Energy

INTRODUCTION

Energy is a topic that permeates all the others in the subject. It affects everything that we do every moment of every day and therefore it is important that you learn to understand, identify and calculate energy in some of its many forms.

When you have completed this unit of work you should be able to:
- understand and identify the many ways that energy affects our lives
- describe the environmental implications of using or producing certain forms of energy
- identify different forms of renewable energy sources
- perform calculations to determine how much energy is present in a system
- produce systems diagrams to show energy transformations
- determine how efficient an energy system is.

What is energy?

Energy is all around us and comes in many different forms. Although it cannot be seen or touched, you can be sure that when anything happens energy is responsible.

Energy is the ability to do work. The 'work' comes in many different forms – from a car driving along, to a television set showing a programme, to a human body running a race. In order to make these machines work they need energy. Energy makes things happen.

Energy cannot be created or destroyed: it can only be transformed, from one type into another. Indeed, this is what all machines and living things do – transform energy. For example, a car converts or transforms the chemical energy in petrol into heat energy inside the engine. The engine then turns the heat energy into mechanical energy, which makes the car move. A television set converts or transforms electrical energy into light energy - to give the picture - and into sound energy for the soundtrack. Humans get the energy they need for their busy lives from the chemical energy in food. They transform it into the energy of movement and heat energy.

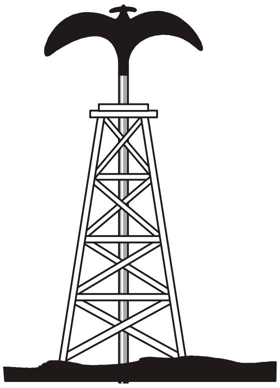
Assignments: what is energy?

1. Why do humans and machines need energy?
2. What happens to the energy in a system if it is never destroyed?
3. What is the ultimate source of energy for the Earth?
4. Describe briefly the three main ways that the sun’s energy is available on Earth.
5. Give some examples of energy sources that can be used from each of the three groups.

Oil and natural gas

Like coal, oil and natural gas are fossil fuels that have taken millions of years to form. Animals, as well as plants, died and settled on the seabed and became buried. Pressure and heat changed the decaying material into oil. Some of the oil decayed even more and made natural gas. These oil and gas reserves supply the world with precious resources that are used today.

Before it can be used, natural gas is purified. The methane is then ready to be piped directly to homes and factories. Oil that comes directly from wells is called crude oil. This is because it is not just one substance but many, all mixed together. It has to be treated before it can be used and the factory where the oil is treated is called a refinery. Crude oil is refined to separate it into products that can be used. These include aircraft fuel, lubricating oil, chemicals from which to make plastics, and many other products.



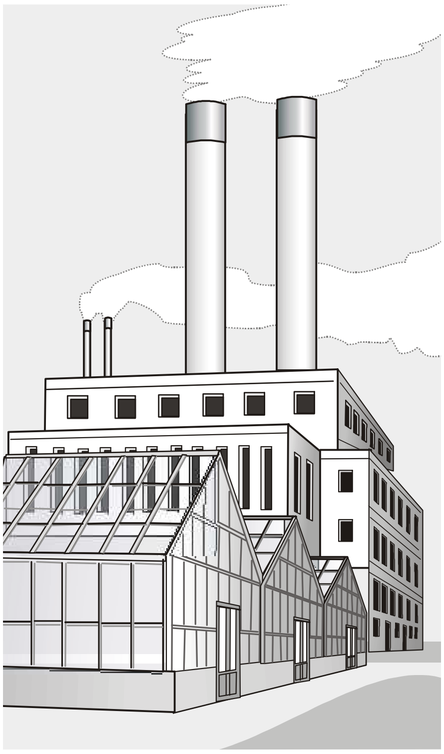
Assignments: fossil fuels

1. What are coal, oil and natural gas made from and why are they called fossil fuels?
2. What is the danger to the Earth’s energy supply if we continue to burn coal, oil and gas?
3. What other resource apart from energy can be extracted from oil?

Energy and the Environment

The 'greenhouse effect'

At present, fossil fuels supply most of the world's power, but when any of these fossil fuels are burnt, carbon dioxide gas is released. There is a small amount of carbon dioxide naturally present in the air, but, because fossil fuels are used so much, it is building up in the atmosphere. In these unnatural quantities, carbon dioxide is one of the gases that cause the greenhouse effect.



Gases such as carbon dioxide allow the sun's heat to enter the atmosphere but stop it escaping back into space. Heat is trapped in a layer around the Earth. As a result of the increased amount of carbon dioxide, temperatures have risen around the world. The air inside greenhouses heats up in a similar way. The glass lets in the sun's heat but stops it escaping back out again. In this way the glass is like the layer of carbon dioxide. Because of this similarity, global warming has become known as the 'greenhouse effect'.

You might think that it would be very pleasant to have a warmer climate, but some scientists think the effect could be very serious. Some animals and plants are very sensitive to temperature, and so global warming could cause them to die out. Also, as the weather gets warmer, the ice caps at the north and south poles will gradually melt. The melting of the southern ice cap will cause sea levels to rise. This will lead to flooding, reducing areas of land and killing off even more living things.

Acid rain

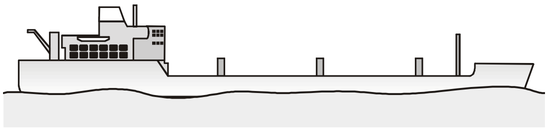
As rainwater falls through the atmosphere, it mixes with carbon dioxide gas and becomes an acid called carbonic acid. This natural acid is so weak that it does not harm the environment.

However, when coal is burned, sulphur and nitrogen in the coal combine with oxygen to give oxides. These mix with rainwater and make it much more acidic. The main acids that this process produces are sulphuric and nitric acids, which are very strong. This acid rain is polluting the environment, causing trees to stop growing and animals and plants in lakes and rivers to die. It also corrodes buildings, making them crumble.

It has become vitally important for scientists and technologists to solve the problem of producing or harnessing energy from the Earth without having to burn fossil fuels.

Oil pollution

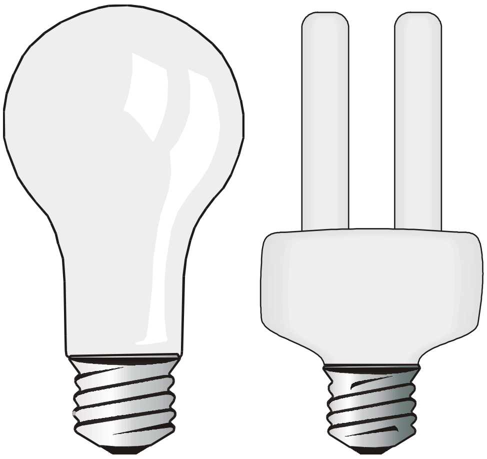
Oil can cause huge problems. Leakage and spills from oil tankers can release tonnes of oil into the environment. All sorts of marine life and birds are destroyed, and beaches are covered in oil. The pollution is very difficult and expensive to clear up properly and safely. The problem is made worse by high winds and rough seas, which break up and spread oil slicks that are already many square kilometres in size.



Assignments – energy and the environment

1. What is 'global warming'?
2. Describe the way that the greenhouse effect is warming the Earth.
3. How is acid rain produced?
4. Why does acid rain have an effect on animals as well as plants?
5. What must be done to reduce the effects of acid rain and global warming?

Most homes have incandescent light bulbs like the one on the left in the diagram above. However, compact fluorescent light bulbs (shown on the right) use less than 25 per cent of the energy to make the same amount of light – and can last ten times longer.



Renewable energy sources

Today, we use so much energy that we depend very heavily on the fossil fuels that have taken nature millions of years to make. It is not surprising that we are using them up faster than they are being formed. There will be a time when the world's limited resources are used up. Because of this, fossil fuels are known as non-renewable energy sources.

Every day, the earth absorbs vast quantities of the sun's energy. Even if only a small proportion of this could be harnessed, there would be enough energy for our needs as long as the sun continued to shine. Energy sources that come from daily sunshine are therefore known as 'renewable'. These include solar power, wind energy, hydroelectricity and energy from the sea.

Many people think that alternatives to fossil fuels should be used more. This is not only because fossil fuels are running out but also because they cause such serious environmental problems. Renewable sources are clean, and most of them are being investigated as alternative energy sources. Some of them are already in use all over the world.

Assignments: renewable energy sources

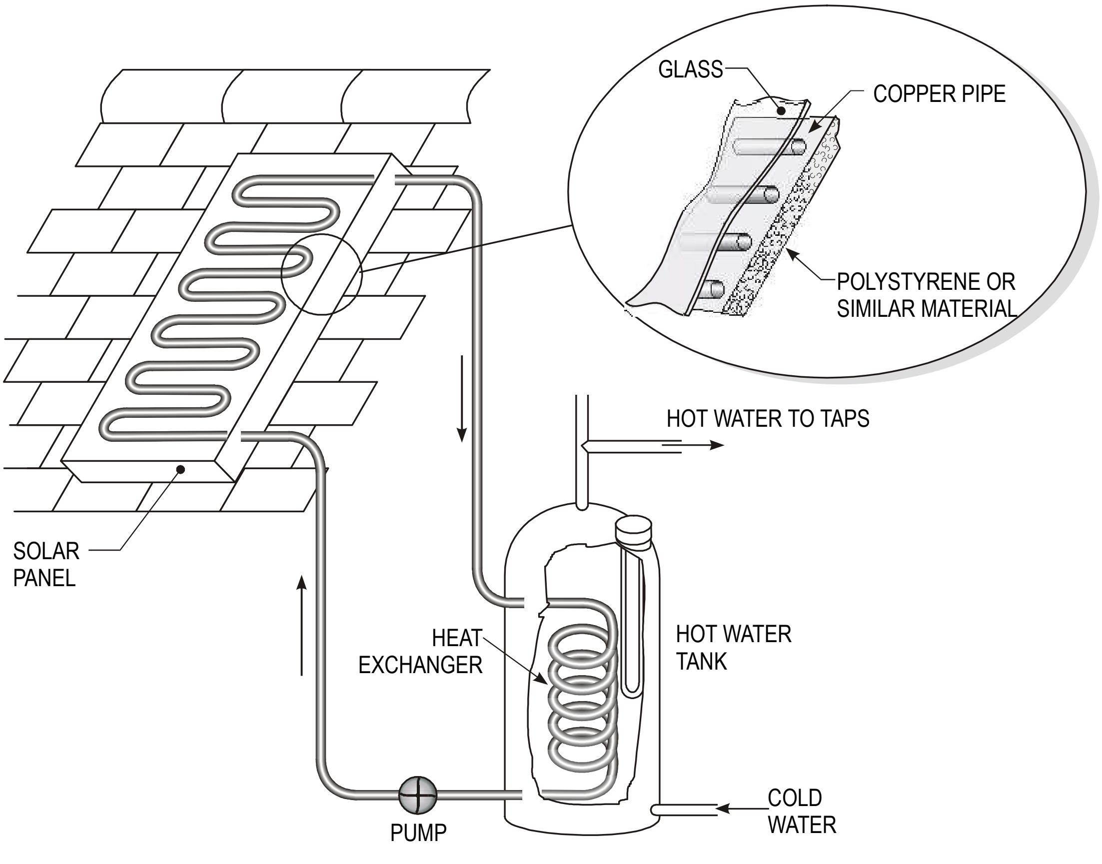
1. What is the difference between a finite and an infinite energy source?
2. Why are fossil fuels thought of as non-renewable, or finite, energy sources?
3. What is a renewable energy source?
4. Name three renewable energy sources.
5. Name a machine that has been used in the Netherlands for many years that harnesses the energy of wind.

Alternative Energy Sources

Solar energy

Science and technology now allow us to trap the enormous power of the sun and use it to produce heat and electricity.

Buildings can be designed to absorb heat on 'heat collectors' during the day and release it when it is most needed, at night. Solar panels on rooftops work in the same way, but the heat is stored in a liquid such as water or oil. This is used to heat the building by passing it around a central heating system, or simply to provide hot water.



The sun's light energy can be turned into electricity using photovoltaic cells that contain crystals of silicon. These cells work in a similar way to a car battery, but instead of being recharged by something that moves, such as an engine, they are recharged by light. They were first made for spacecraft, but now you may find them powering your calculator or watch.

Solar heat can be captured on a vast scale to generate electricity. The sun's light is reflected off many mirrors and on to one small target, to concentrate the energy. This means that much more of the sun's radiation is collected in one place. The intense heat can then turn water into steam to turn a turbine.

Assignments – solar energy

1. Describe three ways in which it is possible to harness solar power.
2. If a word has 'photo' (for example photosynthesis) at the start of it, what does 'photo' refer to?
3. Where would be a good location for a solar power generator?

Wind energy

Wind power has been used to turn windmills for thousands of years. They were used to turn machinery to raise water from deep wells and to grind wheat. In recent years, new ways have been found to capture the wind's energy more efficiently. However, because winds vary from place to place and from day to day, this can prove to be difficult.

Assignments – wind energy

1. Name one method of transport that harnesses the wind's energy.
2. How can wind farms cause environmental problems?
3. Describe the way that electrical energy is generated using a wind turbine like the one shown above.

Hydroelectric energy

Water power has been used for centuries. Nowadays, hydroelectric schemes are used to generate large amounts of electricity. Usually a dam is built across a river valley to control the flow of water and store up the energy. The water collects in a reservoir behind the dam. When electricity is needed, the water is allowed to rush through holes in the dam, turning turbines as it flows.

Assignments – hydroelectric energy

1. Describe the way that electricity is generated in a hydroelectric power station.
2. What is a possible disadvantage of hydroelectric schemes?

Energy from the sea

There are several ways in which the sea can provide us with energy for generating electricity. Some of these ideas are still being tested and improved.

Wave energy

Waves happen because winds transfer their energy to the sea's surface as they blow over the water. Wave power systems use kinetic energy in the waves to turn turbines. These can be either floating or fixed to the seabed, and placed either out at sea or on the shoreline.

Tidal energy

Tides are caused mainly by forces from the moon and the sun. This force is called gravity and it pulls on the water. Tidal energy can be harnessed by building a barrier right across a river estuary. Electricity is generated in the same way as with a hydroelectric dam, except that it is the push and pull of the tides that causes water to flow over the turbines. However, people fear that tidal schemes may upset estuary environments that are rich in wildlife. Also, tidal barriers are a nuisance to shipping.

Assignments – energy from the sea

1. Describe two ways that the sea's energy can be harnessed.
2. Describe one negative aspect of harnessing tidal energy.

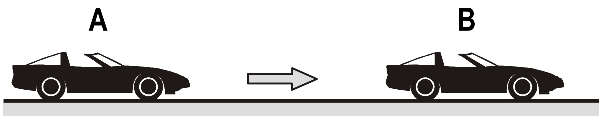
Calculations of Energy

Work and energy

Work done

When a force is used to move an object, 'work' is said to be done.

Consider pushing a car along a road from position A to position B.



The amount of work you do will depend on how difficult the car is to push (the size of the force) and on how far you have to push it (the distance).

The amount of work can be calculated using the formula

work done = force applied x distance moved

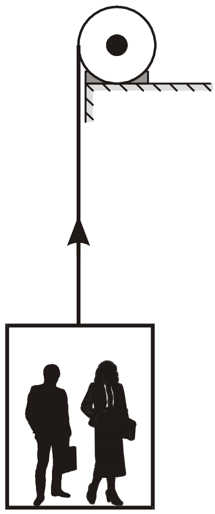
$$W = F \times s$$

Force is normally measured in newtons (N) and distance in metres (m).

The unit for measuring work is therefore newton metres (Nm), or joules (J).

Worked example: work done

A winch raises a lift of mass 1000 kg to a height of 20 m. Calculate the minimum amount of work that must be done by the winch.



Weight of lift = *mg*

Weight of lift = 1000 x 9.81

= 9810 N

Work = force x distance

= 9810 x 20

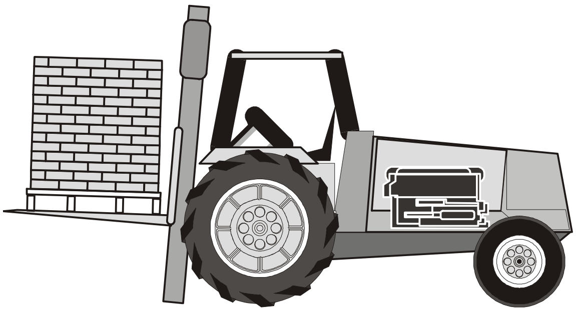
= 196,200 Nm

Assignments: calculating work done

1. Calculate the amount of work done when a force of 150 newtons is used to pull a 50 kg bag of sand 20 metres.

2. In lifting an engine out of a car, a mechanic uses a block and tackle. How much work is done if a force of 500 N is used in pulling the rope a distance of 4 m?

3. During the loading process, a fork-lift truck lifts a pallet of bricks of mass 740 kg up to a height of 2 m.

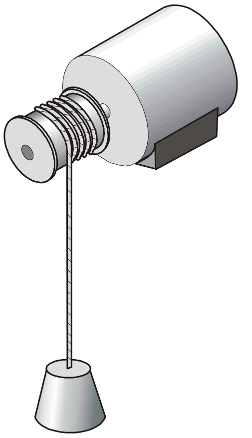


Calculate the minimum amount of work the truck must do during the lift.

Suggest why the actual work done during the lift will be greater than this.

4. A weightlifter lifts a dumbbell from the floor to arm's length, a vertical height of 1.2 m. Calculate the mass of the dumbbell (in kg) if the minimum work done in lifting it is 1800 Nm.

5. A mass of 50 kg is raised to a height of 5 m by a rope, which is wound around a pulley on a motor shaft of diameter 150 mm as shown.



Determine the amount of work done by the motor and the number of revolutions made during the lift.

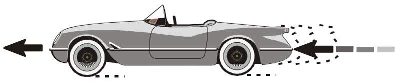
Other forms of energy

Energy is defined as the capacity of a body to make things happen (or to work). It is measured in joules (J). We know that to do more work we require more energy, but we can use various types of energy to do this work for us. Energy comes in several different forms, but the ones we shall deal with in this course are:

- kinetic
- potential
- electrical
- heat.

Kinetic energy

Kinetic energy is the energy of movement. It is the name given to the energy a body possesses due to its motion. The car in the diagram below can be described as having kinetic energy because it is moving.



Potential energy

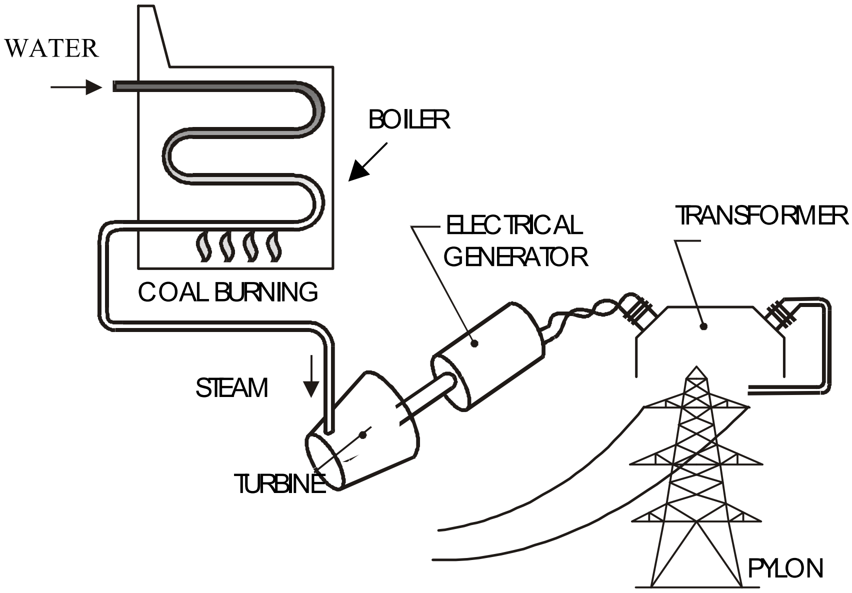
Potential energy can be best thought of as energy stored in a static object. It can be due to how high the object is above a datum (starting point), or due to the fact that work has already been done on the object and the energy is stored in it (for example in a spring). The bucket supported by the pulley in the diagram below has potential energy.

Electrical energy

Electrical energy is one of the most convenient and commonly used forms of energy since it can be transported easily from place to place (along electrical cables) and can be easily changed into other forms of energy.

Most electrical energy is generated in power stations, where one type of energy is converted into electrical energy.

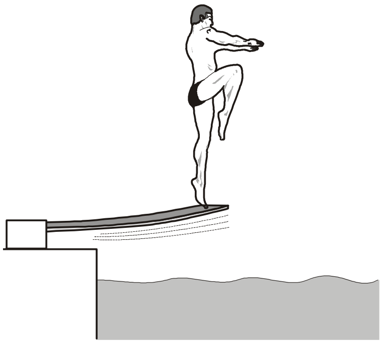
The diagram below shows a simple fossil fuel power station. The fuel is burnt in a boiler and the chemical energy in the fuel is converted into heat energy. This heat energy is used to produce steam at very high pressure (kinetic energy). The high-pressure steam is then used to turn turbine blades (rotational kinetic energy). The turbine is in turn connected to an alternator, which converts the kinetic energy into electricity. This electricity can now be transported around the country along electrical cables, which are suspended from pylons.



Heat energy

Heat energy is the energy transferred to a body that results in a change in the body’s temperature. The diagram below shows a kettle boiling: a certain amount of thermal energy was required to raise the temperature of the water in the kettle to boiling point.

Assignments: identifying different forms of energy



1. When an Olympic diver stands on a diving board 10 m above the pool, what form of energy does he possess?

2. When the diver jumps on the diving board it will bend. What form of energy does the board now possess?

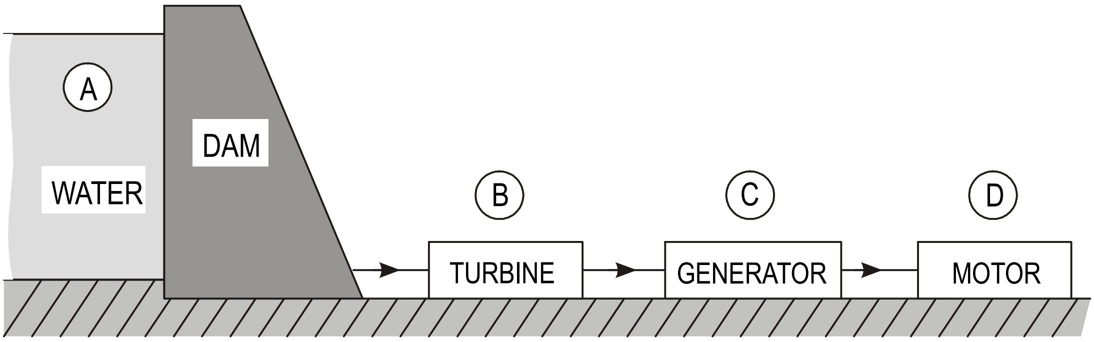
3. When the diver is moving upwards, what form of energy does he now possess?

4. When the diver is at the highest point of his dive why does he not have any kinetic energy?

5. A heating element is used to make sure that the water temperature in the pool is maintained at a suitable level. Complete the simple systems diagram below, showing one energy input and one energy output for the heating system that will solve this problem.

6. Name four sources of energy that can be converted (directly or indirectly) into electrical energy.

7. The diagram below shows a representation of a hydroelectric power station.



Name the energy transformations at each of the stages A, B, C and D.

Calculating kinetic energy

The kinetic energy of a moving object is dependent on two factors: the mass, *m*, of the object (in kg) and its velocity (*v*) (in m/s).

Kinetic energy is calculated using the formula:

$$E_K = \tfrac{1}{2}mv^2$$

Worked example: kinetic energy

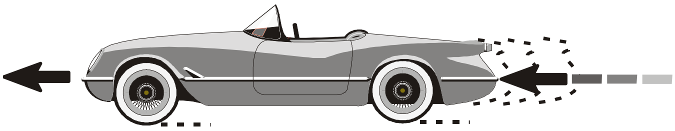
1. If a buggy of mass 90 kg travels at 40 m/s, how much kinetic energy does it possess?

$E_K = \frac{1}{2}mv^2$

$= \frac{1}{2} \times 90 \times 40^2$

= 72,000 joules

= 72 kJ



Assignments: kinetic energy

1. During a sheet-making process, 50 kg ingots of metal are passed along rollers at a speed of 0.5 m/s. Calculate the kinetic energy of each ingot.

2. A racing car drives around a circuit at a speed of 50 m/s. If the car has a kinetic energy of 500 kJ, what is the mass of the car?

3. A girl of mass 50 kg is riding on her bicycle and has a kinetic energy of 2.5 kJ.

   What speed is the girl moving at, and what is the kinetic energy of the bicycle if it has a mass of 30 kg?

4. A crane raises a load of 200 kg a height of 30 m in one minute at uniform speed. Determine the kinetic energy of the load when it is moving.

5. An escalator has six people on it with a total mass of 900 kg. If the escalator moves at a uniform speed of 0.5 m/s, what is the average amount of kinetic energy that each person contains?

6. Since 1975 the US government has required that a container carrying radioactive material must be able to withstand a high speed crash with an impact velocity of 250 m/s. By comparison, the UK safety standards (in 1994) are carried out at 50 m/s. If the container has a mass of 10 kg then calculate the percentage increase in kinetic energy of the American test over the British test.

Calculating potential energy

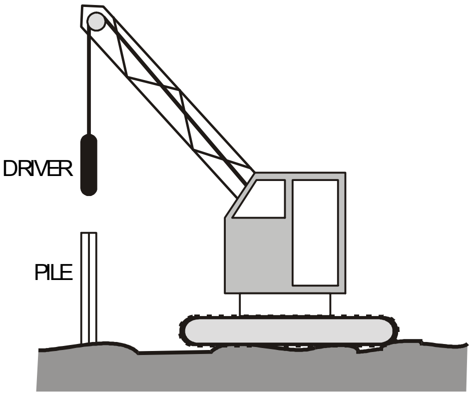
The formula most commonly used to calculate potential energy is

$$E_P = mgh$$

where m is the mass of the object, g is the acceleration of gravity acting on the object and h is the height the object is above the ground or datum.

Worked example: potential energy

1. Metal piles are driven into the ground using a pile driver. This consists of a 500 kg driver, which is raised by a winch to a height of 3 m above the pile and then released.



Calculate the potential energy stored when the driver is lifted.

E_p= mgh

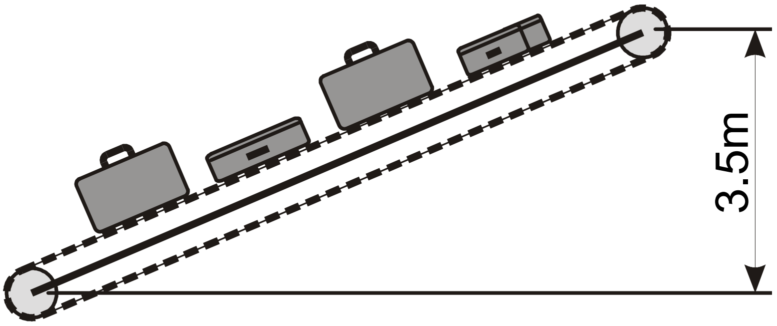
= 500 x 9.81 x 3

= 14,715 joules

= 14.7 kJ

Assignments: potential energy

1. Baggage handlers at an airport, place suitcases on to a conveyor belt, which lifts them up to the hold of the aeroplane as shown.



   Calculate the potential energy stored when a 20 kg case is moved up the belt.

2. At what height must a drum of mass 100 kg be suspended above the ground if it possesses 4 kJ of potential energy?

3. Calculate the potential energy available from a reservoir holding 1800 litres of water at a height of 260 m. (1 litre of water has a mass of 1 kg.)

4. Metal piles are driven into the ground using a pile driver. The driver is raised to a height of 5 m above the ground and then released.
   Calculate the weight of the driver if the potential energy stored when it has been lifted is 9810 joules.

5. A fairground roller coaster has many high and low points on its track. If the highest point - the beginning of the ride - is at a height of 50 m and the height at the end is 5 m, what is the change in potential energy between the start and end for a person of mass 80 kg?

6. If a steeplejack has a potential energy of 2000 J when he scales a ladder to a height of 10 m, what amount of potential energy will he possess at a height of 15 m?

Calculating electrical energy

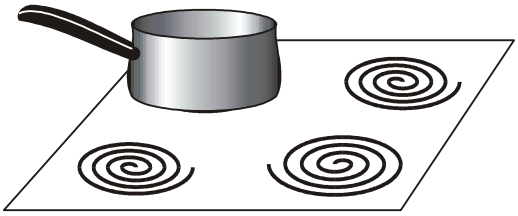
Electrical energy can be calculated using the formula

$$E_e = ItV$$

where V is the voltage of the circuit, I is the current flowing through the circuit and t is the time (in seconds) that the circuit has been operating.

Worked example: electrical energy

1. An electric cooking ring has an operating voltage of 230 volts with a current of 5 amps. Calculate how much electrical energy has been used if the cooking ring takes five minutes to heat a pot of soup.



$E_e = ItV$

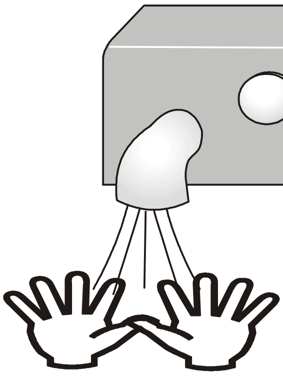
$= 5 \times 300 \text{ (seconds)} \times 230$

$= 345{,}000$ joules

$= 345$ kJ

Assignments: electrical energy

1. A hot-air hand drier is activated for 30 seconds when the switch is pressed.



   The drier operates from a 230 V supply and draws a current of 12 A. Calculate the amount of electrical energy used when the drier is operating.

2. A 12 volt car battery has a capacity rating of 35 amp hours (that is, it can supply a current of 35 amps for 1 hour, or 5 amps for 7 hours, or any other combination giving an equivalence of 35 amp hours).
   Determine the amount of electrical energy the battery can supply.

3. A portable electrical generator can deliver energy at a rate of 6 kJ per second. Calculate the current that can be drawn from the generator if the electricity is supplied at a voltage of 110 volts.

4. If the amount of electrical energy used by a 110 V, 30 A d.c. motor is 1.98 MJ, for how long has the motor been in operation?

5. A turbine is used to drive a 110 V electrical generator. If the output current is 3 amps, how much electrical energy does the generator produce in one hour?

Calculating heat energy

Heat energy can be calculated using the formula

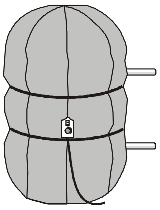
$$E_h = mc\Delta T$$

where m is the mass of the material in kg, $\mathrm{D}T$ is the change in temperature in degrees
(Celsius or Kelvin) and c is the specific heat capacity of the material being heated.

The specific heat capacity of a substance is the amount of energy required to raise the temperature of 1 kg of the material by 1 K.

Worked example: heat energy

1. A hot water tank contains 200 litres of water at 18 °C.



Calculate how much energy is required to raise the temperature of the water to 50 °C. (1 litre of water has a mass of 1 kg.)

The specific heat capacity of water is 4200 kJ/kgK.

$E_h = mc\mathrm{D}T$

$= 200 \times 4200 \times 32$

$= 26.88$ MJ

Assignments: heat energy

1. Calculate the heat energy required to heat 2 kg of water from a temperature of 20 °C until it begins to boil.

2. A hall has dimensions of 8 m x 30 m x 10 m. Assuming no heat losses, calculate the amount of heat energy required to raise the temperature of the air in the hall from 10°C to 20°C.
   The density of air is approximately 1.3 kg/m^3 and the specific heat capacity is 850 J/kgK.

3. The heating element in a shower can produce heat energy at a rate of 7 kJ/s. Water enters the system at a temperature of 15°C and is heated to 40°C. Estimate the flow rate (in litres per second) and state any assumptions you have made.

4. 57 kJ of thermal energy is supplied to 1.7 kg of oil having a specific heat capacity of 2.7 kJ/kgK.
   If the initial temperature of the oil is 3°C, what will be its final temperature?

5. During a test on an engine, the following data were recorded.

   - Oil consumption = 3 kg/hour
   - Specific heat capacity of oil = 1360 kJ/kgK
   - Temperature rise in cooling water = 20°C

   If it is estimated that the cooling jacket of water absorbs 25 per cent of the energy supplied by the fuel, calculate the quantity of water required per second in the cooling jacket.

Power

Power is a measure of the rate of energy transfer; that is, it gives an indication of how quickly the energy is changed from one form to another.

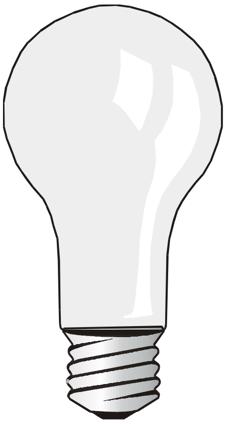
Power can be calculated using the equation:

$$P = E/t$$

P is the power in watts (W).
E is the energy transfer in joules (J).
t is the time in seconds (s) – *t must be in seconds*.

Worked example: power

1. If an electric light bulb uses 60 kJ of energy in 10 minutes, what is the power rating of the bulb?



$P = E/t$

$= 60{,}000/(10 \times 60)$

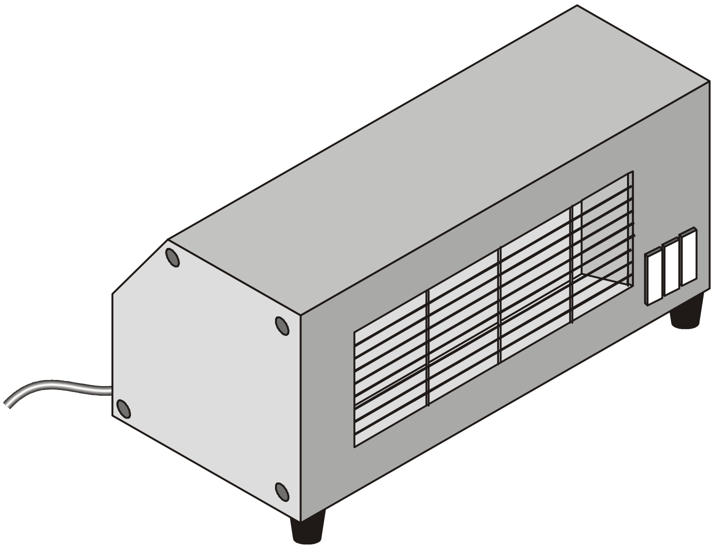
$= 60{,}000/600$

$= 100$ watts

Assignments – power

1. A winch lifts a 500 kg pallet of bricks to a height of 10 m in a time of 15 seconds. Calculate the minimum output power of the lift.

2. An electric heater is rated at 3 kW. Calculate how much heat energy the heater will deliver in one hour.



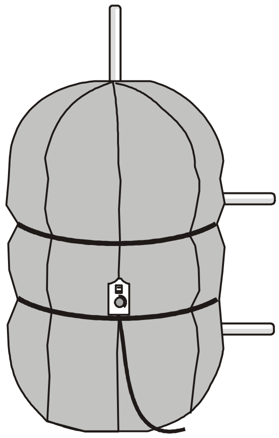
3. A car of mass 800 kg is moving at a steady rate of 70 km/hour. Calculate the kinetic energy of the car and the power output from the car in one minute.

4. An electric motor is rated at 10 kW and runs from a mains supply of 220 V. If it consumes 10 kJ of energy over a period of 30 seconds, what is the current used by the motor?

Conservation of Energy

In everyday usage, the term energy conservation has come to mean conserving energy in the sense of using less of it to do the same amount of work. Examples include improving the heat insulation of houses and other buildings, improvements in the efficiency of lighting and other electrical devices, making cars which use fuel more efficiently, etc.

The diagram below shows the insulating jacket around a hot water tank. This is used to reduce heat loss.



In technology and science 'conservation of energy' has an older and different meaning. It is looked upon as a rule.

The rule states that energy cannot be created or destroyed but can only be changed from one form to another - 'transformed' or 'converted'. This rule is also termed a natural law.

The Law of Conservation of Energy

The law of conservation of energy asserts that for a closed system, where no energy goes in or out, the total energy within the system must always be the same, although its form may change. On the other hand, in an open system such as a power station, this rule leads to the conclusion that the total energy input to the system must be exactly equal to the total energy output.

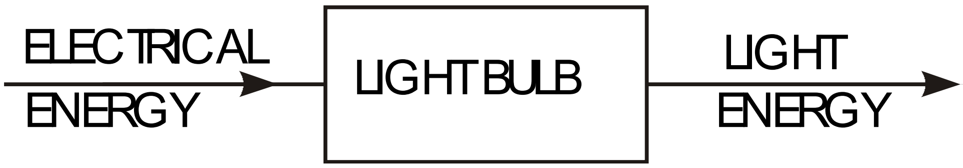
The extent to which the output energy is able to do useful work - that is, of the desired type - is called the efficiency of the system. We calculate this by comparing the useful output from the system with its energy input.

Energy Transformation

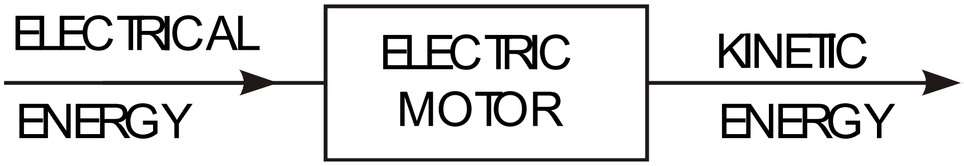
How energy can be converted or transformed is of prime importance to the technologist. Some forms of energy are directly interchangeable (for example potential and kinetic) but others need to go through several changes to arrive at the final desired form (for example *chemical*-heat-kinetic-*electrical*).

The following system diagrams show some very simple energy transformations.

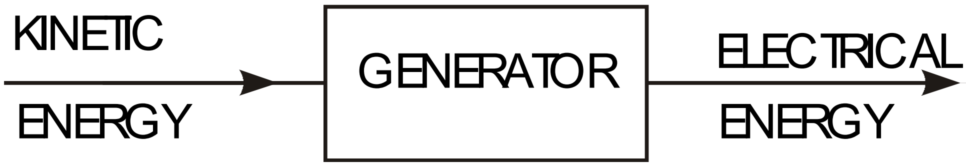
A light bulb converts electrical energy into light energy.



An electric motor converts electrical energy into kinetic energy or movement.



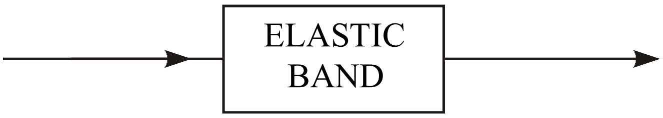
An electric generator converts kinetic energy into electrical energy.



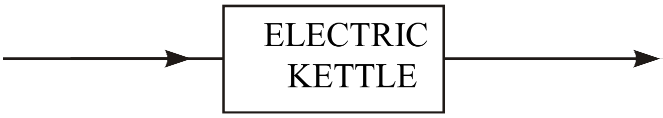
Assignments: simple energy transformations

Copy and complete the following system diagrams showing the energy conversions taking place.

1. A stretched elastic band



2. An electric kettle



3. A wind-up toy car

4. Water passing over a waterfall

More energy transformations

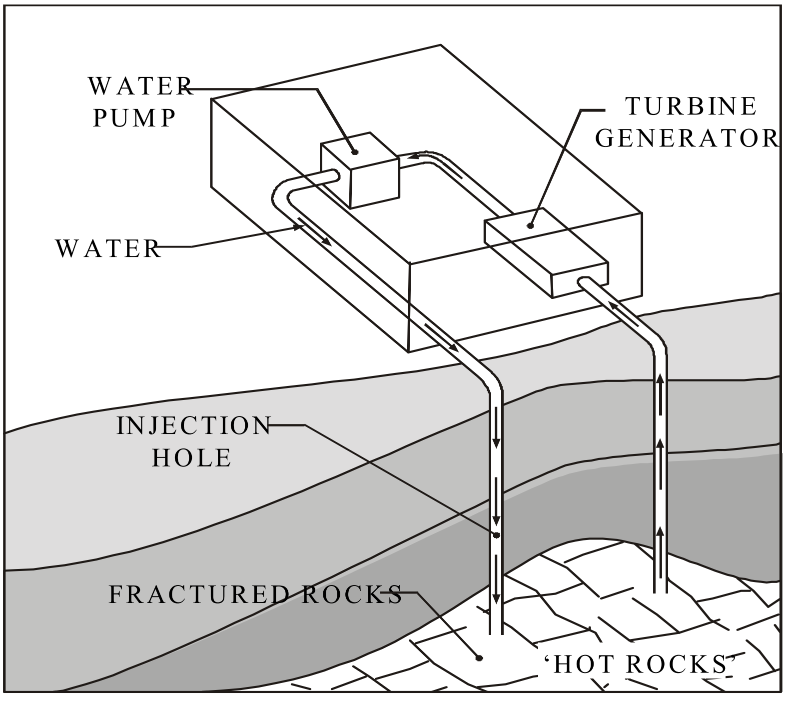
It has already been mentioned that some systems will require more than one energy conversion to arrive at the desired energy output, for example when converting geothermal energy into electrical energy.

Geothermal energy

The Earth is a massive reservoir of natural heat energy. At its 'birth' the Earth was a molten mass at a temperature of around 6000°C. The Earth has been cooling down ever since, and will continue to do so for millions of years.

In some places on the Earth, this natural heat energy reaches close to the surface. Occasionally, molten materials from the Earth's core escape to form volcanoes. In Iceland and New Zealand, water trapped below ground in cavities becomes heated and escapes under pressure as hot water geysers. Even in Britain, hot water springs occur. The Romans took advantage of 'geothermal energy' at the now famous Roman baths in Bath.

If geothermal energy could be harnessed at temperatures of around 250°C or higher, it could be used to make electricity, the heat being used to turn water into high pressure steam to drive turbine generators. To achieve these temperatures, however, it would be necessary to drill deep into the Earth's surface to reach the so-called 'hot rocks'. In Britain it would be necessary to drill as deep as 6000 metres (about four miles) to reach temperatures useful for the generation of electricity.



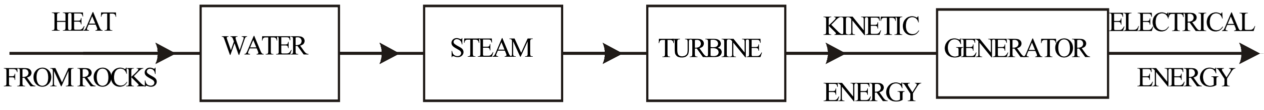
A geothermal power station

One method of 'collecting' geothermal energy for conversion into electricity is shown on the previous page.

The system consists of two boreholes, which penetrate the Earth's crust and then bore into a region of hot rocks. During construction, an explosive charge would be detonated at the bottom of the injection hole to fracture the rocks. When operating, water would be forced down the injection hole under pressure. It would then penetrate the hot rocks, pick up heat, and return to the surface through the second borehole. At the surface, steam would be released from the pressurised system to drive turbine generators.

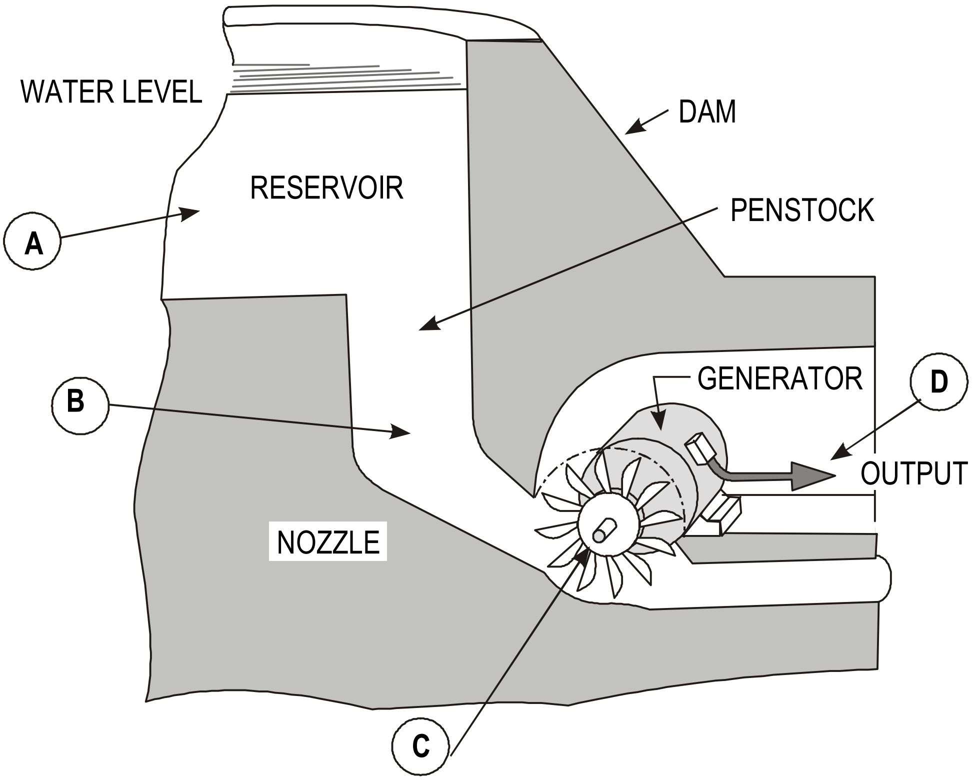
The energy conversions could be described as follows.

The heat energy in the rocks is transferred to the water in the injection-hole pipe. This hot water is changed to high-pressure steam and transported to the surface. The heat energy from the steam is used to turn the blades of a turbine, producing rotational kinetic energy, which is used to create electricity from a generator.



Assignments: Complex energy transformations

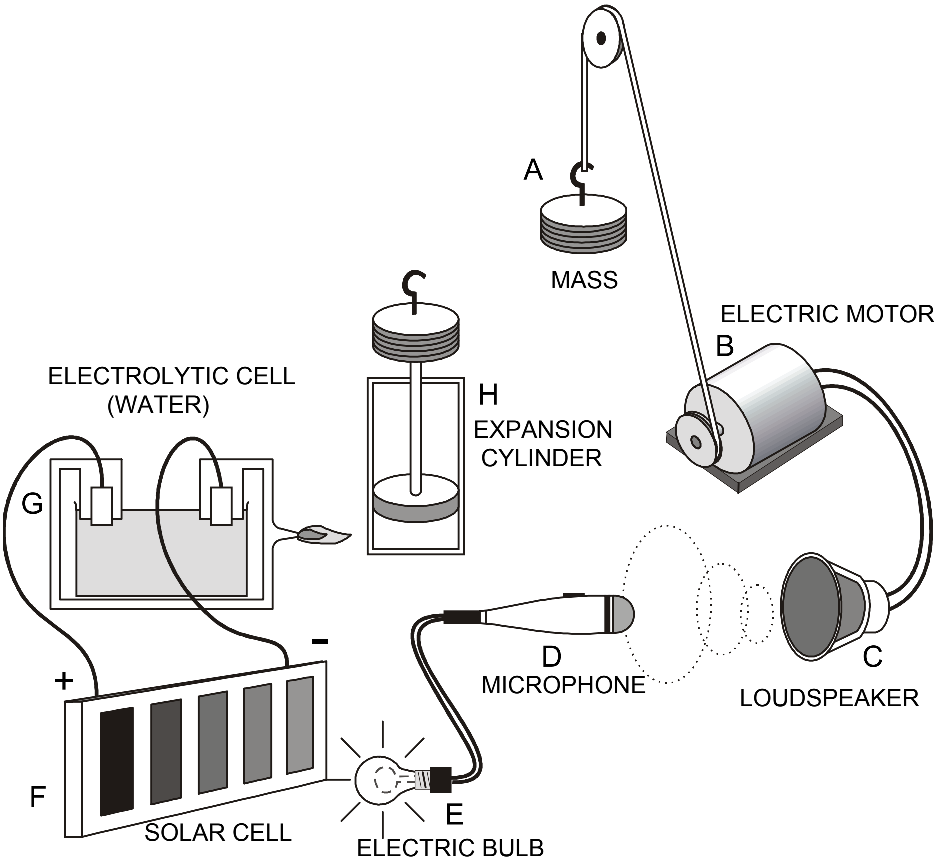
A hydroelectric power station is shown below as an outline diagram.



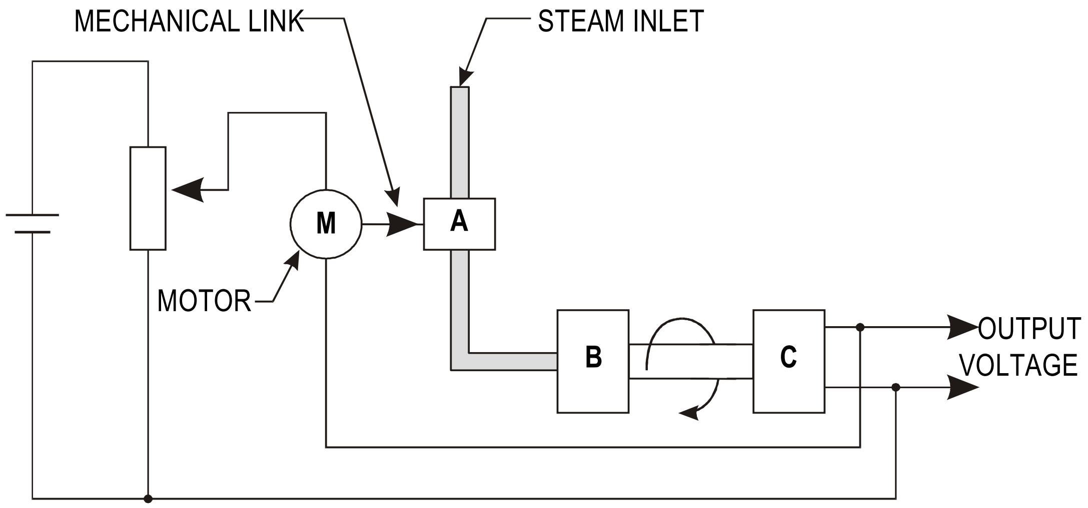
1. State the form of energy at each of the points A, B, C and D.

2. Complete the following statement to describe, using appropriate terminology, the energy changes that take place between stages A and D. *At A the water has ... energy, but as the water flows down the penstock …*

3. Identify the energy change at each of the points A-H indicated in the diagram below.



5. A diagrammatic representation of a simplified thermal power station is shown below.



(a) Identify the components A, B and C.

(b) Describe clearly how the system operates, making reference to any feedback loops.

(c) Draw a block diagram of the power station and identify, with an arrow, the feedback loop.

(d) List the energy changes that take place between the input and the output of the power station.

(e) Name two other commercial methods of producing electricity.

Energy 'losses' during transformations

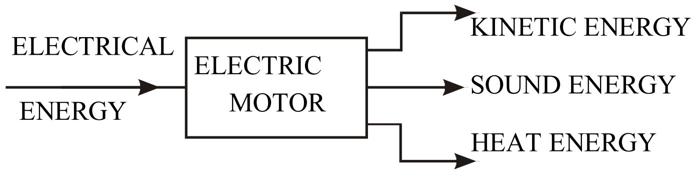
Although we have stated that energy cannot be destroyed and that the energy output from a system is equal to the energy input to the system, not all the energy in the system is used efficiently.

When an energy conversion takes place there is always an energy change that we do not desire - usually a loss in the form of heat, sound or friction from the moving parts of a mechanism.

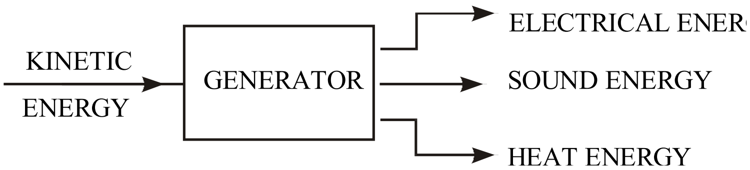
If we look at the simple energy conversions from earlier we can expand the system diagrams to also show the waste energy or energy losses.

Example 1
A light bulb converts electrical energy to light energy but it also produces heat energy.

Example 2
An electric motor converts electrical energy to produce kinetic energy along with sound energy and heat energy.



Example 3
An electric generator converts kinetic energy to produce electrical energy along with sound energy and heat energy.



Assignments: energy losses in a system

A windmill used for generating electricity can have the generator in either of two positions. It can be as shown in figure (a), located at the top and connected directly to the rotating vanes. Alternatively, it can be at ground level, connected by shafts and gears to the rotating vanes, as shown in figure (b).

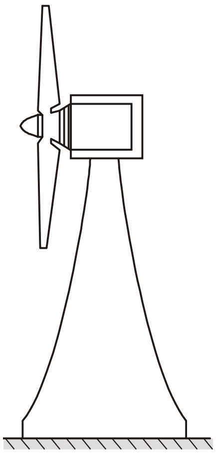


Figure (a)

1. List the energy conversions that take place when a windmill is operating.

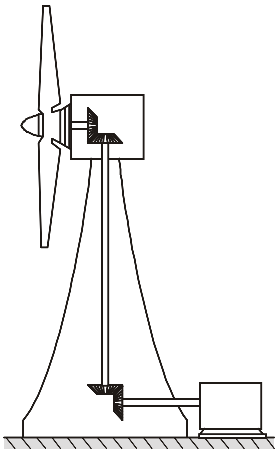
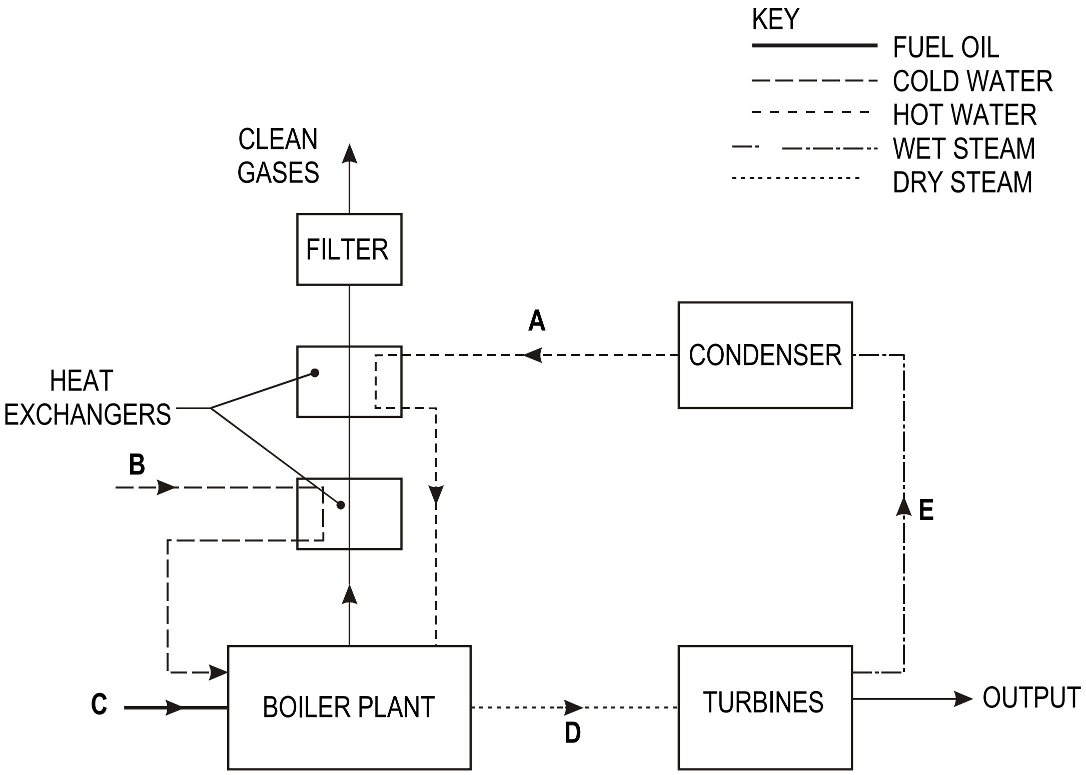


Figure (b)

2. The system shown in figure (b) does not produce as much electricity as the system in figure (a). Describe any energy losses in the system.

3. The diagram below shows sub-systems of a power station.



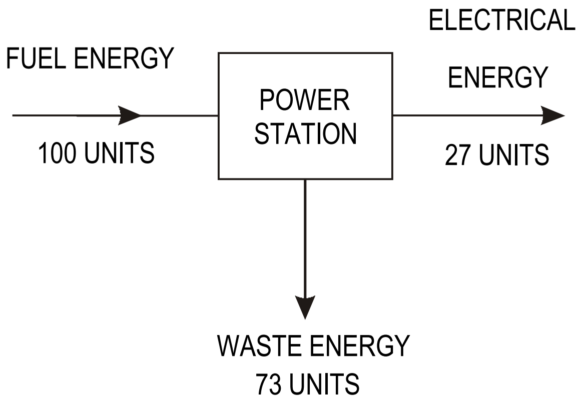
(a) Use the key to identify the fluids at points A, B, C, D, and E.

(b) Describe how the power station operates.

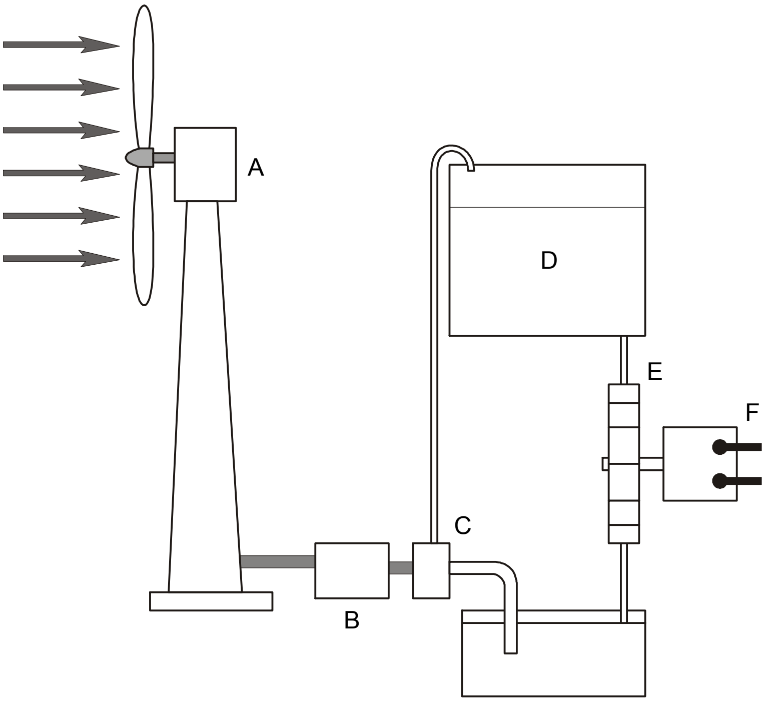
(c) What is the purpose of the heat exchangers?

(d) From the information given below, calculate the overall efficiency of the power station.

Efficiency = Electrical Energy / Fuel Energy x 100%



4. The diagram below shows a method of using the energy from wind.
   (a) Identify the forms of energy at points A (wind vane), B (generator), C (pump), D (water tank), E (water wheel) and F (generator).



   (b) Describe the energy changes taking place within the system.

   (c) Identify and describe any energy losses within the system at points A, B,C, D, E and F.

Calculating Energy Transfers

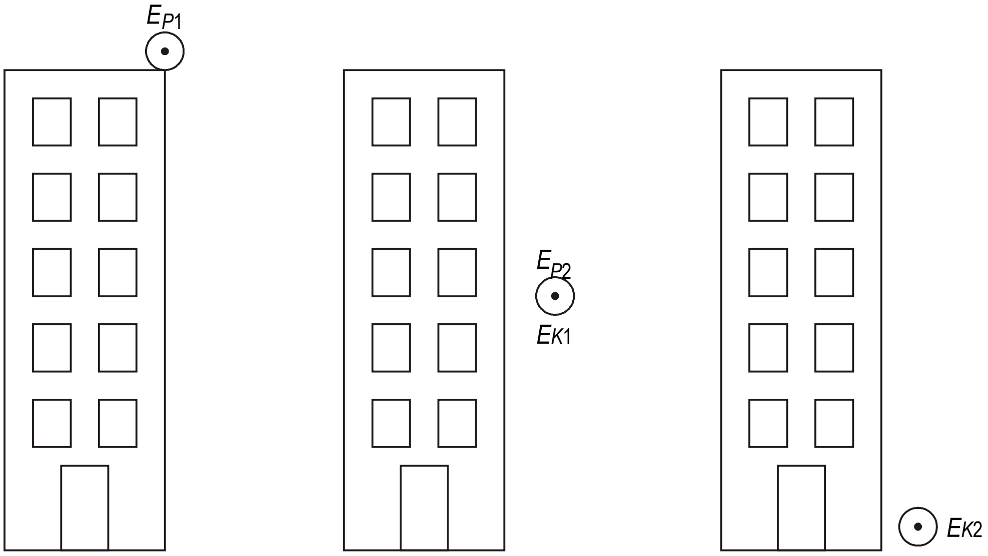
It has already been stated that energy cannot be created or destroyed: it can only be made to change form.

During an energy transformation, therefore, the total energy contained within any *closed system* must remain constant.

Knowing the total amount of energy at the start (or end) of any energy transformation
tells us the total energy at any given time during the transformation.

Example: energy transfer

Consider a ball that is released from a high building.



When the ball is at the top of the building, it has gravitational potential energy (E_{P1}).

The total energy, $E = E_{P1}$

When the ball is released, it falls and some of the potential energy (E_{P2}) is converted into kinetic energy E_{K1}. The total amount of energy (E) the ball possesses at this time is equal to the potential energy plus the kinetic energy.

Total energy $E = (E_{P2} + E_{K1}) = E_{P1}$

Just as the ball hits the ground, it no longer has any potential energy; all the potential energy E_{P1} has been converted into kinetic energy E_{K2}. The total amount of energy consists of the kinetic energy alone.

Total energy $E = E_{K2} = (E_{P2} + E_{K1}) = E_{P1}$

Worked example: transfer of energy (potential to kinetic)
A body of mass 30 kg falls freely from a height of 20 metres. Find its final velocity and kinetic energy at impact.

First calculate the initial potential energy.

$E_P = mgh$

$= 30 \times 9.81 \times 20$

$= 5.88$ kJ

This potential energy is converted or transferred into kinetic energy, which means that the kinetic energy at impact is equal to 5.9 kJ.

To calculate the final velocity of the body we begin by taking $E_K = 5.9$ kJ.

$E_K = \frac{1}{2}mv^2$

$5.88 \times 10^3 = \frac{1}{2} \times 30 \times v^2$

$v^2 = 392.4$

$v = 19.8$ m/s

This type of calculation can be completed for any type of energy conversion: knowing the total energy at any given time (start, end, middle, etc.) tells us the total amount of energy at all other given times.

Assignments: calculating the transfer of energy

1. A 5 kg mass is raised steadily through a height of 2 m. What work is done and what is the body's potential energy relative to the start?

2. A body of mass 30 kg is projected vertically upwards with an initial velocity of 20 m/s. What is the initial kinetic energy of the body and to what height will it rise?

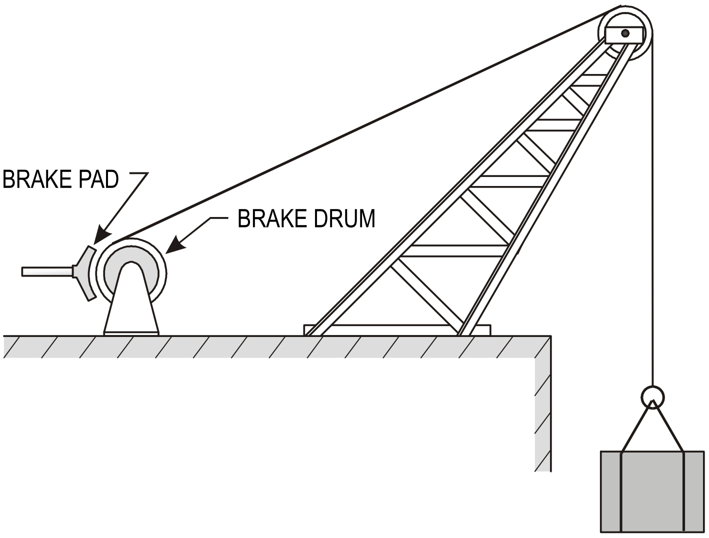
3. A mass of 20 kg is allowed to fall freely from a certain height above a datum. When the body is 16 m above the datum, it possesses a total energy of 3,531 J. What is the starting height of the object?

4. In a stamping machine, the die has a mass of 35 kg and falls through a height of 2 m on to a metal block. If the depth of indentation is 10 mm, find the average stamping force. Assume no rebound.

5. A boy stands on a skateboard at the top of a steep hill that has a height of 500 m and allows gravity to increase his speed all the way to the bottom of the hill. If the boy has a mass of 60 kg, calculate his potential and kinetic energy at the top, middle and bottom of the hill. (Ignore friction or any other resistance.)

6. A derrick is used to lower containers into the hold of a ship as shown in the diagram below. The speed at which the containers are lowered is controlled by a brake pad pushing against the side of a brake drum.

   The derrick is used to lower 1 metric tonne containers at a steady speed.



(a) Calculate the potential energy lost by the containers as they are lowered from a height of 50m.

(b) Assuming all this energy is converted into heat energy at the brake drum, use the following data to calculate the change in temperature of the drum.

Specific heat capacity of drum = 400 J/kgK
Mass of brake drum = 20 kg

7. An electric kettle takes 5 minutes to boil some water. The original temperature of the water is 20°C and the kettle contains 2 litres of water. Calculate how much electrical current is used by the kettle from a 230 volt mains supply. (The specific heat capacity of water is 4200 J/kgK.)

Energy Efficiency

It was stated earlier that it was very important to try and conserve energy and to waste as little as possible. It is possible to look at how well an energy system is operating by calculating the efficiency of the system.

Calculating efficiency

The efficiency of an energy transformation is a measure of how much of the input energy appears as useful output energy.

The efficiency of any system can be calculated using the equation:

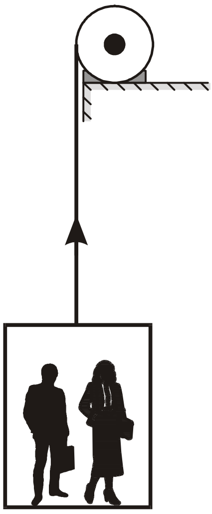
$$\textbf{Efficiency, } \eta = \frac{\textbf{Useful energy output}}{\textbf{Total energy input}}$$

$$\eta = \frac{E_{out}}{E_{in}}$$

Note: h is the ratio of output to input energy. This can never be greater than one. In order to convert h to a percentage, the efficiency, h, is multiplied by 100.

Worked example: efficiency

An electric lift rated at 110 V, 30 A raises a 700 kg load a height of 20 m in two minutes.



By considering the electrical energy input and the potential energy gained by the mass, determine the percentage efficiency of this energy transformation.

Energy into the system is electrical:

$E_e = ItV$

$= 30 \times 120 \times 110$

$= 396$ kJ

Potential energy gained is calculated as follows.

$E_P = mgh$

$= 700 \times 9.81 \times 20$

$= 137.3$ kJ

$$\text{Percentage Efficiency} = \frac{\text{Useful Energy Output}}{\text{Total Energy Input}} \times 100\%$$

$$= \frac{137.3}{396} \times 100\%$$

$$= 34.7\%$$

Assignments: efficiency

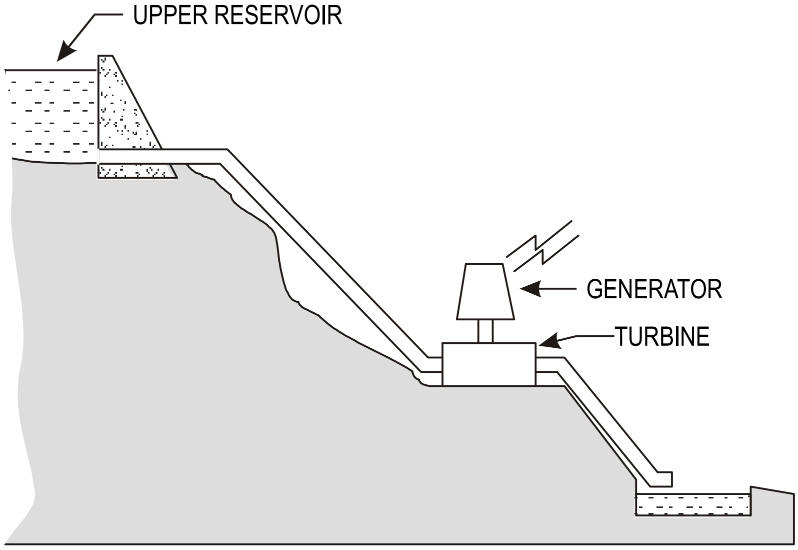
1. An electric kettle is rated at 240 V, 10 A. When switched on it takes three minutes to raise the temperature of 0.5 kg of water from 20°C to 100°C.

   Determine:
   (a) the electrical energy supplied in the three minutes

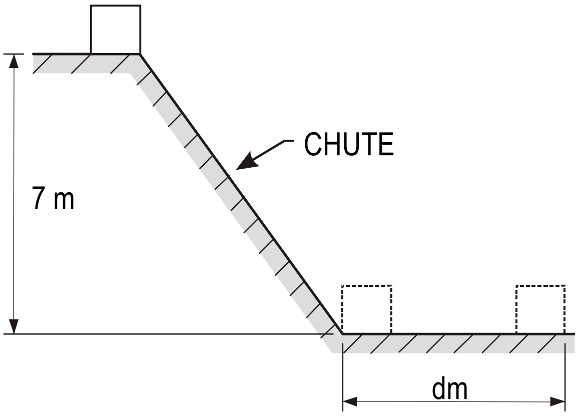
   (b) the heat energy required to raise the temperature of the water

(c) the efficiency of the kettle.

2. In a hydroelectric electricity generating station, water is allowed to flow downhill through a turbine, which is connected to a generator.



The water falls through a vertical height of 500 m at a rate of 5,000 kg/s. If the energy transfer is 65 per cent efficient, determine the amount of electrical energy produced per second.



3. Boxes in a factory are transferred from one floor to another using a chute system as shown above. The boxes start from rest at the top of the chute and during the decent there is a 40 per cent loss of energy. The boxes weigh 10 kg each.

   (a) Calculate the velocity of the boxes at the bottom of the chute.

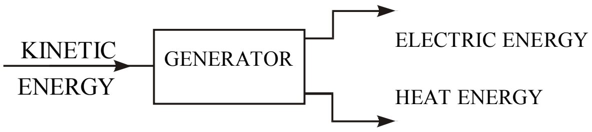
   (b) What is the distance *d* that each box will travel along the bottom floor before coming to rest if the frictional force opposing the motion of each package is 25 per cent of its weight?

Energy audits

It has already been stated that energy cannot be created or destroyed: it can only be made to change form.

During an energy transformation, all the energy going IN to the system must come OUT and appear as other forms. It is not possible to *destroy* energy: it must go somewhere!

Unfortunately, not all of the energy being put into a system appears as *useful* energy at the output. For example, a generator is designed to convert kinetic energy into electrical energy; however, due to the frictional forces, some heat energy will also be produced.



Since this heat energy is *useless* in terms of generating electricity, it is sometimes referred to as *waste* energy or (confusingly) as *lost* energy.

Even systems that are designed to produce heat will have some energy losses. For example, the element of a kettle is designed to heat up water, but not all of the energy will go into heating up the water. Some of the energy is used to heat up the kettle; some heat will be 'lost' to the room, etc.

Since we know, however, that the total energy in any closed system must be constant, we can still carry out meaningful calculations if we remember to take all types of input and output energy into account.

In the generator example above:

- the input energy is in the form of kinetic energy (E_K)
- the total output energy will be electrical energy plus the heat energy ($E_e + E_h$).

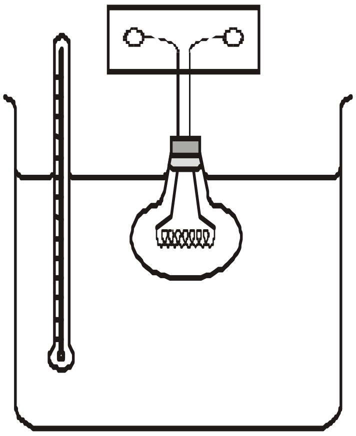
Hence, through conservation of energy, $E_K = E_e + E_h$

In order to ensure that we have taken all energies into account, it is useful to carry out an energy audit.

An energy audit is a list of all the energies coming IN and going OUT of a system. The total for the energies IN must be the same as the totals for the energies OUT.

Worked example

In order to estimate the efficiency of an electric light bulb, the bulb is immersed into a beaker of water as shown.



Assuming all the heat energy generated by the bulb is transferred to the water, use the data provided to calculate the efficiency of the light bulb as a light energy producer. Calculate also the amount of waste energy.

Data

Power supply = 12 V

Current drawn by bulb = 5 A

Volume of water in beaker = 0.5 litres

Initial temperature of water = 18 °C

Temperature of water after 10 minutes = 30 °C

Energy IN to the system is electrical (E_e)

$$\begin{aligned} E_e &= ItV \\ &= 5 \times 600 \times 12 \\ &= 36{,}000 \text{ J} \\ &= 36 \text{ kJ} \end{aligned}$$

Energy OUT of the system is light (E_l) and heat (E_h).

$$
\begin{aligned}
E_h &= mc\Delta T \\
&= 0.5 \times 4200 \times 12 \\
&= 25{,}200 \text{ J} \\
&= 25.2 \text{ kJ}
\end{aligned}
$$

Energy OUT = Energy IN

Energy IN = 36 kJ

Energy OUT = E_h + E_l = 25.2 kJ + E_l

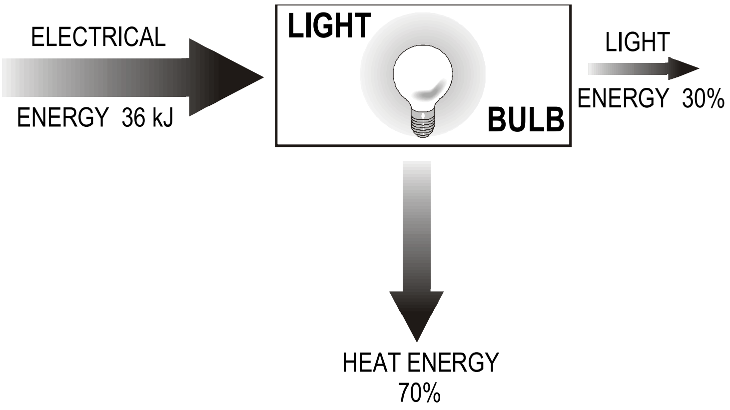
Therefore 25.2 + E_l = 36 kJ

El = 36 - 25.2 = 10.8 kJ

$$
\begin{aligned}
\text{Efficiency} &= \frac{\text{Energy out}}{\text{Energy in}} \\
&= \frac{10.8}{36} \text{ x } 100\% \\
&= 30\%
\end{aligned}
$$

Waste energy (heat energy) 70% of input = 25.2 kJ

This can be represented by a systems diagram.



Assignments - energy audits

1. A deep fat fryer uses 2 kJ of electrical energy per second. It can raise the temperature of 1.5 kg of cooking oil from 20 °C to 80 °C in six minutes. If the specific heat capacity of the oil is 2400 J/kgK, calculate the heat energy taken in by the oil every second and hence the efficiency of the fryer.

2. When full, a container of water holds 1.5 litres of water. The initial temperature of the cold water is 20 °C. A heater that operates from a 240 V supply draws a current of 8 A and has an efficiency of 75 per cent. Determine how long it will take to heat the container of water to 90 °C.

3. A lift is used to raise a mass of 200 kg to a height of 10 m in two minutes. If the lift motor produces 12 MJ of energy in one hour, how efficient is the lift?

4. A vending machine, which dispenses hot drinks, heats one cupful of water (0.15 kg) from 30 °C to 90 °C. The heating element operates from a 240 volt supply and has a resistance of 12 ohms.
   (a) Calculate the current drawn by the heating element.

   (b) Calculate the heat energy transferred to the water.

(c) Calculate the time taken to heat the water if the system is 100 per cent efficient.

(d) Calculate the percentage of energy lost if it actually takes 12 seconds to heat the water.

(e) Draw a system diagram showing the input to and outputs from the system. Include the percentages.