy is turning into something else). When energy dissipates, it stays the same except that it is more spread out and therefore less useful. This dissipation of energy can be represented by Sankey diagrams:



Sankey diagrams can be used both qualitatively and quantitatively.

Making measurements

The energy transfer unit can also be used to make measurements of the quantity of energy transferred and stored in different kinds of change.

It is not too difficult to make comparisons of the quantities of energy involved in the same kinds of change – for example, it is clear that burning a log of wood releases more energy than burning a match. But comparing different kinds of changes is not so easy. In which change does most energy escape? And least? • burning a candle • 1 tonne of water flowing down a 100m hill • large saucepan of boiling water cooling down • lying in bed for 3 hours • 1 tonne car at 70mph coming to rest	Many people are more impressed, for example, by the energy in large moving objects than by that in hot objects. In fact, in all of the changes listed approximately the same amount of energy escapes – 1MJ! The calculations for the car, the flowing water and the saucepan of water use the following formulae • kinetic, $\frac{1}{2}mv^2$ • gravitational potential, mgh • thermal, $mc\theta$ The values for the candle and the human body are based on data for enthalpies of combustion and metabolic rates.
You can make comparisons quantitatively using the energy transfer unit. To measure quantities of energy transferred electrically, use an ammeter and a voltmeter (power = VI, energy = VIt). Here are some suggestions: • Power output of hand-turning dynamo to drive motor (use ammeter and voltmeter). • Power input to rechargeable battery (dynamo) and output from (running the motor). How much energy can it store in total? (Use mains charger and discharge with motor.) • Driving a motor using light – power input from bulb to solar cell (from power of bulb, distance and efficiency) and power output of cell (ammeter and voltmeter). • Using light to lift a load (solar cell connected to dynamo and slotted masses) – calculate total energy falling on solar cell in time taken to raise the load, and potential energy of raised load (*mgh*).	The quantities of energy involved in the changes on the energy transfer unit are clearly much smaller than those in the examples above. A unit of 1 joule is more convenient to make the comparisons between these changes. Each of the following involves a transfer of about 1J of energy: • Hand turning the dynamo at 60rpm to drive the electric motor for 20 seconds • Using the rechargeable battery to drive the electric motor for 100 seconds. • Light falling on solar cell from a 60W bulb in a desk lamp at a distance of 20 cm for 10 seconds. • A mass of 100g falling through a height of 1 metre. Further details of quantitative work on energy will appear on the SEP website (www.sep.org.uk).

You can download the written materials in this booklet, and find further information from: Science Enhancement Programme www.sep.org.uk

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