ENERGY

IDEAS YOU HAVE MET BEFORE:

WE CAN MEASURE HOW MUCH ENERGY IS TRANSFERRED AND HOW QUICKLY

- Energy can be stored and also transferred from one store to another. Energy changes are measured in joules (J) or kilojoules (kJ).
- The energy values of different foods can be compared.
- The power ratings of appliances are measured in watts (W) or kilowatts (kW).

TEMPERATURE AND ENERGY

- Temperature tells us how hot something is.
- When there is a difference in temperature between two objects, energy is transferred from the hotter object to the colder one.
- Energy transfer tends to reduce the temperature difference.

TRANSFER OF THERMAL ENERGY

- Thermal energy is transferred by conduction, convection and radiation.
- In conduction and convection energy is transferred by the movement of particles.
- Radiation is the only way energy can be transferred in a vacuum.

FOSSIL FUELS AND ALTERNATIVE ENERGY RESOURCES

- Fossil fuels are burnt to release the energy stored in them.
- Fossil fuels were formed over millions of years and supplies are running out.
- There are alternative energy resources which have advantages and disadvantages.

1

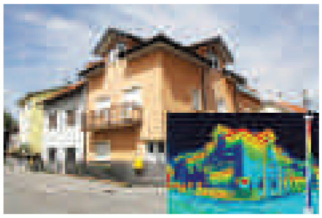
IN THIS CHAPTER YOU WILL FIND OUT ABOUT:

WHAT IS THE CONNECTION BETWEEN ENERGY TRANSFER AND POWER?

- Energy is transferred by heating, by electric current in a circuit, and when work is done by a force.
- We can measure the rate at which energy is being transferred or the rate at which work is done – this is called power.

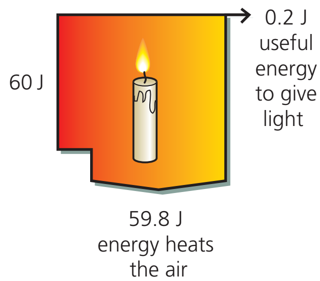
WHAT IS THE CONNECTION BETWEEN ENERGY CHANGES AND TEMPERATURE CHANGE?

- We can calculate the energy stored in or released from a system when its temperature changes.
- The rate of cooling of a building is affected by the thickness and the thermal conductivity of its walls. Insulation can be used to reduce the transfer of energy by conduction and convection.



HOW CAN WE MONITOR AND CONTROL THE TRANSFER OF ENERGY?

- Energy can be transferred usefully, stored or dissipated. The total amount of energy does not change. We can calculate the energy efficiency for any energy transfer. Some energy transfers are wasteful; we can try to reduce them.



WHAT IS THE ENVIRONMENTAL IMPACT OF DIFFERENT ENERGY RESOURCES?

- Fuels such as coal, oil, gas and nuclear fuel are not renewable. Supplies will run out.
- The use of fossil fuels is changing as more renewable energy resources are used for transport, electricity generation and heating.
- Most renewable resources do not generate a predictable (reliable) amount of electrical power.
- There are different environmental issues for each different energy resource.

Potential energy

Learning objectives:

- consider what happens when a spring is stretched
- describe what is meant by gravitational potential energy
- calculate the energy stored by an object raised above ground level.

KEY WORDS

energy transfer
elastic potential energy
gravitational potential energy
gravitational field strength

On Jupiter, gravity is three times stronger than on Earth. If the same mass was lifted to the same height on Earth and Jupiter, on Jupiter it would store three times the gravitational potential energy.

Stored energy

When a spring is stretched it stores energy. We call this potential energy. The stretched spring stores **elastic potential energy.** It stretches more if a greater force is applied, and returns to its original length when the force is removed.

Compressed springs are also used to store elastic potential energy, for example, to keep the batteries in position in a mobile phone.

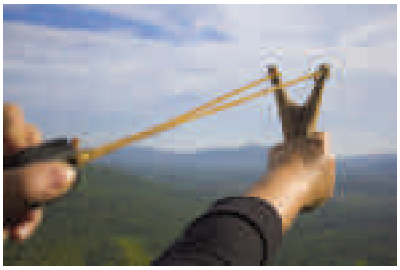


Figure 1.1 A stretched catapult stores elastic potential energy

1. **Imagine slowly stretching a rubber band. Describe what you would feel as you stretch it more.**
2. **Suggest what happens to the amount of energy stored in the spring inside a the toy in Figure 1.2 as the key is turned.**

Water stored behind a dam also stores potential energy. It is called **gravitational potential energy (GPE)**. The GPE stored by an object can be increased by moving it upwards. For example, you gain GPE by going up stairs.

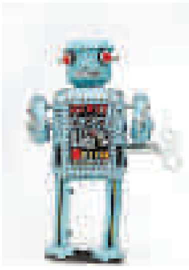


Figure 1.2 Turning the key twists a spring inside the toy. This stores elastic potential energy which can be transferred to kinetic energy

3. **An aircraft is flying horizontally at a height of 10 000 m. Explain whether its gravitational potential energy is increasing, decreasing or remaining constant.**

Calculating changes in gravitational potential energy

Tom lifts a box. The amount of gravitational potential energy gained by the box depends on:

- the mass of the box, m, in kilograms, kg
- the height Tom raises the box, h, in metres, m.

We can calculate the amount of gravitational potential energy gained (E_p) using the equation:

$E_p = mgh$

Figure 1.3 The stored gravitational potential energy of water held behind a dam can be transferred to kinetic energy if the water is released

where m is measured in kg, g is the **gravitational field strength** in N/kg and h is measured in m.

The pull of gravity on the box (its weight) is calculated from the equation:

weight = mass × gravitational field strength, $W = m \times g$

The gravitational field strength is the pull of gravity on each kilogram. The value of g is 10 N/kg at the Earth's surface. Changes in E_p are measured in joules (J).

Zack gains gravitational potential energy when he walks up some stairs (Figure 1.4). The E_p Zack gains can be calculated using $E_p = mgh$ where h is the vertical height he raises her body.

Zack then walks on a level floor. He does not gain or lose any gravitational potential energy now because his height above the floor does not change.

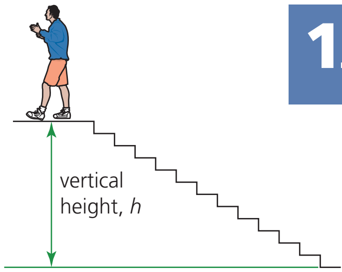


Figure 1.4 Vertical height, *h*

4 **Lars is a weight lifter. He lifts a mass of 300 kg through a height of 2 m. Calculate the gravitational energy gained by the weight.**

5 **Sian picks up a ball from the floor and holds it 2 m above the ground. The ball has a mass of 60 g. Calculate the gravitational potential energy gained by the ball.**

DID YOU KNOW?

A new pumped storage hydropower project in Chile will use solar power to pump water from the Pacific Ocean 600 metres above sea level to the top of a cliff. The total reservoir capacity of about 55 million cubic metres gives a maximum total energy stored of about 3.3×10^{14} J. However, the amount of water that can be pumped by solar power is only 45 cubic metres per day.

Calculating elastic potential energy

The amount of elastic potential energy stored in a spring can be increased by

- increasing the extension of the spring, *e*, in metres, m
- increasing the spring constant, *k*, in newtons per metre, N/m

We can calculate the elastic potential energy stored in a spring using the equation:

$$E_e = \frac{1}{2}ke^2$$

Example: Calculate the energy stored in a spring when it is extended by 6 cm. The spring constant is 150 N/m.

Answer: 6 cm = 0.06 m

$E_e = 0.5 \times 150\ \text{N/m} \times (0.06\ \text{m})^2$

$= 0.27$ J

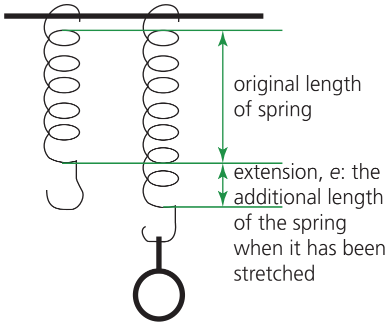


Figure 1.5 Extension of a spring

6 **Calculate the energy stored in a spring which has a spring constant of 300 N/m and is extended by 0.1 m.**

7 **A spring has a spring constant of 500 N/m. The original length of the spring is 20 cm. It is stretched to a length of 25 cm. Calculate the energy stored in the spring.**

8 **A spring stores 12 J when it is stretched by 16 cm. Calculate the spring constant.**

9 **A stretched spring has a total length of 20 cm and a spring constant of 200 N/m. It is storing 0.25 J in its elastic potential energy store. Determine the unstretched length of the spring.**

MATHS

Always put values into an equation using SI units (time in seconds, distance in metres etc.). If the values in the question are not in SI units, you have to change the values to SI units before starting the calculation.

REMEMBER!

Use the vertical height when finding the change in an object's height.

Investigating kinetic energy

Learning objectives:

- describe how the kinetic energy store of an object changes as its speed changes
- calculate kinetic energy
- consider how energy is transferred.

KEY WORDS

energy store
gravitational potential energy
kinetic energy

Formula 1 racing cars reach speeds of 300 km/h or more. This means the kinetic energy store is very large. If the car is involved in a collision this energy store may be reduced to zero very rapidly, causing lots of damage.

Kinetic energy

Energy must be transferred to make things move. A car uses energy from petrol or diesel to move. The greater its mass and the faster it goes, the more energy is transferred the car's **kinetic energy** store and the higher the rate at which fuel is used.

Figure 1.6 The engine applies a force that transfers energy from a store in the fuel to a store of kinetic energy

1. **Why does an adult have more kinetic energy than a child when running at the same speed?**
2. **What is the 'fuel' for a child running around a playground?**

Calculating kinetic energy

The kinetic energy store of a moving object can be increased by:

- increasing the mass of the object, m in kg
- increasing its speed, v in m/s.

We can calculate the kinetic energy (E_K) of an object by using this equation:

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

Example: A car of mass 1600 kg is travelling at a steady speed of 10 m/s.

a Calculate the car's kinetic energy.

b The car's speed increases to 20 m/s. Calculate how much its kinetic energy store increases.

a E_k at 10 m/s $= \frac{1}{2}mv^2 = \frac{1}{2} \times 1600\text{ kg} \times 10^2$
$= \frac{1}{2} \times 1600\text{ kg} \times 100 = 80\,000$ J.

b E_k at 20 m/s $= \frac{1}{2}mv^2 = \frac{1}{2} \times 1600 \times 20^2$
$= \frac{1}{2} \times 1600 \times 400 = 320\,000$ J.

The increase in the car's $E_k = 320\,000 - 80\,000 = 240\,000$ J.

Doubling the speed has increased the car's E_k by a factor of 4. Note that speed is squared in the equation for E_k.

DID YOU KNOW?

Hollywood star Idris Elba smashed an 88-year-old record by driving at an average speed of 180.361 mph over a measured mile across the Pendine Sands in Wales in May 2015. The award-winning star beat the 1927 record set by Sir Malcolm Campbell.

3 a Meena is riding her bicycle at 2 m/s. She has a mass of 50 kg. Calculate her kinetic energy.

b Meena doubles her speed. What happens to her kinetic energy?

We can convert from km/h to m/s by

- multiplying by 1000 (there are 1000 m in a km)
- dividing by 3600 (there are 3600 seconds in an hour).

For example, 300 km/h = $\frac{(300 \times 1000 \text{ m})}{3600 \text{ s}}$ = 83.3 m/s

4 A car of mass 1200 kg increases its speed from 10 m/s to 30 m/s. By how much has its E_k increased?

5 Change a speed of 240 km/h to m/s.

REMEMBER!

Take care when calculating kinetic energy using $\frac{1}{2}mv^2$. Only the speed is squared. Start by squaring the speed.

Dropping a ball

If a ball is held 2 m above the ground it has **gravitational potential energy**, relative to a ball on the ground. Allowing it to fall transfers energy from a gravitational potential energy store to a kinetic energy store as it drops. As the ball bounces back up, the kinetic **energy store** decreases as energy is transferred back to the gravitational potential energy store. The ball does not return to its original height though, because some of the energy is transferred to the surroundings by heating.

KEY INFORMATION

Energy is transferred from one energy store to another. Before the ball is dropped it has a store of gravitational potential energy. As the ball falls, energy is transferred to a store of kinetic energy.

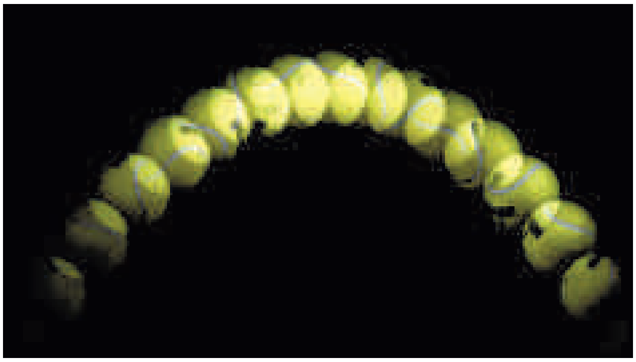


Figure 1.7 Time-lapse photo showing the path of a ball that is dropped and bounces off a surface

6 At what point does the ball in the photo

a have most gravitational potential energy?

b have most kinetic energy?

7 Describe the changes to energy stores when a ball is thrown upwards.

8 A ball with a mass of 2 kg is dropped from a height of 20 m. Assuming all of the GPE transfers to E_k, calculate the speed of the ball as it hits the ground (g = 10 N/kg).

Work done and energy transfer

Learning objectives:

- understand what is meant by work done
- explain the relationship between work done and force applied
- identify the transfers between energy stores when work is done against friction.

KEY WORDS

energy transfer
force
kinetic energy
work

People on a roller coaster experience rapid energy changes and experience G-forces similar to those experienced by astronauts.

Work done by a force

In science, **work** is only done by a **force** when an object **moves.**

More work is done when

- the force is bigger
- the object moves further – its displacement is bigger.

Sam's car has broken down. He tries to push it but the car does not move. He is not doing any work though. Work is only done when a force *moves*. Sam gets some friends to help. Together, they can push with a larger force and the car moves. They are all doing work.

1 **What affects the amount of work done by a force?**

2 **What force moves when someone jumps off a wall?**

REMEMBER!

Work is only done when a force causes a displacement of the object (that is, movement along the line of action of the force).

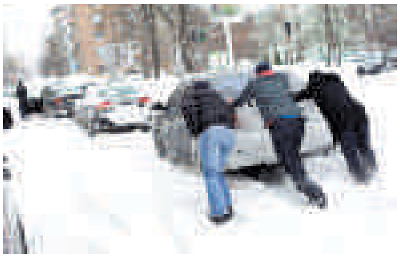


Figure 1.8 These men are doing work

Calculating work done

The equation that links work, force and distance is:

Work done = force × distance moved along the line of action of the force

where work, W, is in joules, force, F, is in newtons and distance, s, is in metres.

$W = F \times s$

When a person climbs stairs or jumps in the air the force moved is their weight.

Example: Dev climbs a flight of stairs rising a vertical height of 5 m. He weighs 600 N. Calculate the work Dev does by lifting his weight up the stairs.

Work done = force × distance moved along the line of action of the force.

Work done = 600 N × 5 m = 3000 J.

3 **A gymnast (Figure 1.9) weighs 400 N. How much work does she do when she jumps from the ground onto a beam 1.5 m above the ground?**

ADVICE

One joule of work is done when a force of one newton causes a displacement of one metre.

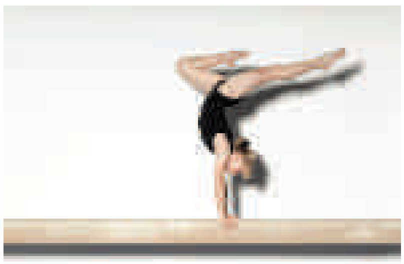


Figure 1.9 The gymnast does work when she jumps up onto the beam from the floor

4 **Mia is holding a 20 N weight without moving. How much work is she doing?**

5 **Amrita does 300 J of work in lifting a box with a force of 200 N. How high does she lift it?**

Energy calculations

When work is done on an object there can also be a change in its **kinetic energy**. We can use this to calculate the force needed to stop a car when the distance it travels while coming to rest is known.

Example: A car of mass 1000 kg does an emergency stop when travelling at 15 m/s. It stops in a distance of 20 m. Calculate the braking force.

$$E_k \text{ of car} = \frac{1}{2}mv^2$$

$$= \frac{1}{2} \times 1000 \text{ kg} \times (15 \text{ m/s})^2$$

$$= 112\,500 \text{ J}$$

Work has to be done to reduce the kinetic energy of the car and bring it to a stop. The force that does the work is the friction force between the brakes and the wheel. The work done by the braking force is 112 500 J.

$W = F \times s$, where F is the braking force and s is the distance moved during braking. We can rearrange this to make F the subject of the equation.

$$F = \frac{W}{s}$$

$$= \frac{112\,500 \text{ J}}{20 \text{ m}}$$

$$= 5625 \text{ N}$$

Work done against the frictional forces acting on an object causes a rise in the temperature of the object. The temperature of the brakes increases.

6 **Tom does 3000 J of work against friction in pushing a small van a distance of 12 m. How big is the friction force he has to push against?**

7 **A car of mass 800 kg is travelling at 12 m/s.**

a Calculate its kinetic energy.

b The brakes are applied. What force from the brakes is needed if the car stops after travelling 8 m?

8 **A pole-vaulter has a weight of 500 N.**

a She vaults to a height of 4 m. How much work does she do?

b How much kinetic energy does she have just before she lands?

c When she lands, her trainers compress by 1 cm. Calculate the average force acting on her trainers as she is landing.

DID YOU KNOW?

A water-powered inclined railway has no engine. The top car has a water tank which makes it slightly heavier than the car at the bottom. The two cars are attached by a cable going over a pulley. The extra weight of the top car does work to lift the lower car up the slope. Work is also done to overcome the force of friction.

Figure 1.10 Inclined railway

MAKING LINKS

You will need to link the information given here to the forces topic 5.13, where you will look at the factors that affect stopping distance.

Understanding power

Learning objectives:

- define power
- compare the rate of energy transfer by various machines and electrical appliances
- calculate power.

KEY WORDS

energy transfer
power

A human being can be considered an energy transfer device. Our energy comes from our food, about 10 MJ (10 million joules) every day.

Power

Imagine a tall office block with two lifts, the same mass. One lift takes 40 s to go up to the tenth floor; the other, newer lift, takes 25 s. Both lifts do the same amount of work but the newer one does it more quickly. The transfer of energy is more rapid; the new lift has more **power**.

Power is the rate of doing work or transferring energy. A machine that is more powerful than another machine transfers more energy each second.

Power is measured in watts (W). If one joule of energy is transferred in one second this is one watt of power. 1 W = 1 J/s.

The table shows the typical power of various electrical appliances.

	Power / W
Kettle	2500
Microwave oven	1100
Iron	1000
Hairdryer	2000
Vacuum cleaner	1600
Television	114
Food blender	150

1. **Which appliance is the most powerful?**
2. **Explain why a television might do more work than a food blender.**

Calculating power

$$\text{Power} = \frac{\text{work done in J}}{\text{time in s}} \text{ or } \frac{\text{energy transferred in J}}{\text{time in s}}$$

These formulae can be written as:

$P = W/t$ and

$P = E/t$

Example: A machine does 1000 J of work in 8 seconds. What power does it develop?

$$\text{Power} = \frac{\text{work done}}{\text{time}} = \frac{1000\text{ J}}{8\text{ s}} = 125\text{ W}$$

3 **A toaster transferred 108 000 J of energy in 2 minutes. What is the power of the toaster?**

4 **An electric kettle is rated at 2 kW (2000 W). How much energy is transferred in 30 s?**

5 **A crane lifts a load weighing 4000 N through a height of 6 m in 20 s.**

a **How much work does the crane do to lift the load, assuming there is no friction?**

b **What is the power of the crane?**

ADVICE

Energy is measured in joules (J) and power in watts (W). An energy transfer of 1 joule per second is equal to a power of 1 watt.

Personal power

Mel decides to work out her leg power. She runs up 16 stairs each 20 cm high in 10 s (Figure 1.11). Mel's mass is 50 kg.

Work done = force × distance moved **in the direction of the force.**

The force moved is Mel's weight = 50 × 10 = 500 N.

The **vertical** height of the stairs (in m) = 16 × 0.2 = 3.2 m

Work done = 500 N × 3.2 m = 1600 J.

$$\text{Power} = \frac{\text{work done}}{\text{time taken}} = \frac{1600\text{ J}}{10\text{ s}} = 160\text{ W}$$

Figure 1.11 How can Mel measure the vertical height?

6 **Al weighs 800 N. He climbs 5 m vertically in 10 s when he runs up the stairs of an office block.**

a **How much work does he do?**

b **Calculate his power.**

7 **The Eiffel Tower in Paris (Figure 1.12) is 300 m high. Louis took 15 minutes to climb its 1792 steps. He has a mass of 60 kg. What was his average power output during the climb?**

8 **Emma decides to measure her personal leg power doing step-ups. The step is 10 cm high. Emma does 20 step ups in 30 s. Her mass is 60 kg. Calculate her leg power.**

9 **A car is moving at 108 km/h and the engine provides a constant force of 1000N. Calculate:**

a **the distance the car moves in 1 second**

b **the power of the engine.**

Figure 1.12 The Eiffel Tower

Specific heat capacity

Learning objectives:

- understand how things heat up
- find out about heating water
- find out about specific heat capacity.

KEY WORD

specific heat capacity

If you eat a jam sponge pudding soon after taking it out of the oven the jam seems to be hotter than the sponge, even though they have been cooked at the same temperature. This is because at the same temperature the jam stores more thermal energy than the pudding around it.

COMMON MISCONCEPTION

Heat and temperature are not the same thing. When something is heated, thermal energy is being transferred to it. Temperature is a measure of how hot or cold something is.

Hot and cold

It takes more energy to get some things hot than others. Different materials need different amounts of energy to raise the temperature by a given amount. Imagine a 1 kg block of copper and a 1 kg block of steel. From experiments we can show that:

- it takes 380 J of energy to raise the temperature of 1 kg of copper by 1 °C
- it takes 450 J of energy to raise the temperature of 1 kg of steel by 1 °C.

The amount of energy needed to change the temperature of an object depends on:

- its mass
- what it is made of
- the temperature change.

Substance	*c* in J/kg °C
Water	4200
Copper	380
Steel	450
Concrete	800

1 The same mass of two different substances is heated. The amount of thermal energy transferred is the same in each case. Why does one material have a bigger increase in temperature?

Hot water

It takes a lot of energy to raise the temperature of 1 kg of water by a certain amount; more than for most other substances.

Specific heat capacity (*c*) is a measure of how much energy is required to raise the temperature of 1 kg of a substance by 1 °C.

You can calculate the amount of energy stored in a system when it is heated using the equation:

change in thermal energy = mass × specific heat capacity × change in temperature

$\Delta E = mc\Delta\theta$

where ΔE is in J, m is in kg, c is in J/kg°C and $\Delta\theta$ is in °C.

Example: Calculate the change in thermal energy when 2 kg of water is heated from 20 °C to 80 °C.

MATHS

In maths, the symbol Δ means the difference or change in a quantity. ΔE means a change in energy, $\Delta\theta$ means a change in temperature.

$\Delta E = mc\Delta\theta$
$= 2\ \text{kg} \times 4200\ \text{J/kg°C} \times (80\ \text{°C} - 20\ \text{°C})$
$= 504\ 000\ \text{J}$
$= 504\ \text{kJ}$

2 **How much energy is needed to heat 1 kg of copper by 20 °C?**

3 **How much energy is given out when the temperature of 2 kg of steel falls by 30 °C?**

Water has a very high specific heat capacity. This means it can absorb a large amount of thermal energy from a hot object for a given temperature change of the water. Water is used to cool many car engines. The thermal energy store in the engine decreases and the thermal energy store in the water increases. Energy is then transferred from the thermal energy store in the water to the store in the air surrounding the radiator.

Water can also release a lot of energy without a large temperature decrease. This makes it a very useful way of transferring large amounts of thermal energy around a house in a central heating system.

Figure 1.13 Water is used to cool many car engines

DID YOU KNOW?

Several tonnes of liquid sodium metal are used as a coolant in some types of nuclear reactor. The liquid sodium transfers thermal energy from the reactor core to water, which then turns to steam and drives the generators.

4 **Explain why a hot-water bottle is so effective at warming a bed.**

5 **What is meant by specific heat capacity?**

6 **How much energy is needed to raise the temperature of 3 kg of steel by 15 °C?**

More about specific heat capacity

Example: 0.5 kg of copper at 90 °C is added to 2 kg of water at 10 °C. Calculate the final temperature of the copper and water (T).

Assume that the decrease in thermal energy store of the copper = increase in thermal energy store of the water.

Change in thermal energy store of copper

$= 0.5\ \text{kg} \times 380\ \text{J/kg°C} \times (90\ \text{°C} - T)$

Change in thermal energy store of water

$= 2\ \text{kg} \times 4200\ \text{J/kg°C} \times (T - 10\ \text{°C})$

$190 \times (90 - T) = 8400 \times (T - 10)$

$(8400 + 190)T = 17\ 100 + 84\ 000$

$T = 101\ 100/8590$

$T = 11.8\ \text{°C}$

7 **A night storage heater contains 50 kg of concrete. The concrete is heated during the night when electricity is cheaper, gradually emitting stored energy during the day. How much thermal energy is required to warm the concrete from 10 °C to 30 °C? Suggest why concrete is chosen.**

8 **A 1 kg steel block at 80 °C is added to 0.5 kg of water at 10 °C. Calculate the final temperature of the block and the water.**

REQUIRED PRACTICAL

Investigating specific heat capacity

Learning objectives:

- use theories to develop a hypothesis
- evaluate a method and suggest improvements
- perform calculations to support conclusions.

KEY WORDS

energy store
energy transfer red
specific heat capacity

A useful way of thinking about energy and energy transfers is the concept of stores. Energy can be stored in a variety of ways and one of those is by heating something up. If this object is put somewhere cooler then energy will be transferred from one store (the object) to another store (the surroundings).

Using scientific ideas to plan an investigation

When a lump of brass is immersed in ice-cold water its temperature decreases. It would end up at 0°C (as long as we left it in contact with the ice for long enough). If we then take the brass out of the ice-cold water and put it into another beaker of hot water, thermal energy transfers from the store in the water to the brass. The brass warms up and the water cools down until they are both at the same temperature.

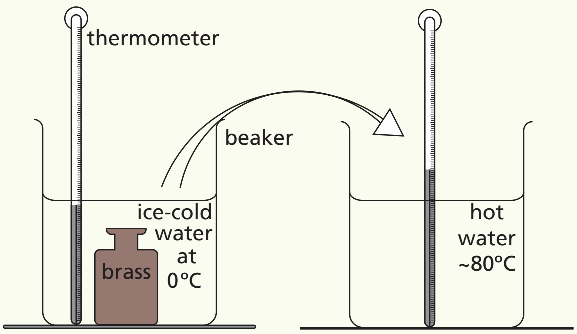


Figure 1.14 The lump of brass is transferred from the water at 0 °C to the hot water

1. **How could we find out what the temperature of the water became when the brass was added to it?**
2. **How could we calculate the decrease in temperature of the water?**
3. **How could we calculate the temperature rise of the brass?**
4. **What would happen to the temperature of the water and the brass in the second beaker if we left them for a long time (e.g. an hour)?**

These pages are designed to help you think about aspects of the investigation rather than to guide you through it step by step.

DID YOU KNOW?

Stone age man, Native American Indians and backwoodsmen all have used hot stones to boil water. Hot stones from a fire are dropped into a wooden bowl of cold water. Thermal energy stored in the stones is transferred to the water, making it hot enough to boil. This is an example of a decrease in one **energy store** producing an increase in another. You can make use of this method to find the specific heat capacity of different materials.

KEY INFORMATION

~ 21 °C means about 21 °C

Evaluating the method

This experiment is used to find the **specific heat capacity** of brass by assuming that all the thermal energy transferred from the hot water increases the temperature of the lump of brass. We are equating the decrease in thermal energy store of the water to the increase in thermal energy store of the brass. If this assumption is not true, the method will not be valid.

5. **The lump of brass has to be moved from one beaker to the other. Consider how this step in the method could affect the accuracy of the results.**
6. **The energy transferred from the water to the brass will cause the lump of brass in the second beaker to get hotter. Why will the energy transferred to the lump of brass not be stored there permanently?**
7. **What are the implications of your answers to questions 5 and 6 for the way the experiment is carried out?**
8. **Why is it important that the lump of brass is covered in water in the second beaker?**

KEY INFORMATION

When thinking about this experiment, remember that energy tends to move from hotter areas to cooler ones.

Using the data to calculate a value for SHC

We find the specific heat capacity of brass by calculating the energy transferred into the brass when its temperature increases and equating that to energy transferred out of the water when its temperature decreases.

Decrease in thermal energy of water = increase in thermal energy of brass

$$m_{water} \times c_{water} \times \text{temperature decrease}_{water}$$

$$= m_{brass} \times c_{brass} \times \text{temperature increase}_{brass}$$

The final temperature of the water and brass is the same (they reach thermal equilibrium). As long as we know the values of the mass of water, mass of brass, specific heat capacity of water and initial temperatures of the water and brass, we can find the unknown value for the specific heat capacity of brass.

9. **There is 250g of water (c_{water} = 4200 J/kg °C) in the second beaker and its temperature rises from 17 °C to 26 °C. Determine how much energy has been transferred into it.**
10. **How much energy can we assume has been transferred out of the brass when it is put into the second beaker?**
11. **If the brass had been in boiling water, by how much would its temperature have decreased?**
12. **The lump of brass has a mass of 150 g. Calculate the specific heat capacity of brass.**
13. **Explain why is this method likely to give a lower value for the specific heat capacity than its true value.**

Dissipation of energy

Learning objectives:

- explain ways of reducing unwanted energy transfer
- describe what affects the rate of cooling of a building
- understand that energy is dissipated.

KEY WORDS

conduction
energy dissipation
radiation
thermal conductivity

Thermograms (Figure 1.15) are infrared photographs in which colour is used to represent temperature.

Reducing energy transfer

Sometimes the transfer of thermal energy is useful, such as in cooking, but on other occasions we might want to reduce it. For example, pushing a supermarket trolley with stiff wheels needs a lot of work to be done against frictional forces. This means the wheels transfer some energy to the surroundings as thermal energy. This energy is wasted and we would want to reduce this energy transfer.

Lubrication – oiling the moving parts of a machine reduces the friction force so less energy is wasted as thermal energy.

We might want to reduce thermal energy being transferred so that a parcel of fish and chips stays hot for longer or so that a block of ice cream stays frozen until we get it home.

Thermal insulation – surrounding a hot object with an insulating material reduces the rate at which energy is transferred away from it so the hot object cools more slowly (Figure 1.16). Clothing made of wool is a good insulator. Air is trapped between the wool fibres. Wool and air are bad **conductors** of thermal energy.

1 **The wheels of a scooter do not move freely. Describe how unwanted energy transfers in the wheels can be reduced.**

2 **Explain why a wrapping of newspaper is as good at keeping fish and chips hot as it is at keeping a block of ice cream cold.**

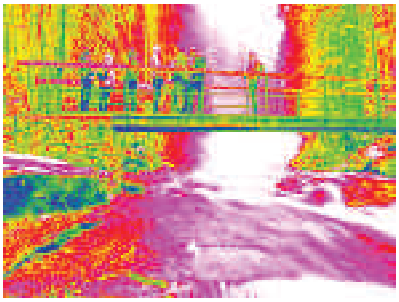


Figure 1.15 White represents the hottest area and blue the coolest

Figure 1.16 Why is this a good insulator?

Insulating a building

A building needs to be well insulated so that less energy is needed to keep the building warm. Loft and cavity wall insulation reduce the rate of energy transfer from inside a building to the colder outside.

Look at Figure 1.17. White, red and yellow represent the hottest areas. Black, dark blue and purple represent the coldest areas.

DID YOU KNOW?

The foam blocks used for cavity wall insulation in new houses have shiny foil on both sides. This further reduces energy transfer, as shiny objects reflect **radiation** rather than absorbing or emitting it.

The diagram of thermal energy losses from a house (Figure 1.18) shows that it is important to insulate the walls and roof.

Insulation reduces the amount of energy transfer by **conduction**. The lower the **thermal conductivity** of the insulating material and the thicker the layer, the more the rate of energy transfer by conduction is reduced.

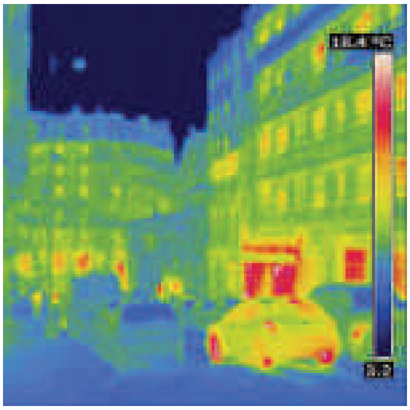


Figure 1.17 The wheels of the car are red because they are hot

3 **Looking at Figure 1.17, where is most thermal energy lost? Explain how you could reduce this unwanted energy transfer.**

4 **Explain, using examples, how an eco home that has no heating system can stay warm.**

Energy dissipation

A system is an object or group of objects. The total energy in a closed system is always constant. Energy is never created or destroyed.

Work done against the frictional forces acting on a moving object cause energy to be transferred from the object. This energy transfer raises the temperature of the surroundings by such a small amount that it is of no use. This is wasted energy – energy is transferred to a store where it cannot be used. Some energy is always **dissipated** when it is transferred.

5 **Explain why are we unable to reclaim thermal energy arising from energy due to friction or air resistance.**

6 **A car engine is designed to transfer energy from fuel into kinetic energy, making the car move. Name the other energy transfers that are likely to take place.**

7 **Look at the thermal image in Figure 1.17. Describe some of the features you can see. Use technical terms such as *thermal energy*, *thermal conductivity* and *dissipated* in your description.**

KEY INFORMATION

Trapped air reduces energy loss by conduction and convection but not by radiation.

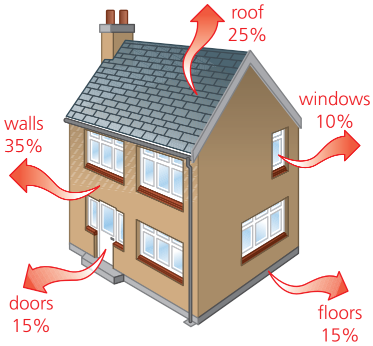


Figure 1.18 Thermal energy loss from a house

MAKING LINKS

The idea that energy can be transferred usefully, stored or dissipated without changing the total amount of energy is a key concept in science. You will use this idea in many contexts, and not just in physics.

Energy efficiency

Learning objectives:

- explain what is meant by energy efficiency
- calculate the efficiency of energy transfers
- find out about conservation of energy.

KEY WORDS

conservation of energy
energy efficiency

Electric cars have an efficiency of about 85% compared with about 15% for a petrol car. This means an electric car can transfer a greater portion of energy in the form of kinetic energy from the original energy store. But batteries have to be charged – and the fossil fuel plant supplying the electric current is only about 35% efficient.

Useful energy output of a system

It is not possible for the useful energy output of a system to be greater than the total input energy. The laws of conservation of energy also says that when a system changes, there is no change to the total energy of the system.

Even so, not all of the total energy input to a system is stored or usefully transferred. Some energy is always dissipated. This reduces the amount of energy that is usefully transferred.

For example, as an electric car accelerates, the engine transfers energy from the chemical energy store of the battery to the kinetic energy store of the car. Some of the input energy is wasted by transfer of thermal energy by heating the wheels and the surrounding air.

1. **What effect does the waste energy from a light bulb have on the surroundings?**
2. **Suggest why is an electric vehicle more efficient than a petrol or diesel vehicle.**

Figure 1.19 The least efficient light bulbs are being replaced with more energy-efficient alternatives, including LED light bulbs

Calculating energy efficiency

Efficiency is an indication of how much of the energy supplied to a device is transferred as a useful output. If all of the energy supplied was transferred usefully the transfer would be 100% efficient.

$$\textbf{Energy efficiency} = \frac{\text{useful output energy transfer}}{\text{total input energy transfer}}$$

OR

$$\text{Energy efficiency} = \frac{\text{useful power output}}{\text{total power input}}$$

MATHS

To convert from a decimal to a percentage, multiply the decimal by 100.

Quite a lot of energy transfers are not very efficient; a lot of energy is transferred in a way that isn't useful.

Example: Tina is an athlete. She applies a force of 75 N for a distance of 100 m using 44 000 J of chemical energy stored in food. What is her efficiency? Give your answer as a percentage.

Useful work done = force × distance = 75 N× 100 m = 7500 J

$$\text{Efficiency} = \frac{\text{useful energy output}}{\text{total energy input}}$$

$$= \frac{7500\ \text{J} \times 100}{44\ 000\ \text{J}} = 17\%$$

When you exercise, you get hot – your body temperature increases. Most of the chemical energy stored in food is transferred to thermal energy of your body.

3 **For every 100 J of energy supplied to a motor, 80 J of useful work is done. Calculate the efficiency of the motor. Give your answer as a percentage.**

4 **For every 500 J of energy in coal, 135 J are transferred to a room as heat from a coal fire.**

a) Calculate its efficiency.

b) Suggest why coal fires are inefficient.

5 **Suggest why a kettle is not 100% efficient.**

6 **The efficiency of a television is 0.65. Calculate the useful energy output if the total energy input = 200 J.**

Conservation of energy

Energy cannot be created or destroyed, only transferred from one store to another. In a closed system (one in which no energy can enter or leave) the *total* amount of energy put into the system equals the *total* amount of energy output. We say that energy is conserved. This is the law of **conservation of energy**. However, only some of the energy output is useful to us. The rest is dissipated as wasted energy. This affects the efficiency of a machine.

7 **What is meant by 'conservation of energy'?**

8 **Explain why heating a material does not increase only the thermal energy store of the material.**

9 **When sound transfers energy from the store in a vibrating cymbal to your eardrums, the decrease in the kinetic energy of your eardrums. Suggest how some of the energy is wasted.**

10 **An electric car is 85% efficient. The electricity for the car is supplied by a coal power station with an efficiency of 35%. Determine how much energy is needed from the chemical energy store of the coal for the car to provide 100 J of useful energy.**

DID YOU KNOW?

25% of all carbon dioxide emissions in the UK are as a result of heating and lighting our homes.

COMMON MISCONCEPTION

You often hear phrases like, '*Conserve energy*; turn off the lights'. However, to scientists, *conservation of energy* means that there is no net change to the total energy of a system.

REQUIRED PRACTICAL

Investigating ways of reducing the unwanted energy transfers in a system

Learning objectives:

- use scientific ideas to make predictions
- analyse data to identify trends
- evaluate an experimental procedure.

KEY WORDS

conduction
energy transfer
insulation
thermal radiation

Energy will always be transferred from warmer places to cooler ones. Sometimes this is useful, as in a domestic heating system. However on other occasions we need to stop that transfer, or at least slow it down.

These pages are designed to help you think about aspects of the investigation rather than to guide you through it step by step.

Developing a hypothesis

Tazim's group are investigating insulation materials and they are trying to predict which will work well. They are going to use the material to pack around a hot cooking pot that will be put into a wooden box with a close-fitting lid. The pot also has a lid. The liquid in the pot needs to be kept as hot as possible.

They are investigating the use of:

- expanded polystyrene
- wood shavings
- air.

One of the ways that thermal energy is transferred is by conduction.

1. **Tazim thinks that all the materials will have the same insulating effect, because only metals are good thermal conductors. Is he right?**
2. **Write a list of all the factors that may affect the thermal insulation properties of the box around the hot cooking pot.**
3. **Write a hypothesis connecting one of these factors to the temperature of the liquid in the pot.**
4. **Plan a method that would enable the hypothesis to be tested. Include in this an indication of the variables to be kept the same, the variables to change and the variables to measure.**

Analysing the results

The students then set up an experiment to investigate the cooling of the cooking pot when insulated with different materials. They left a similar pot on the bench to act as a control. The results are shown in the table.

Thermal insulator	Temperature of the pot (°C)					
	Start	1 hour	2 hour	3 hour	4 hour	5 hour
Control	90.0	38.0	26.5	25.5	25.0	25.0
Air	90.0	43.5	28.0	25.5	25.5	25.0
Polystyrene	90.0	55.0	43.5	37.5	30.0	26.5
Wood shavings	90.0	52.5	40.0	32.5	28.0	25.5

5 **Draw a graph of how the temperature of the pot changes with time for each insulator.**

6 **What feature on the graph indicates which material is best at reducing energy transfer?**

7 **Explain why the graph lines levelled out.**

8 **Suggest how you could calculate the rate of cooling from the graphs.**

9 **Suggest why the rate of cooling changed from during the first hour to during the fifth hour.**

Evaluating the experiment

Think about their experiment and the evidence it produced. The students are sharing ideas about how effective the experiment was.

10 **These are some of the comments made. Respond to each of these, justifying your point of view:**

a ‘This experiment didn’t work because all the pots ended up nearly cold.’

b ‘To make it a fair test we should have used the same mass of liquid in each experiment.’

c ‘The control was pointless – it’s just using air as an insulator.’

d ‘If you draw a straight line from the starting temperature to the final temperature for each of the experiments they have nearly the same gradient, showing that there’s little difference between the types of insulation.’

11 **a Show that the energy transferred to the surroundings in the first hour was about 1.33 times more when air was used as the insulator compared with polystyrene.**

b Calculate what this value would be for the second hour.

DID YOU KNOW?

Figure 1.20 A haybox

During World War 2, fuel for cooking was rationed and people were encouraged to use an older method of cooking, using a haybox. Hayboxes were ideal for slow cooking simple foods such as stews and soups. Food would be heated up using conventional methods and then put in the haybox to finish cooking. A haybox works by greatly reducing the transfer of energy from the hot food to the surroundings. As the name suggests, they were boxes packed with hay or shredded paper. This traps still air which acts as an excellent insulator.

ADVICE

Measuring the rate of cooling in the first hour gives a good basis for comparing the materials.

Using energy resources

Learning objectives:

- describe the main energy sources available for use on Earth
- distinguish between renewable and non-renewable sources
- explain the ways in which the energy resources are used.

KEY WORDS

non-renewable resource
renewable resource

Across the world we use over five hundred million trillion joules of energy every year. This has to come from somewhere.

The need for energy

Industrial societies use huge amounts of energy. Much of it is used for the generation of electricity in power stations. Electricity is useful because appliances can use it to transfer energy to many different types of useful energy stores. For example, a kettle can use electricity to transfer energy to the thermal energy store of the water that it is heating up.

Figure 1.21 A gravity light has been developed that transfers the GPE of a falling 12 kg weight to power a light

1 Identify an electrical device that transfers energy to:

a a kinetic energy store

b a gravitational potential energy store.

We can also use electricity for transport (such as trains and electric cars) and for heating. However, it is often cheaper and easier to use energy resources directly for these purposes.

2 Give an example of an energy resource being used to heat something.

3 State the energy resource you are using when you ride a bicycle.

4 Suggest why we mainly use electricity to power trains but fuel to power aeroplanes.

DID YOU KNOW?

Tidal energy comes from the gravitational potential energy store of the Moon. Nuclear and geothermal resources store energy that was produced by stars exploding in a supernova.

Energy resources

Most of the energy resources available to us store energy that has originally come from the Sun. These include fossil fuels (coal, oil and gas), bio-fuel, wind, wave, hydroelectric and solar energy. Other resources include geothermal energy (from hot, underground rocks), tidal energy and nuclear energy.

All of these resources have advantages and disadvantages. For example, in fossil fuels the energy is very concentrated – a small amount of fuel stores a large amount of chemical energy. Bio-fuels (such as wood pellets) are produced from plants and animals. They are not as concentrated as fossil fuels so you need a much larger mass to release the same amount of energy.

Reliability is another issue. Some energy resources are available all the time but others are not. You cannot use solar energy during the night or in bad weather. Rain is needed for hydroelectric power and wind and wave energy requires it to be windy.

5 **Give two ways of generating electricity in which no fuel is burned.**

6 **Suggest why wave energy is only useful for a few countries**

7 **Satellites orbiting the Earth use solar panels to provide them with their energy needs. Suggest why they also carry rechargeable batteries.**

Figure 1.22 Wind turbines are usually placed on high hills or out at sea

Renewable and non-renewable energy resources

Renewable resources never run out (at least not for the foreseeable future). They can be replenished as soon as they are used.

- Solar, wind, wave and hydroelectric resources are usually available. The Sun always shines and it always creates wind and rain. However, there may be short periods of time when there is little wind or rain and no waves.
- Any thermal energy extracted from hot rocks from the geothermal resource is replenished by physical processes in the rocks.
- The Moon produces two high tides nearly every day, whether we extract energy from them or not.

8 **Wood is a form of bio-fuel. Explain why we can regard wood as a renewable resource.**

Non-renewable resources will run out eventually. This is because they are not being replenished at the same rate that we are using them.

9 **Identify a non-renewable resource that is not a fossil fuel.**

10 **Both bio-fuels and fossil fuels are formed from plants and animals. Explain why bio-fuels are renewable resources but fossil fuels are non-renewable.**

11 **a Describe the difference between energy and energy resource.**

b Explain why energy is conserved but an energy resource is not conserved.

Global energy supplies

Learning objectives:

- analyse global trends in energy use
- understand what the issues are when using energy resources.

KEY WORD

efficiency

The white clouds coming from a power station are not smoke but water vapour coming from the cooling towers. In a coal-fired power station about half the energy stored in coal is lost in this way. We need the electricity, but do we have to have the waste?

Global trends

Figure 1.23 shows how energy resources have been used in the past and how they are likely to be used in the future.

You can see that the amount of energy we need increases every year. This is partly because the population of the world is increasing. Also, more countries are developing technologically and need more energy for industry. China's energy use, for example, grew rapidly between 2000 and 2015.

Although there are environmental problems with fossil fuels, they are likely to provide the world with most of its energy for many years to come.

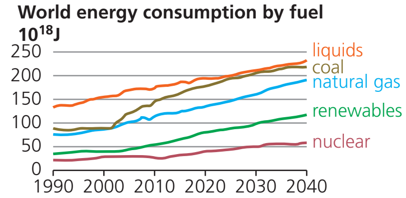


Figure 1.23 The world's use of energy resources

1. **Explain why some of the lines on the graph will eventually stop rising.**
2. **Look at Figure 1.23. Suggest the energy resource that China used the most from 2000 to 2010. Explain your answer.**
3. **Suggest why fossil fuels are likely to provide most of the world's energy for the foreseeable future.**

Energy issues

Scientists have discovered that using some energy resources is having an environmental impact. For example, fuel-burning power stations cause pollution.

They release carbon dioxide into the atmosphere which traps the Sun's energy and contributes to global warming. They also emit sulfur dioxide which causes acid rain.

Nuclear power stations create waste, some of which remains dangerous for thousands of years. There is also the danger of a nuclear accident which could contaminate the area with radioactive materials.

Scientists do not always have the power to make the decisions about energy use – these decisions are made by governments.

DID YOU KNOW?

Mean sea level has risen by about 20 cm in the last 100 years. Most scientists think this is due to global warming. Levels are expected to rise as much as a further 240 cm in the next 100 years.

Governments have to weigh up ethical, social and economic considerations as well as the likely impact on the environment. They also need to make sure they represent the views of the population that elected them.

Ethical considerations are to do with whether something is morally right or wrong. An example is making sure that energy resources are plentiful for the future. Although it will not affect us, it would be wrong to cause problems for future generations.

Social considerations concern how they affect people. Fossil fuel power stations need to be built to power factories and so provide people with jobs.

Economic considerations involve money. Although a particular energy resource is not as harmful to the environment it might be too expensive to produce.

Figure 1.24 A protest sign against plans to extract shale gas from the ground

4 **A local council has plans to extract shale gas from the ground and to burn it as fuel. Suggest some considerations that the council needs to make before they decide whether to go ahead.**

HIGHER TIER ONLY

Using energy resources efficiently

One way of preserving energy resources is to use them efficiently. This means you need to find ways to reduce the amount of wasted energy in any energy transfer.

The chart shows the efficiencies of some typical engines and motors.

	Efficiency (%)
Petrol engine	25
Diesel engine	35
Electric motor	80

Fuel-burning engines have a low efficiency. It is impossible to transfer thermal energy into kinetic energy without wasting most of it.

You can use this equation to calculate **efficiency:**

$$\text{Efficiency} = \frac{\text{useful power output} \times 100}{\text{total power input}}$$

5 **Suggest why the electric motor is more efficient than the fuel-burning engines.**

6 **The output power of an electric motor is 3 kW. Calculate the input power it needs.**

7 **The power station that produced the electricity for the electric motor is 40% efficient. Use this value and your answer to question 6 to determine whether using an electric motor is more efficient than a diesel engine.**

8 **Besides increasing the efficiency of the engine, what else could you do to increase the efficiency of a car?**

KEY CONCEPT

Energy transfer

Learning objectives:

- To understand why energy is a key concept in science
- To use ideas about stores and transfers to explain what energy does
- To understand why accounting for energy transfers is a useful idea.

KEY WORDS

chemical
dissipate
energy
store
thermal
transfer

Young children often love to run around and play on swings. After a while they'll get tired. 'I've run out of energy!' they'll say, and flop down. A few minutes later they're up again, announcing 'I've got my energy back!' and run off again.

What is energy?

The concept of energy is one of the most important ideas in science. We use it to explain what's happening when a torch is turned on – and when the batteries run flat. We talk about an energy crisis, and whether we have enough energy to keep our lamps lit and our cars on the road. It's important in chemistry because when reactions take place energy is transferred, and it's important in biology because cells need energy to carry out important processes.

However, we sometimes find it difficult to explain what we mean by energy. It's easier to understand what stores energy, rather than what energy is.

1. **Decide which of these is an energy store:**

   a **a ball rolling down a ramp**

   b **a stretched string**

   c **a hot object**

   d **a mixture of oxygen and fuel.**

2. **For each of a to d in Question 1, suggest if and how energy might be transferred from one store to another and used for something useful.**

Transferring energy

Sometimes we use names for energy, such as electrical, kinetic or gravitational potential. Actually it's more useful to identify where the energy is. This tells us more. We can then work out how it's been transferred.

Think about a wind-up torch (Figure 1.25). When you turn the handle you transfer energy from your muscles to the energy

Figure 1.25 Energy is transferred into this torch when it is wound up and out of it when it used to project light

store in the torch's battery. The energy store in your body decreases while the the energy store in the battery increases. When you turn the torch on, the energy store in the battery decreases and an electric current transfers energy in the bulb. The internal energy of the bulb increases (it increases in temperature), and the bulb transfers energy by light waves to the surroundings. Since the bulb is hot, it dissipates energy to the surroundings, increasing the internal energy of the surroundings. When the battery is flat, its energy store is zero and all the energy has been transferred to the surroundings.

3. **Draw a flow diagram to represent where energy has been transferred from and to.**
4. **Identify which energy store increases and which decreases when:**
   - **a in a bicycle, being ridden**
   - **b in a match, being struck.**

Accounting for energy

Energy does not disappear when it is transferred to other stores. It is still there but it is sometimes hard to see where it is being stored. For example, a charged battery is storing energy. When the battery is flat, the energy has been transferred to the surroundings.

The physicist Richard Feynman suggested that one of the ways of understanding accounting for energy was to compare it to a set of child's building blocks. The parent knows how many blocks there are in the set. If there is a block missing when you put them away, you look for it. Energy is similar. When you start with a certain amount of energy in a system, it is all still there, but you may have to look for it.

Coal has a chemical energy store. When the coal is burned, the chemical energy store of the coal decreases and the thermal energy store of the coal increases. In a steam engine, energy is transferred from the store in the coal to the water (as steam) in the boiler. The steam turns the wheels and makes the train move, so there is a kinetic energy store associated with the train. At the end of the journey the coal is burnt, the steam used and the train has come to rest, but the energy is still there – the thermal energy store of the surroundings has increased.

Because scientists think this is an important idea, they go to a lot of trouble to measure the amounts of energy (look at the labels on prepared food), to account for the energy transfers and to calculate the efficiency from this (which can be given as a percentage).

Figure 1.26 Accounting for energy is rather like checking on the number of bricks in a set

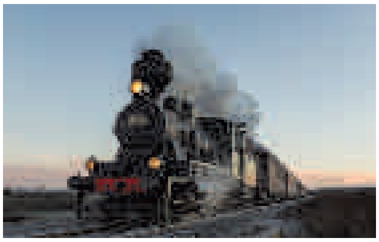


Figure 1.27 Energy is being transferred here; can it all be accounted for?

5. **How does the story of the child's bricks explain the concept of conservation of energy?**
6. **Energy is conserved within a system. In the case of the steam engine, what does the system include?**

MATHS SKILLS

Calculations using significant figures

Learning objectives:

- substitute numerical values into equations and use appropriate units
- change the subject of an equation
- give an answer to an appropriate number of significant figures.

KEY WORDS

substitute
rearrange an equation
subject of an equation
significant figures

People have been trying to invent a perpetual motion machine for centuries. Perpetual motion means moving forever. But where there are energy transfers, some energy is always dissipated. This is why the idea of perpetual motion is an impossible dream.

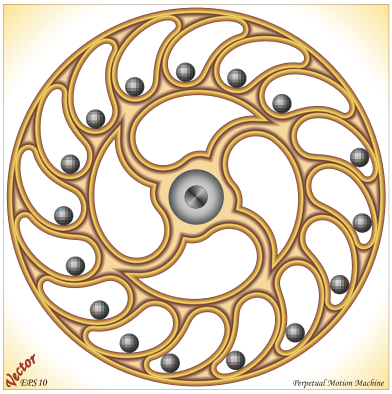


Figure 1.28 An idea for a perpetual motion machine. Such a machine could not work because it would violate the law of conservation of energy.

Calculating changes in energy

Example: A diver dives into water from a board 10.0 m above the water surface. The mass of the diver is 50.0 kg. The gravitational field strength is 9.8 N/kg.

a) Calculate the change in gravitational potential energy of the diver as she falls from the board to the surface of the water.

b) Calculate the diver's speed when she hits the water.

a) Use $E_p = mgh$

$E_p = 50.0 \text{ kg} \times 9.8 \text{ N/kg} \times 10.0 \text{ m}$

$= 4900 \text{ J}$

b) As the diver falls, energy is transferred from a gravitational potential energy store to a kinetic energy store.

The energy transferred from the gravitational potential energy store to the kinetic energy store = 4900 J

Use $E_k = 0.5\ mv^2$

You need to **rearrange the equation** to find v (make v the **subject of the equation**).

Multiply both sides by 2: $2E_k = mv^2$

Divide both sides by m: $\frac{2E_k}{m} = v^2$

So: $v = \sqrt{\frac{2E_k}{m}}$

Substituting the values for E_k and m:

$v = \sqrt{\frac{2 \times 4900}{50}}$

$v = \sqrt{196}$

$v = 14 \text{ m/s}$

1 **Calculate the change in gravitational potential energy of a diver of mass 70.0 kg who dives from a board 2.0 m above the water.**

2 **Calculate the gravitational potential energy gained by a ball of mass 50.0 g thrown to a height of 10.0 m.**

Significant figures

The answer to a calculation can only have the same number of **significant figures** as the data provided.

Example: A diver stands on a board 5.0 m above water. The mass of the diver is 50.0 kg. The gravitational field strength is 9.8 N/kg. Calculate the diver's speed when he hits the water. Give your answer to two significant figures.

Increase in kinetic energy store = decrease in gravitational potential energy store

= mgh

= 50.0 kg × 9.8 N/kg × 5.0 m

= 2450 J (Do not round to two significant figures yet.)

Energy transferred to the kinetic energy store, $E_k = 0.5\,mv^2$

Rearranging as before, $\frac{2E_k}{m} = v^2$

$$v = \sqrt{\frac{2E_k}{m}}$$

$$= \sqrt{\frac{2 \times 2450}{50}}$$

$$= \sqrt{98}$$

= 9.899, or 9.9 m/s, to two significant figures

3 **A spring of spring constant k = 350 N/m is extended by 9.0 cm. Calculate the elastic potential energy, E_e, stored in the spring. Give your answer to two significant figures.**

Two-step problems

Example: A lift raises four people with a combined weight of 3500 N to the third floor of a building in 25.0 seconds. The height gained is 15 m. Calculate the power required.

You need to use: Power = $\frac{\text{work done}}{\text{time taken}}$, or $P = \frac{W}{t}$

You have the time taken, but not the work done. You must approach this problem in two steps. First, calculate the work done, then **substitute** that value into the equation for power.

Work done = force × distance moved along the line of action of the force

The force used (the weight that is lifted) is 3500 N.

Work done = 3500 N × 15 m

= 52 500 J, or 52.5 kJ

Substituting this value for work done into the power equation:

$$\text{Power} = \frac{52500\ \text{N}}{25.0\ \text{s}}$$

= 2100 W, or 2.1 kW

KEY INFORMATION

You should keep at least one extra significant figure in your calculations to avoid rounding errors. Only round to the required number of significant figures when you have calculated the answer.

KEY INFORMATION

To round a number to two significant figures, look at the third digit. Round up if the digit is 5 or more, and round down if the digit is 4 or less.

MAKING LINKS

A set of readings taken with the same instrument should all have the same number of significant figures. So if the extension of a spring is measured with a ruler as 4.1, 4.2, 5.9 and 6 cm, the table of data should list 6 cm as 6.0 cm.

MATHS SKILLS

Handling data

Learning objectives:

- recognise the difference between mean, mode and median
- explain the use of tables and frequency tables
- explain when to use scatter diagrams, bar charts and histograms.

KEY WORDS

continuous data
frequency table
scatter diagram
correlation
line of best fit
bar chart
histogram
independent variable
dependent variable
mean
median
mode
anomalous

The purpose of an experiment is to find out the relationship, if there is any, between the variables you are investigating. You do this by looking for a pattern in the data that is collected. It is difficult to spot a pattern from a mass of numbers, but it is much easier from a picture – a graph or a chart.

Tables and frequency tables

Tables are used to capture the information from an experiment and from graphs. A simple table is used for **continuous data**, where information is measured on a continuous scale – for example, when loading a spring with different weights and measuring the extension produced (Table 1.1).

Force (N)	Extension of spring (mm)		
	1st reading	2nd reading	3rd reading
10	8	9	7
20	19	16	15
30	23	21	29
40	34	32	33
50	35	44	39

Table 1.1 Investigating the relationship between force and the extension of a spring

Another way of collecting data is to use tally marks and make a **frequency table**. This method is best where your data can only have certain values such as shoe sizes, or the information can be categorised such as the names of countries.

Using scatter diagrams, bar charts and histograms

The data in Table 1.1 is continuous and is best displayed by using a **scatter diagram** (Figure 1.29). Plotting the data points will give a clearer picture of the relationship between the two variables, to see if there is a **correlation**. If there is a

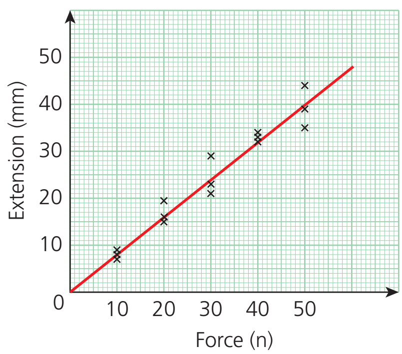


Figure 1.29 Data from Table 1.1
A scatter graph with a line of best fit

Age	Tally	Number of people
11–20	𝍸 IIII	9
21–30	𝍸 𝍸 𝍸 I	16
31–40	𝍸 𝍸 II	12
41–50	IIII	4
51–60	𝍸 I	6
61–70	I	1

Table 1.2 Frequency distribution of the ages of people on a street

a correlation, you can draw a **line of best fit** (this may be a curve) and then use this to extrapolate further trends and information.

The data in Table 1.3 is not continuous. It is best represented by a bar chart (Figure 1.30).

The data in Table 1.2 is grouped. It is best represented by a **histogram**. Each column represents a group of data, and the frequency of the data is shown by the area of each bar (Figure 1.31).

Country	Tally marks	Number of new nuclear power stations being built
Russia	~~IIII~~ II	7
UK	~~IIII~~	5
India	~~IIII~~ I	6
USA	~~IIII~~	5
Pakistan	III	3

Table 1.3 Number of new nuclear power stations being built in selected countries

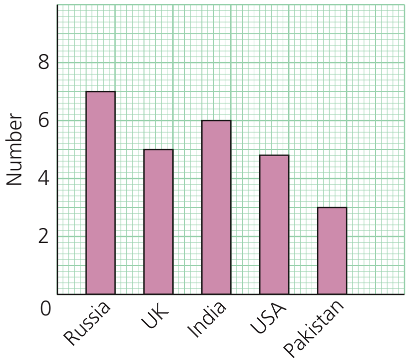


Figure 1.30 Data from Table 1.3: A bar chart

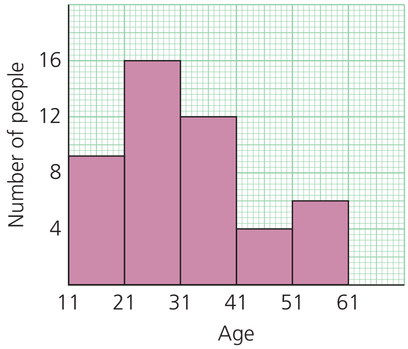


Figure 1.31

Renewable energy resource with the greatest share of total renewable energy production	Frequency
Solar energy	2
Biomass & renewable waste	31
Geothermal energy	0
Hydropower	0
Wind energy	1

Table 1.4 Renewable energy sources in the EU for 2013

Mean, median and mode

To find the **mean**, add up all the values and divide by the number of values.

Example: The mean of four repeated measurements of temperature, 7°C, 12°C, 9°C and 11°C, is

$$\frac{7°C + 12°C + 9°C + 11°C}{4} = 9.75°C$$

or 10°C, rounded to the nearest whole number.

The **median** is the middle value when the values are rearranged in sequence. For example, from the data set above:

7°C, 9°C, 11°C, 12°C

When there are an odd number of data points, it is easy to spot the median. If there is an even number of data points, calculate the median as the midpoint of the two middle values. In this example, the median is halfway between 9°C and 11°C. So the median is 10°C, even though that is not one of the data points.

The **mode** is the value, or item, that occurs most frequently in a set of data. It is easy to spot the mode in a frequency table. In Table 1.4 the mode is 'Biomass & renewable waste'.

When should you use which average? In the repeated measurements of temperature above, the mean and the median turn out to be the same value. But if one of the measurements was **anomalous**, for example, 22°C instead of 12°C, this would skew the mean.

Example: The mean of 7°C, 22°C, 9°C and 11°C is

$$\frac{7°C + 22°C + 9°C + 11°C}{4}$$

= 12.25°C

or 12°C, rounded to the nearest whole number.

The median, 10°C, is unchanged, so it is the more accurate representation of your data set when there are some anomalous results (or 'outliers').

Check Your Progress

You should be able to:

☐ describe how energy can be stored by raising an object up or by stretching or compressing it	☐ use the equations for gravitational potential energy and elastic potential energy	☐ apply the equations for gravitational potential energy and elastic potential energy in a variety of contexts, and change the subject of these equations
☐ describe how a moving object has kinetic energy	☐ know that kinetic energy is related to mass and velocity squared and use the equation to calculate it	☐ use the equation for kinetic energy to solve problems, including changing the subject of the equation
☐ recognise that when a force moves an object along the line of action of the force, work is being done ☐ state that various devices do work and, in doing so, transfer energy	☐ calculate the work done by a force from the size of the force and the distance moved	☐ use the equation for work done to solve problems, including changing the subject of the equation
☐ state that some materials require more energy than others to increase a certain mass by a certain temperature rise	☐ describe what is meant by the specific heat capacity of a material and use the equation for specific heat capacity ☐ plan an experiment to measure the specific heat capacity of a material	☐ calculate temperature changes, masses or specific heat capacities given the other values ☐ evaluate an experiment to measure the specific heat capacity of a material
☐ recognise that some energy transfers are unwanted	☐ describe how lubrication and insulation can be used to reduce unwanted energy transfers ☐ calculate energy efficiency ☐ describe how some energy transfers are more useful than others	☐ explain how thermal conductivity affects the rate of energy transfer across a material and affects the rate of cooling of a building ☐ recognise that in a closed system there may be energy transfers that change the way energy is stored, but there is no net change to the total energy
☐ state that various resources are used as fuels and to generate electricity	☐ describe the advantages and disadvantages of fossil fuel, nuclear and renewable energy resources	☐ evaluate and justify the use of various energy resources for different applications

Worked example

Jo's group is investigating the energy changes that take place when a toy car runs down a ramp.

1 **The mass of the car is 500 g, *g* is 10 N/kg and the vertical height of the top of the ramp is 20 cm. Calculate the GPE of the car at the top of the ramp.**

GPE = mgh = 500 × 10 × 20 = 100 000 J

This answer correctly uses the equation to multiply the variables together but hasn't converted the mass or the height into standard units. It should be 0.5 kg × 10 N/kg × 0.2 m = 1 J

2 **The pupils use a speed detector to measure the speed of the car when it gets to the bottom of the ramp. They find out it is travelling at 0.8 m/s. Calculate its kinetic energy at the bottom of the ramp.**

$KE = \frac{1}{2}mv^2 = \frac{1}{2} \times 0.5 \times 0.8 \times 0.8 = 0.16$

This answer correctly uses the equation and has converted g to kg. The speed (only) is squared but there is no indication of the correct unit at the end.

3 a **How could they calculate the percentage efficiency of the system at converting GPE into KE?**

b **Explain why it will be less than 100%.**

Efficiency could be found by dividing output by input, so $\frac{KE}{GPE}$.

Nothing is perfect and efficiency is always less than 100%

This is correct in that it is the output divided by the input but it is important to use the **useful** output. Furthermore, the question asked for the efficiency as a percentage, so the answer has to be multiplied by 100.

This is true but is not an explanation. The reason it is not 100% is because not all of the GPE store has been transferred to the kinetic energy store of the car. Some energy is dissipated to the surroundings, raising the temperature of the car body and the surrounding air.

4 **Jo says that if the ramp was 100% efficient then doubling the height of the top of the ramp would double the speed at the bottom. Referring to the relevant formulae, suggest whether she is correct.**

GPE = mgh and KE = 1/2mv². Increasing h will increase GPE and this will increase KE which will increase v so Jo is correct.

This quotes the correct formulae and identifies that an increased h will mean an increased GPE. In fact, doubling *h* will double the GPE which will double the KE (if it's 100% efficient). However, $KE = 1/2mv^2$ and the squaring means that although the speed will increase, it won't double (it will actually go up by a factor of about 1.4). If the question includes a quantitative approach (it refers to doubling) it's not enough to give a qualitative response (say **how much** it increases).

End of chapter questions

Getting started

1 Sally is choosing a new electric kettle. One is rated at 1.5 kW and the other at 2 kW. What does this show? 1 Mark

- a The first one is smaller.
- b The second one is a newer design.
- c The first one will keep the water hot for longer.
- d The second one will transfer energy more quickly.

2 Write down the equation for efficiency. 1 Mark

3 What is meant by a non-renewable resource? 1 Mark

4 When energy is being wasted we say it is

- a diffusing
- b propagating
- c dissipating
- d refracting

1 Mark

5 Describe the difference between elastic potential energy and gravitational potential energy. 2 Marks

6 Two steel blocks, one with a mass of 100 g and the other with a mass of 200 g, are placed in boiling water for several minutes. Which of these statements is **not** true? 1 Mark

- a They are both at the same temperature.
- b They are made of the same material.
- c They have the same amount of stored thermal energy.
- d They remain solid.

7 Order these light bulbs from most to least powerful. 1 Mark

15 W, 0.1 kW, 60 W, 0.08 kW, 150 W

8 Elise has a weight of 400 N and can clear a high jump of 2 m. Calculate how much work she does in raising her body up 2 m. 2 Marks

Going further

9 Which of these does **not** affect the amount of energy needed to heat up a sample of material? 1 Mark

- a Its colour.
- b Its mass.
- c Its specific heat capacity.
- d The temperature rise.

10 Explain why bubble wrap is an effective insulator. 2 Marks

11 A hot parcel of fish and chips is taken outside on a cold night. Describe what movement of energy will take place, identifying where the energy is stored.

More challenging

12 **Look at the image of the house and suggest what this thermogram of a house shows.** 2 Marks

13 **The power of a kettle is 2000 W. Explain what 2000 W means in terms of energy transfer.** 1 Mark

14 **Write down what each of the symbols stands for in $\Delta E = mc\Delta\theta$** 1 Mark

15 **Night storage heaters heat up during the night time and release energy during the day. Explain why they are made from a material with a high specific heat capacity.** 2 Marks

16 **A student was given some rods made from different materials. He was asked to arrange the rods in order of increasing thermal conductivity. Describe a procedure the student could follow to carry out the task safely by using a fair test.** 6 Marks

Most demanding

17 **Explain the difference between thermal energy and temperature.** 2 Marks

18 **Explain why energy is conserved within a closed system.** 2 Marks

19 **A student was investigating how the efficiency of a squash ball changed with temperature. The efficiency of a squash ball can be worked out by using the equation:**

gravitational potential energy associated with the squash ball before it is dropped ÷ gravitational potential energy associated with the squash ball when it reaches its maximum height after it bounces.

The student placed the ball in a beaker of water and heated the water to the desired temperature. She then removed the ball from the water and dropped it from a height of 1m onto a hard surface. Once the ball had bounced, the student measured the height that the ball bounced up to by using a metre ruler.

Here are her results:

Mass of squash ball = 25 g

Gravitational field strength on Earth = 10 N/kg

Temperature (°C)	20	30	40	50	60
Bounce height 1 (cm)	6	28	39	43	45
Bounce height 2 (cm)	18	23	36	40	42

The student concluded that the higher the temperature of the squash ball, the more efficient it was.

Discuss whether the student made a valid conclusion and evaluate the limitations of the experiment. 6 Marks

Total: 35 Marks