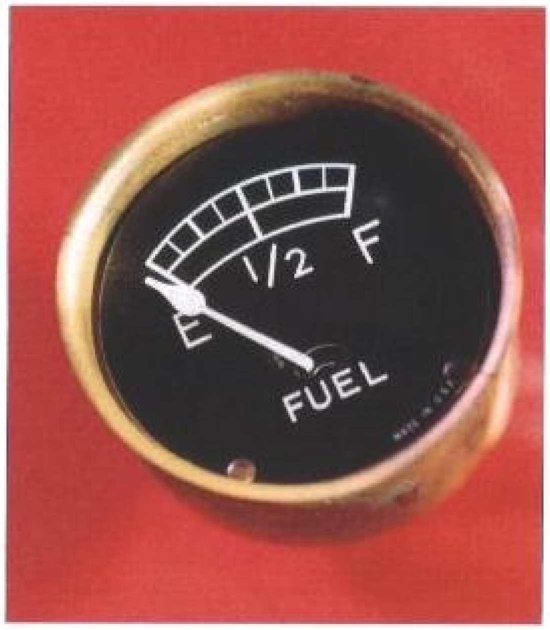
6 Energy, work and power

Energy

If you own a car, it will not move without fuel. At present this fuel could be petrol, or alcohol or diesel fuel. In the past the fuel could, just possibly, have been coal; and in the future it could be hydrogen, or electricity stored in a battery. But whatever fuel you use, you are buying something with the ability to make that car move. This stored ability is known as potential energy.

A clock needs energy to make the hands move, and this energy can be stored in a spring that you wind up with a key, in an electrical battery, or in weights that are raised up.



Fuel, whatever form it comes in, gives a car the ability to move.

These electric streetcars take electrical energy from the overhead wire and convert it into kinetic energy.

Stored, or hidden, energy is called **potential energy** (p.e.). *In this context 'potential' does not mean 'with qualities that may lead to future success'* (as in 'potential film star') but rather 'containing power'. If a spring is stretched, the spring will have potential energy. If a load is raised above the ground, it will have **gravitational potential energy**.

If the spring is released or the load moves back to the ground, the stored potential energy is transferred to movement energy, which is called **kinetic energy** (k.e.).

In all of the examples above, the potential energy can be used to make an object move, and hence give it kinetic energy. Kinetic energy can also be turned into potential energy, and this can be seen most clearly in the action of a pendulum, where at each end of its swing the pendulum has a maximum amount of gravitational potential energy, and at the middle of its swing where some of the potential energy has been used (the pendulum is lower down) and turned into kinetic energy (the pendulum is moving fastest).

Gravitational potential energy can be calculated using the formula:

gravitational potential energy = mass × gravitational field strength × height

$$\text{p.e.} = m\,g\,h$$

p.e. = gravitational potential energy in joules (J)

m = mass in kilograms (kg)

g = gravitational field strength of 10 N/kg

h = height in metres (m)

WORKED EXAMPLE

A skier has a mass of 70 kg and travels up in a ski lift a vertical height of 300 m. Calculate the change in the skier's gravitational potential energy.

Write down the formula:	p.e. = $m\,g\,h$
Substitute values for m, g and h:	p.e. = $70 \times 10 \times 300$
Work out the answer and write down the unit:	p.e. = 210 000 J or 210 kJ

KINETIC ENERGY

The kinetic energy of an object depends on its mass and its speed. The kinetic energy can be calculated using the following formula:

kinetic energy = $\frac{1}{2}$ × mass × speed^2

$$\text{k.e.} = \tfrac{1}{2}mv^2$$

k.e. = kinetic energy in joules (J)

m = mass in kilograms (kg)

v = speed in m/s

WORKED EXAMPLE

An ice skater has a mass of 50 kg and travels at a speed of 5 m/s. Calculate the ice-skater's kinetic energy.

Write down the formula:	k.e. = $\frac{1}{2}mv^2$
Substitute the values for m and v:	k.e. = $\frac{1}{2} \times 50 \times 5 \times 5$
Work out the answer and write down the unit:	k.e. = 625 J

A* EXTRA

- As a skier skis down a mountain the loss in potential energy should equal the gain in kinetic energy (assuming no other energy transfers take place, as a result of friction, for example). Calculations can then be performed using:
  Loss in p.e. = Gain in k.e.
  ($mgh = \frac{1}{2}mv^2$)

POTENTIAL ENERGY

As can be seen in the pendulum, energy can either be stored or can be seen in motion in some way.

The different types of stored energy are all forms of potential energy. Here are some important examples:

Gravitational energy or gravitational potential energy

This is energy stored by an object being raised up in a gravitational field, for example, a ball on top of a hill.

Strain energy

The word 'strain' means stretched. Strain energy can be stored in springs (in clocks, for example) and in bows when they are drawn back before the arrow is released.

Chemical energy

In any object the atoms are held together by forces that are called bonds. These bonds behave like springs. In some materials, such as fuels and explosives, the bonds are forced to be shorter or longer than they wish. This stores energy in the bonds that can be released by breaking up the structure of the fuel or the explosive.

A battery is ready to turn chemical energy into electrical energy, and a rechargeable battery is so called because every time that it is discharged it can be recharged by forcing electricity through it backwards. The electrical energy that is fed is stored as chemical energy.

Nuclear energy

The energy in a nucleus of an atom is stored in the extremely strong bonds between the particles of which the nucleus is made. Some of this energy can be released, in the case of uranium (and a couple of other metals) by splitting the nucleus of the atom into two smaller nuclei. This can be done either slowly and for good purposes in a nuclear power station, or very rapidly in an atomic bomb.

Here are some other important types of energy. They are actually all different sorts of kinetic energy, but this is far from obvious in some cases:

If people just use the words 'kinetic energy', then they are referring to the energy of a visible moving object with k.e. = $\frac{1}{2}mv^2$.

Internal energy

This is contained within an object and makes the difference between the object being hot or cold. As we see on page 56, a hot object contains atoms that are moving fast or vibrating strongly.

Electrical energy

Electrical currents carry electrical energy from one place to another. Electrical energy can easily be turned into kinetic energy in a motor or internal energy in a resistor, perhaps used as a heater.

Light energy

Light carries light energy as it travels. This will be turned into internal energy if it strikes most objects, but it can be made to generate electrical energy if it hits a solar panel.

Sound waves

These carry a very small amount of energy from the source of the noise. (Do not confuse the 2000 W of electricity consumed by the equipment of a rock group performing on stage, with the 100 W of sound being emitted by the loudspeakers. The ear is extremely good at detecting sound.)

CONVERSION OF ENERGY

We have already explained how kinetic energy and gravitational potential energy can be converted backwards and forwards. In fact any type of energy can be converted into any other type of energy. In some cases this conversion can be done efficiently, such as between kinetic energy and electrical energy. In other cases the conversion is inefficient, the most notorious example of this being the power station where only between 40 and 60 per cent of the internal energy in the fuel is converted to electricity.

In every case of conversion of energy, some of the energy is converted to internal energy. The light bulb creating light energy from electrical energy gets hot; the electric motor turning electrical energy to kinetic energy gets hot; the diesel engine using chemical energy gets hot, the battery that is being charged gets hot. Even the pendulum eventually stops swinging because the movement of the pendulum through the air heats up the air.

CONSERVATION OF ENERGY

Don't confuse the words **conversion** and **conservation.**

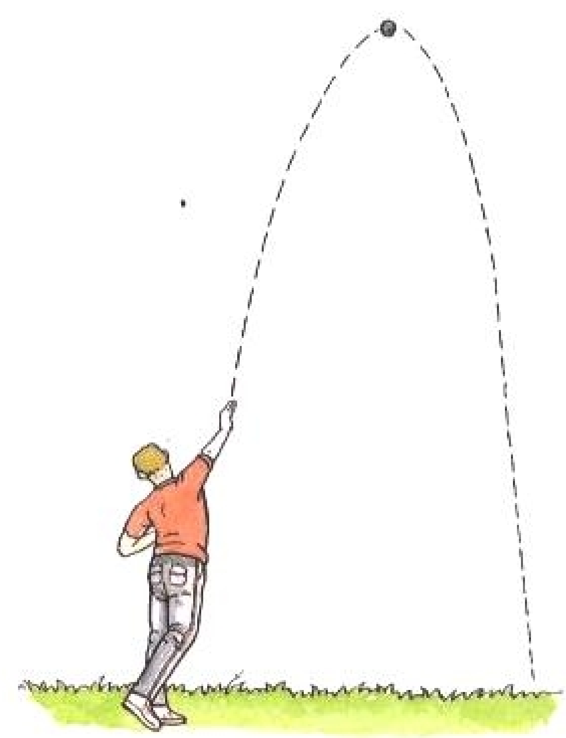
Energy cannot be created or destroyed. You may need to describe how energy is transferred in different situations, but remember that total energy is always conserved: the total energy at the start and at the end must have the same total value.

So you must account for all of the energy, and that includes the internal energy that will have been created, as well perhaps as light or sound.

For example, the tram takes electrical energy and converts it mainly into kinetic energy, but also into internal energy and sound.

You can use the principle of the conservation of energy to calculate what happens when kinetic energy and potential energy are converted from either one to the other.

So long as negligible energy is lost in the conversion, $mgh = \frac{1}{2}mv^2$.



The kinetic energy given to the stone when it is thrown is transferred to potential energy as it gains height and slows down. At the top of its flight practically all the kinetic energy will have been converted into gravitational potential energy. A small amount of energy will have been lost due to friction between the stone and the air.

WORKED EXAMPLE

If a stone thrown vertically upwards reaches a height of 6 m above the hand of the thrower, with what speed was it thrown?

The decrease in k.e. of the stone as it rises = the increase in the p.e. of the stone.

As the final k.e. of the stone = 0, the initial k.e. of the stone = the increase in the p.e. of the stone at the top of its flight.

Write down the formula:	$\frac{1}{2}mv^2 = mgh$
Note that the mass has cancelled out; the mass does not matter in this case.	$\frac{1}{2}v^2 = gh$
Substitute values for g and h:	$v^2 = gh \times 2$
	$= 10 \times 6 \times 2$
	$= 120$
Work out the answer and write down the unit:	$v = \sqrt{120}$
	$= 10.95$ m/s

Energy resources

Most of the energy we use is obtained from **fossil fuels** – coal, oil and natural gas.

Once supplies of these fuels have been used up they cannot be replaced – they are **non-renewable**.

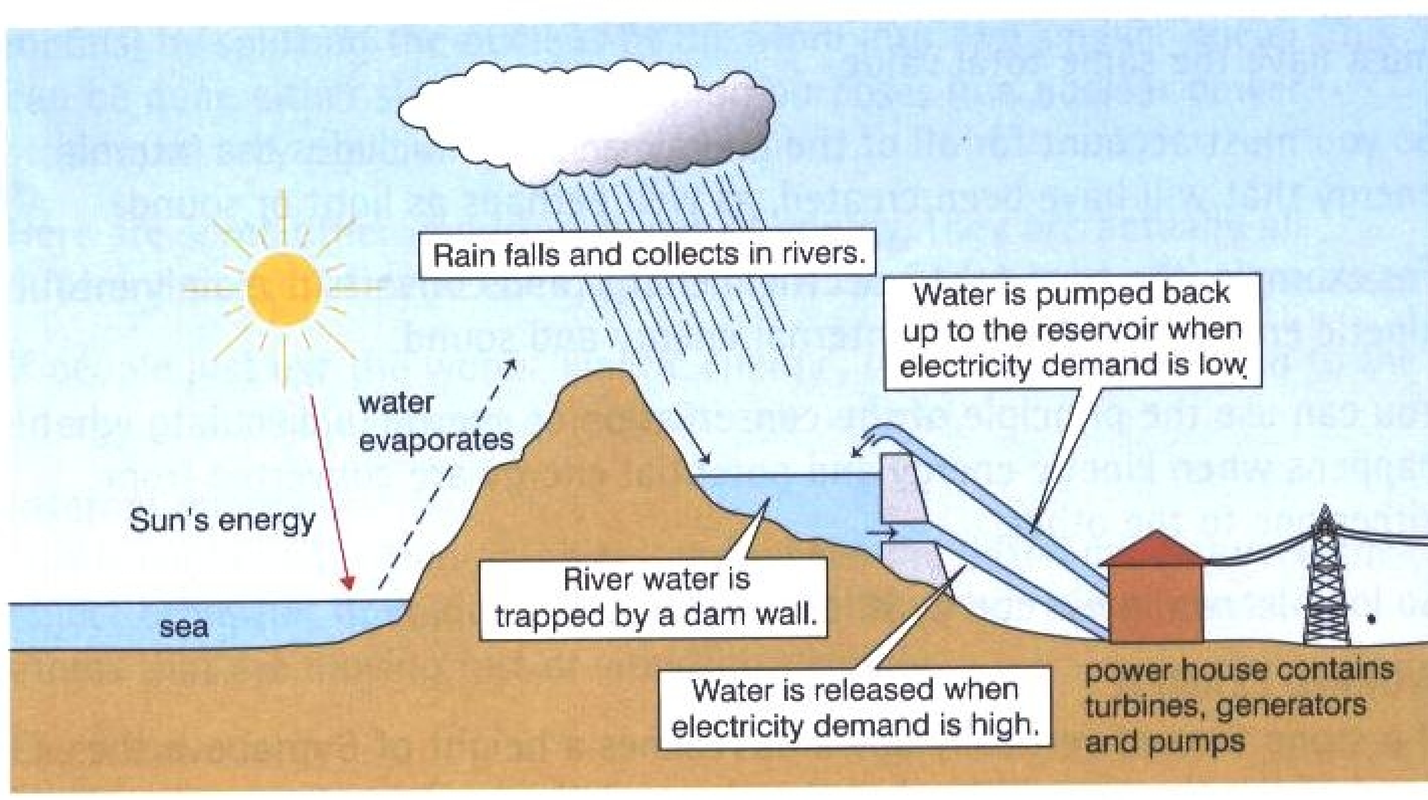
At current levels of use, oil and gas supplies will last for about another 40 years, and coal supplies for about a further 300 years. The development of **renewable** sources of energy is therefore becoming increasingly important.

On a windy day this wind turbine generates 2000 kW of electricity. That's enough for 1200 families.

The **wind** is used to turn windmill-like turbines which generate electricity directly from the rotating motion of their blades. Modern wind turbines are very efficient but you would need several thousand to equal the generating capacity of a modern fossil-fuel power station.

The motion of **waves** can be used to move large floats and generate electricity. A very large number of floats is needed to produce a significant amount of electricity.

Dams on tidal estuaries trap the water at high tide. When the water is allowed to flow back at low tide, it can turn turbines to drive electrical generators. This obviously limits the use of the estuary.



A 'pumped storage' hydroelectric power station.

Dams can be used to store **water** which is allowed to fall in a controlled way that generates electricity. This is particularly useful in mountainous regions for generating **hydroelectric power**. When demand for electricity is low, spare electricity from a nuclear power station (which has to be run continuously) can be used to pump water back up into the high reservoir for use in times of high demand.

Plants use energy from the Sun in photosynthesis. Plant material can then be used as a **biomass fuel** – either directly by burning it or indirectly. A good example of indirect use is to ferment sugar cane to make ethanol, which is then used as an alternative to petrol. Waste plant material can be used in 'biodigesters' to produce methane gas. The methane is then used as a fuel.

Geothermal power is obtained using the heat of the Earth. In certain parts of the world, water forms hot springs which can be used directly for heating. Water can also be pumped deep into the ground to be heated.

SUN – NUCLEAR FUSION

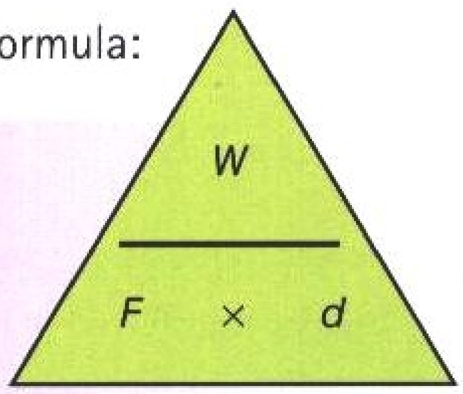
Solar power is energy from the Sun, which itself is powered by nuclear fusion reactions (where the small nuclei of hydrogen atoms join to make larger nuclei that are, in fact, helium and an enormous amount of energy is released.

The Sun's energy is trapped by solar panels and transferred into electrical energy or, as with domestic solar panels, is used to heat water. The cost of installing solar panels is high, but in sunny countries solar power is of increasing importance.

Work

Work is done when the application of a force results in movement. Work can only be done if the object or system has energy. When work is done energy is transferred.

Work done can be calculated using the following formula:



work done = force × distance moved

$W = F\,d = \Delta E$

W = work done in joules (J)

F = force in newtons (N)

d = distance moved in the direction of the force in metres (m)

ΔE = energy, transferred in joules (J)

In this position the gymnast is not doing any work against his body weight – he is not moving (he will be doing work pumping blood around his body though).

DELTA NOTATION

We use the Greek letter Δ (delta) to stand for 'the change in'. For example, ΔE means 'the change in the energy'. When you are using ΔE in an equation, treat them as one symbol meaning 'the change in energy'; so don't even think of separating them.

WORKED EXAMPLES

1 A cyclist pedals along a flat road. She exerts a force of 60 N and travels 150 m. Calculate the work done by the cyclist.

Write down the formula:	$\Delta W = F\,d$
Substitute the values for F and d:	$\Delta W = 60 \times 150$
Work out the answer and write down the unit:	$\Delta W = 9000$ J

The gymnast is doing work. He is moving upwards against his weight. Energy is being transferred as he does the work.

2 A person does 3000 J of work in pushing a supermarket trolley 50 m across a level car park. What force was the person exerting on the trolley?

Write down the formula with F as the subject:	$F = \frac{\Delta W}{d}$
Substitute the values for ΔW and d:	$F = \frac{3000}{50}$
Work out the answer and write down the unit:	$F = 60$ N

Power

A powerful engine in a car can take you up a road to the top of a mountain more quickly than a less-powerful engine. Both engines can do the work, given enough time, but the powerful engine can do the work more quickly. In the same way, a powerful electric motor on a cooling fan will move the air in the room more quickly; and the 'powerfully built' athlete will, by transferring more kinetic energy to it as it is launched, throw the javelin further.

Power is defined as the rate of doing work or the rate of transferring energy. The more powerful a machine is, the quicker it does a fixed amount of work or transfers a fixed amount of energy.

Power can be calculated using the formula:

$$\text{power} = \frac{\text{work done}}{\text{time taken}} = \frac{\text{energy transfer}}{\text{time taken}}$$

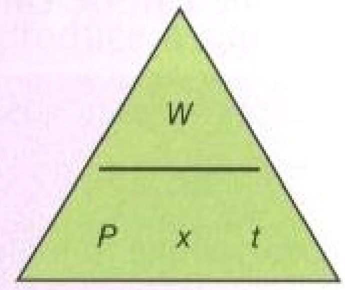
$$P = \frac{W}{t} \text{ or } P = \frac{E}{t}$$

P = power in joules per second or watts (W)

E = energy transferred in joules (J)

W = work done in joules (J)

t = time taken in seconds (s)

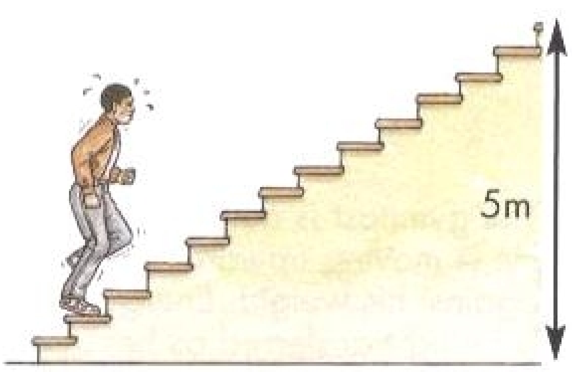


WORKED EXAMPLES

1 A crane lifts a 100 kg girder for a skyscraper by 20 m in 40 s. Hence it does 20 000 J of work in 40 seconds. Calculate its power over this time. Note: this calculation tells you the size of electric motor that the crane needs.

Write down the formula:	$P = \frac{W}{t}$
Substitute the values for W and t:	$P = \frac{20\,000}{40}$
Work out the answer and write down the unit:	$P = 500$ W

2 A student with a weight of 600 N runs up the flight of stairs shown in the diagram (left) in 4 seconds. Calculate the student's power.



The student is lifting his body against the force of gravity, which acts in a vertical direction. The distance measured must be in the direction of the force (that is, the vertical height).

Write down the formula for work done:	$W = F\,d$
Substitute the values for F and d:	$W = 600 \times 5 = 3000$ J
Write down the formula for power:	$P = \frac{W}{t}$
Substitute the values for W and t:	$P = \frac{3000}{4}$
Work out the answer and write down the unit	$= 750$ W