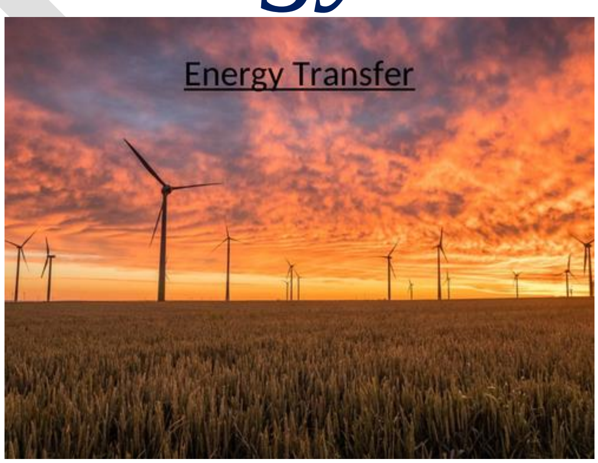
Edexcel IGCSE

Physics

CODE: (4PH13)

Unit 4

Energy resource and energy transfer



4.1 Energy transfers

Energy is essential for various functions such as sound production, transportation, lifting objects, machinery, and electricity. As the world's population grows, the demand for energy increases, as people consume more energy for necessities like warmth and light. As wealthier individuals demand more, the need for energy also increases.

Stores of energy

Energy is found in many different stores:

■We get our energy from the food we eat. Food provides stored chemical energy that we can burn to transfer it to other types of energy.

■We use the energy from food to generate thermal energy (heat energy) to help to keep us warm.

■Our muscles transfer the chemical energy to movement energy (kinetic energy).

■Some of this movement energy is transferred as we speak to sound energy.

■We need heat for our homes, schools and workplaces. We also need to transfer energy to light for our buildings, vehicles and roads.

■Most of the energy needed for these purposes is transferred from electrical energy. We shall see later that electrical energy can be transferred from other stores of energy, like chemical or nuclear energy.

■Some electrical energy is produced from the gravitational potential energy in water kept in reservoirs in mountainous areas.

■Energy from the heat underground is called geothermal energy.

■Energy can also be stored in springs as elastic potential energy. This type of stored energy is used in things like clocks and toys.

The main resource of energy for the Earth is our Sun. This provides us with heat, light and other stores of energy.

Energy transfers

For energy to be useful, we need to be able to transfer it from one store into whichever store we require. Unfortunately, when we try to do this there is usually some energy transferred to unwanted stores. We often refer to these unwanted stores as 'wasted' energy because it is not being used for a useful purpose.

Some energy transfers

We have many ways of transferring energy from one store to another.

▲ Figure 14.2 Energy is transferred from one store to another, and to another, and so on.

Conservation of energy

The principle of conservation of energy states that energy is not created or destroyed but transferred from one store to another. However, the energy crisis arises as our reserves of fuels like oil and gas are being used up. Physicists believe that energy in the Universe is constant, but our small piece of the Universe faces a problem as we make energy useful.

Sankey diagram

Sankey diagrams are a simpler and clearer way of showing what happens to an energy input into a system. The energy flow is shown by arrows whose width is proportional to the amount of energy involved. Wide arrows show large energy flows, narrow arrows show small energy flows.

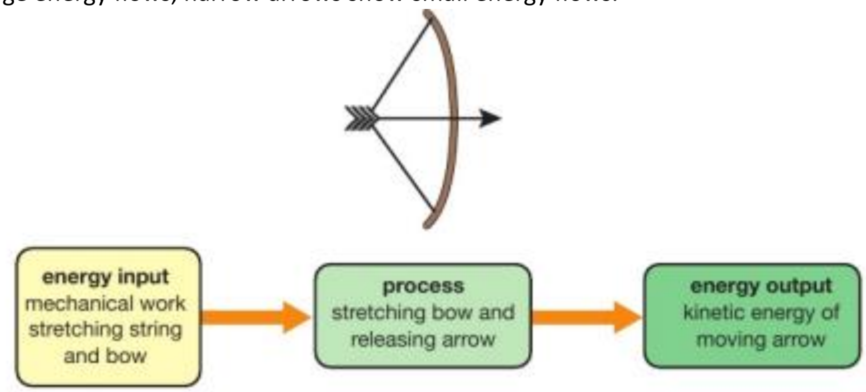


Figure 14.3 Energy transfer diagram for an arrow being fired from a bow

Figure 14.4 shows a Sankey diagram for a complex system - the energy flow for a car. Chemical energy in the form of petrol is the input to the car. The energy outputs from the car are:

■Electrical energy (from the alternator) to drive lights, radio and so on, to charge the battery (transferred to chemical energy) and allow the car to switch on
■Movement (kinetic) energy from the car engine
■Wasted energy as electrical heating in wiring and lamp filaments, as frictional heating in various parts of the engine and alternator, and as noise.

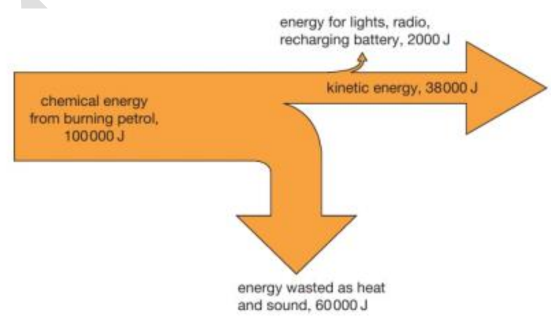


Figure 14.4 Sankey diagram showing the energy flow in a typical car

Efficiency

Whenever we are considering energy transfers, we must remember that a proportion of the energy input is wasted. Remember that wasted means transferred into stores other than the useful store required.

Real systems always have an unwanted energy output so can never have 100% efficiency.

The efficiency of an energy conversion system is defined as:

$$\text{efficiency} = \frac{\text{useful energy output}}{\text{total energy output}} \times 100\%$$

Efficiency is a ratio, often expressed as a **fraction** of energy output in the wanted or useful store, typically less than 1, in real energy transfers.

4.2 Thermal energy

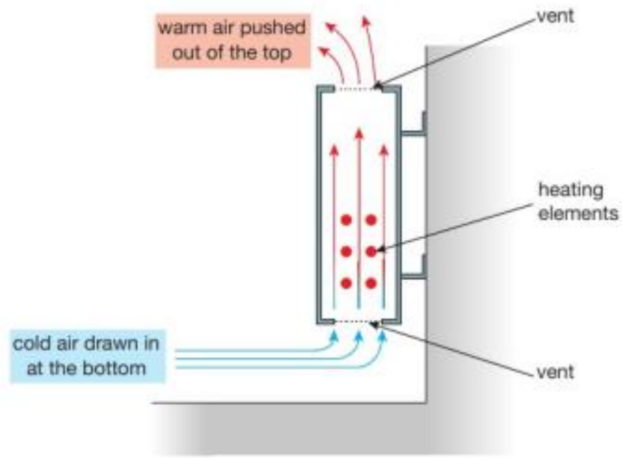
Conduction

Thermal **conduction** is the transfer of heat energy through a substance through the vibration of atoms. It occurs in all materials, but metals are good thermal conductors due to their free electrons that can move easily through their structure. This process occurs in hot parts of a substance, like the part of the skewer over the charcoal, where more energetic particles transfer energy to nearby particles. Wood, on the other hand, is a good thermal insulator.

convection

Convection is the transfer of heat through fluids (liquids and gases) by the upward movement of warmer, less dense regions of fluid.

You may have seen a demonstration of convection currents in water, like the one shown in Figure 15.4. The water is heated just under the purple crystal and the crystal colours the water as it **dissolves,** which lets you see the movement in the water.



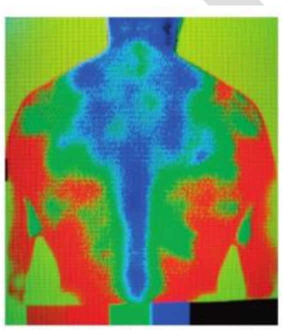
▲ Figure 15.6 A convector heater relies on the effects of convection.

Radiation

Thermal radiation is the transfer of energy by infrared waves.

▲ Figure 15.9 Heat is transferred from a heater by radiation.

▲ Figure 15.12 Shiny and white surfaces reflect thermal radiation, while matt black surfaces, like in the solar heating panels, absorb it.



▲ Figure 15.10 This is a thermal image of a patient showing areas of different temperatures.

▲ Figure 15.13 **a** A shiny kettle stays warmer longer. **b** The heat sink needs to be matt black to lose heat to the surroundings quickly, and so stop the transistor overheating.

Energy – efficient houses

Heating is the primary energy source in homes, schools, and workplaces, primarily producing carbon dioxide. This contributes to global warming. Energy efficiency involves using energy for its intended purpose, such as keeping homes warm and preventing heat escape. Insulation is crucial for energy-efficient housing, as it reduces energy transfer between the inside and outside.

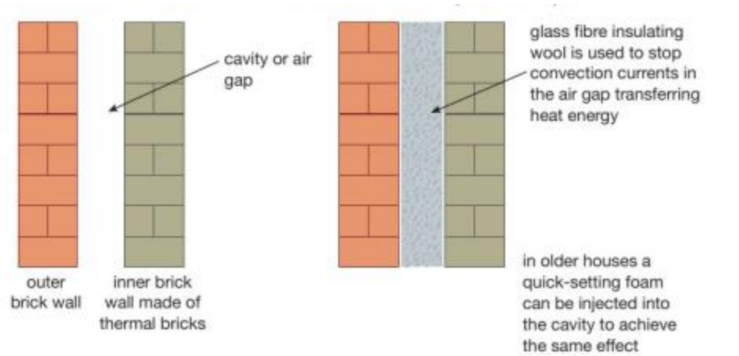


Figure 15.15 Two-layered wall construction, with the gap filled with insulation panels, helps to reduce heat loss by conduction, convection and even radiation.

How is heat lost?

To effectively insulate a house, consider heat energy escape routes, including conduction between the inside and outside, focusing on walls, windows, and roofs.

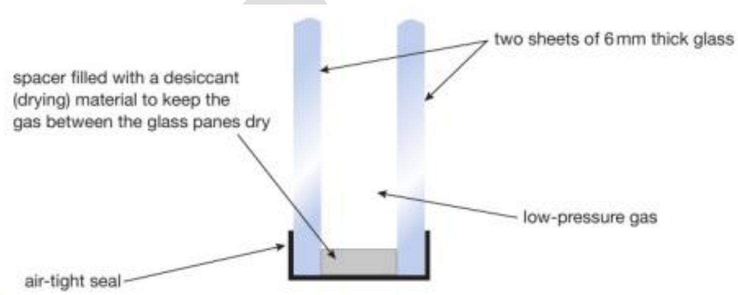


Figure 15.16 Double glazing helps to stop heat escaping from the home.

Building materials like bricks can reduce heat loss through walls by providing good insulation. The outer layer is made of bricks, which are strong and can withstand bad weather conditions. The inner layer is made of thermal bricks, which are lightweight, cheap, and quick to work with. The gap between the brick layers is filled with insulating panels made of glass fibre matting and thin aluminium foil, which reflect heat in the form of infrared radiation.

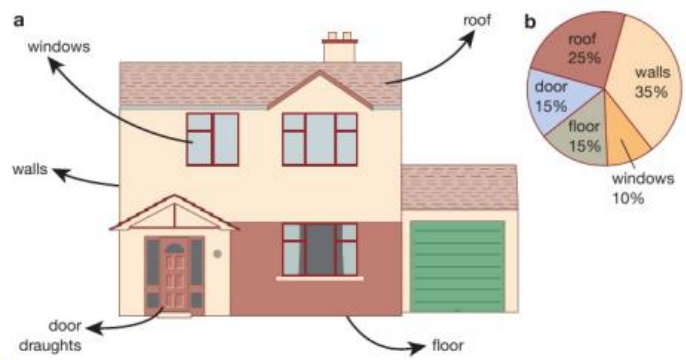


Figure 15.18 **a** How heat energy can be lost from the home; **b** Percentage of energy lost in different ways

Double-glazed windows in modern houses use two layers of glass to trap air, reducing insulation and allowing convection currents to circulate. In cold countries, triple glazing is used. Modern double glazing uses special glass to increase the greenhouse effect. Roof insulation uses similar panels to wall cavities, trapping a thick layer of air. Reflective foil reduces radiation heat loss. Other energy-saving measures include thermostats and computer control systems for central heating and reducing draughts from poorly fitting doors and windows. Understanding heat travel can save money, keep warm, and reduce global warming.

Insulting people and animal

Clothing can help reduce heat loss from the body by trapping air around the body and providing insulation. Hats are the human equivalent of loft insulation. Wind can cause rapid heat loss by forced convection and rapid cooling, contributing to the wind-chill factor. To reduce this, wind-proof outer clothing is recommended. Hypothermia can occur when body heat loss is too high, potentially fatal.

Figure 15.19 Penguins stand close together for warmth.

4.3 Work and power

Energy and work

Energy is the ability to perform work, not its nature. It is found in various stores but is primarily focused on its ability to perform work. Measuring work is crucial, as mechanical tasks like lifting heavy objects are easily quantifiable.
The definition of work in physics is:

work done, W (joules) = force, F (newtons) × distance moved, d (metres)

$$W = F \times d$$

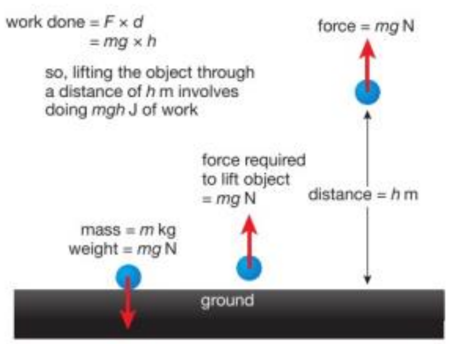
Gravitational potential energy (GPE)

The gravitational potential energy of an object that has been raised to a height, h, above the ground is given by:

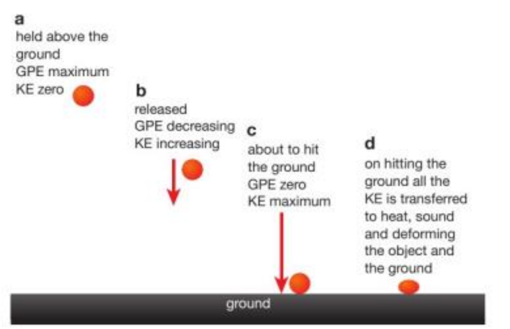
gravitational potential energy, GPE (joules) = mass of object, m (kilograms) × gravitational field strength, g (newtons per kilogram) × height, h (metres)

$$GPE = m \times g \times h$$

The gravitational potential energy (GPE) of an object increases when applied in the opposite direction to gravity, while falling objects lose GPE. In the weight-lifting example, some chemical energy is transferred to heat in the weightlifter's body, while the rest is transferred to the weight due to increased height in the Earth's gravitational field.



▲ Figure 16.4 The work done to lift an object is equal to the GPE the object has at its new height.



▲ Figure 16.5 When a raised object falls, its gravitational potential energy is transferred first to kinetic energy and then to heat and sound.

Kinetic energy

The kinetic energy of a moving object is calculated using the equation:

kinetic energy, KE (joules) = mass, m (kilograms) × speed squared, v^2 (metres squared per seconds squared)

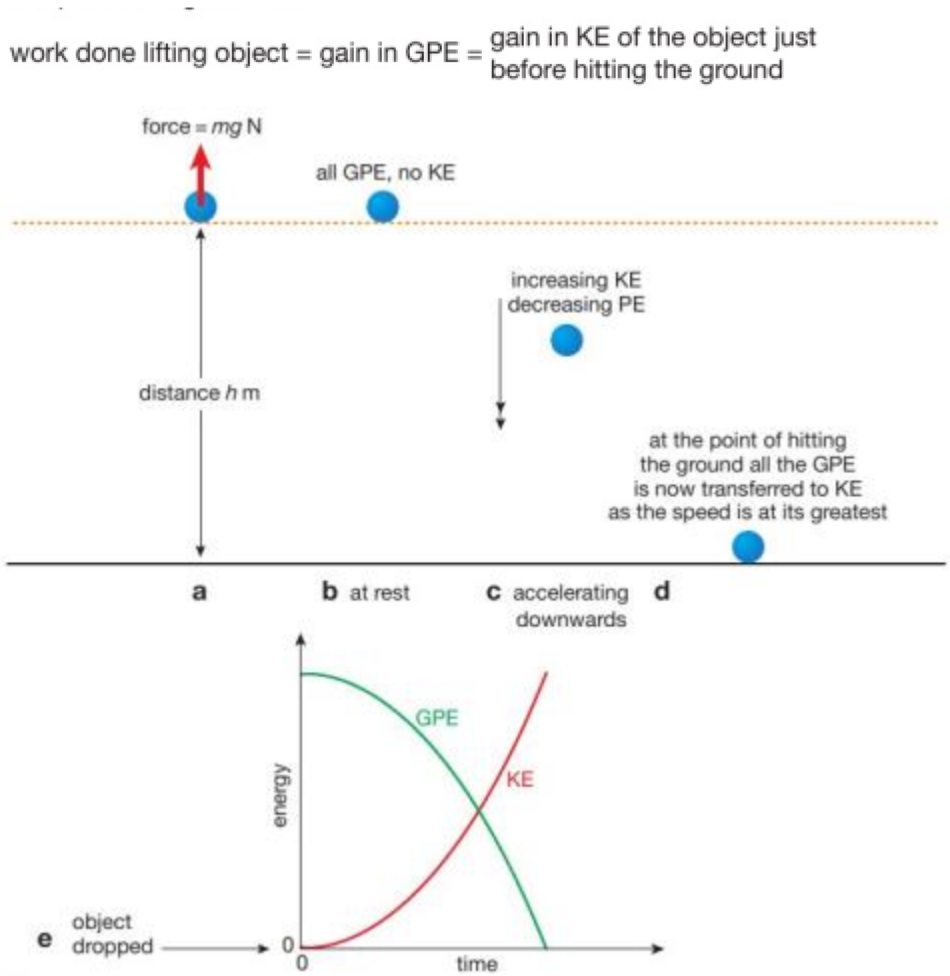
$$KE = \frac{1}{2} mv^2$$

Kinetic energy of an object depends on its speed and mass. Earth, orbiting the Sun, may collide with matter drawn into the Solar System's gravitational field. This is common, as seen in shooting stars and meteors, where kinetic energy is transferred to heat and light through friction.

▲ Figure 16.7 This crater was created when a meteorite collided with Earth in Arizona.

Calculations using work, GPE and KE

The concept of work transfers energy to an object, with mass (m) and force (F) being the same. When an object falls, it loses GPE but gains speed (KE). Energy is conserved, so the loss of GPE is equal to the gain in KE. This concept is illustrated in Figure 16.8.



▲ Figure 16.8 GPE and KE of a falling object: **a** doing work to lift an object; **b** all GPE; **c** GPE transferring to KE during fall; **d** all KE at end of fall; **e** graph showing relationship between GPE and KE as the object falls

Power

James Watt, inventor of the steam engine, was inspired by the pressure of steam forming inside a kettle. He worked with Matthew Boulton to develop improvements, making the engine a commercial product and significantly changing industry and transport. The story is not entirely accurate.

The SI unit of power is named in honour of James Watt. The watt (W) is the rate of transfer or conversion of energy of one joule per second (1 J/s).

$$\text{power, } P \text{ (watts)} = \frac{\text{work done, } W \text{ (joules)}}{\text{time taken, } t \text{ (seconds)}}$$

$$P = \frac{W}{t}$$

4.4 Energy resources and electricity generation

Non - renewable energy sources

Fossil fuels

Fossil fuels, including coal, oil, and natural gas, are non-renewable energy resources, formed over millions of years from dead vegetation or creatures, and will take millions of years for new reserves to form.

Fossil fuels are non-renewable energy resources that cannot be replaced once used, primarily releasing carbon dioxide into the atmosphere. This greenhouse gas, known as carbon dioxide, causes global warming and changes in climate. Burning coal releases more carbon dioxide than oil or gas, while natural gas produces less. Some energy companies are researching ways to capture and store carbon dioxide underground. Sulphur in coal and oil is converted into sulphur dioxide, which forms acid rain, damaging people, plants, and buildings. International agreements force companies to clean up waste gases, but acid rain remains a problem in developing countries.

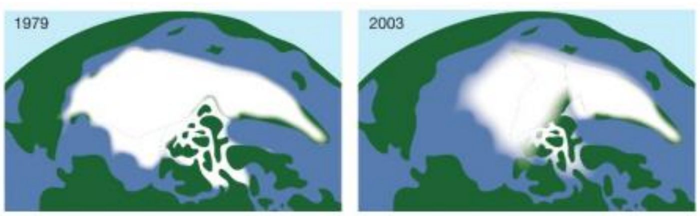


Figure 17.3 Polar ice caps melting

Figure 17.5 Many products are manufactured using extracts from oil and coal.

Nuclear fuel

Nuclear reactors utilize uranium, a non-renewable resource, to produce energy. However, uranium is limited and requires a specific form or isotope. Nuclear power is clean and cost-effective, but it also poses risks of accidents and disposal of **radioactive** materials. Accidents releasing radioactive materials into the atmosphere pose long-lasting risks to living things.

Electricity

Electricity is not an energy resource but must be generated using other energy sources. Currently, most electricity is generated in power stations using heat from nuclear or fossil fuels to heat water, creating high-pressure steam and turning turbine blades. Renewable energy resources can also be used for electricity generation.

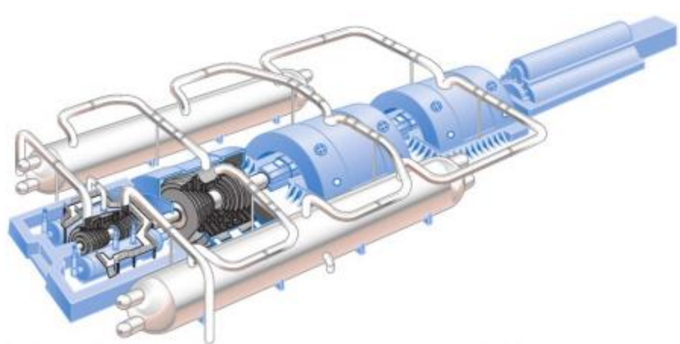


Figure 17.6 Turbines and generators like these are used to produce electricity in power stations.

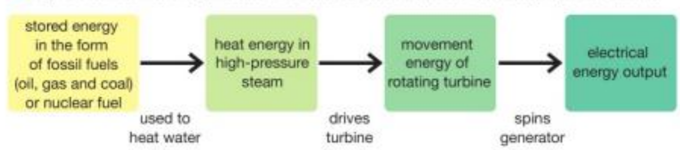


Figure 17.7 Several energy changes are involved in producing electricity.

Renewable energy sources

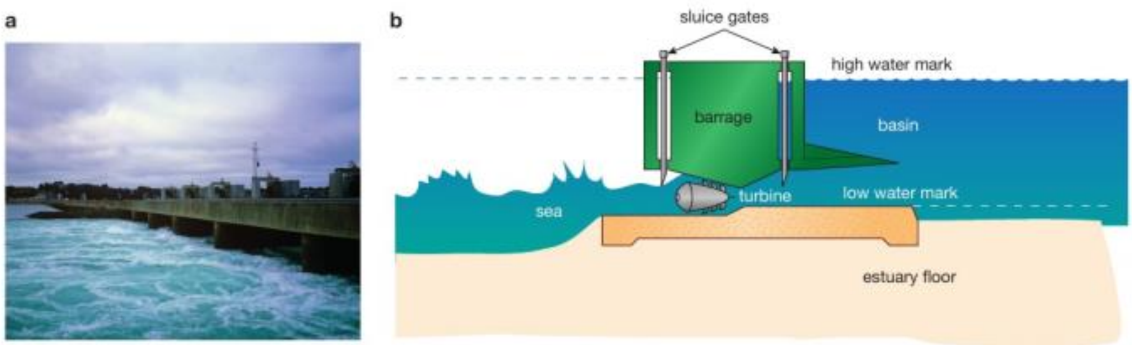
Wood is a renewable energy resource that can be maintained indefinitely through careful management. Burning wood produces pollution and greenhouse gases, but it's valuable for building or furniture. The demand for fuel and concerns about global warming have led to the search for alternative energy sources.

Hydroelectric power

Hydroelectric power stations harness the kinetic energy of moving water for centuries, using water wheels and turbines to power industrial machinery. The stored gravitational potential energy (GPE) of water in mountain reservoirs is converted into kinetic energy (KE) as it flows down the mountain. This renewable energy is clean and clean, but the construction of reservoirs can damage the landscape and wildlife habitats.

Tidal power

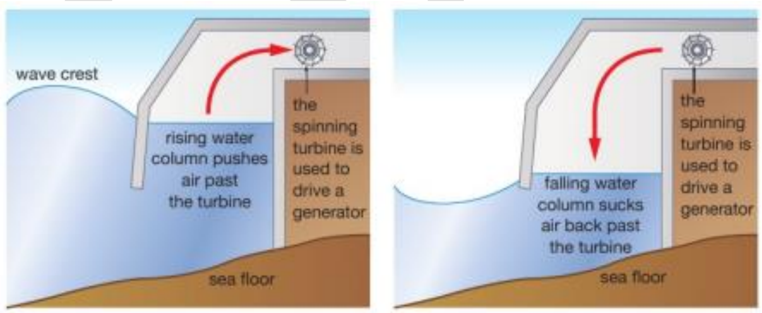
Tidal power generation schemes, like those at La Rance in Brittany, utilize the gravitational pull of the Moon and Sun to generate power from the movement of large amounts of water. However, dams are not suitable for tidal energy due to potential habitat damage. Instead, companies are developing 'tidal stream turbines', powered by tidal currents.



▲ Figure 17.9 **a** Tidal power station at La Rance, Brittany. **b** Tidal power also involves harnessing (using) the energy in moving water.

Wave energy

Waves, a combination of tides and wind, provide renewable energy through their continuous movement. Various methods have been developed to utilize this energy, ensuring clean waterpower without greenhouse gases or waste products.



▲ Figure 17.11 An oscillating water col

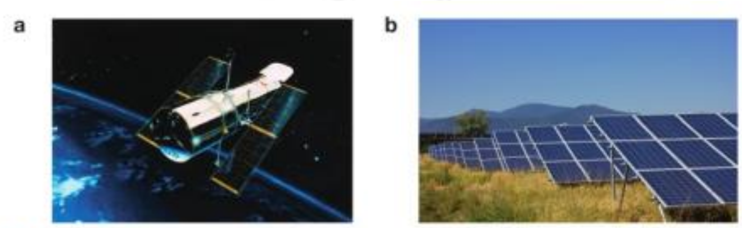
Wind power

Wind, powered by the Sun's heat energy, is a renewable energy source used for centuries. Today, wind turbines provide clean electricity. However, wind power is only harvested in regions with sufficient wind energy, causing environmental damage, noise pollution, and potential bird and bat deaths.

▲ Figure 17.12 Old windmills were a way of using wind energy.

Solar power producing electricity

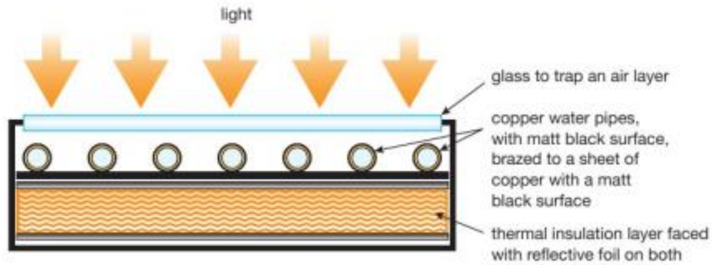
Photovoltaic cells, a 15% efficient renewable energy source, directly convert sunlight into electricity. With increasing efficiency and cost-effectiveness, more PV energy farms are being established to provide large amounts of electricity and small amounts for remote areas. While PV cells are environmentally friendly, concerns arise about the potential pollution and loss of farming land.



▲ Figure 17.13 Photovoltaic cells **a** on the Hubble space telescope, and **b** on an energy farm produce electricity when sunlight falls on them.

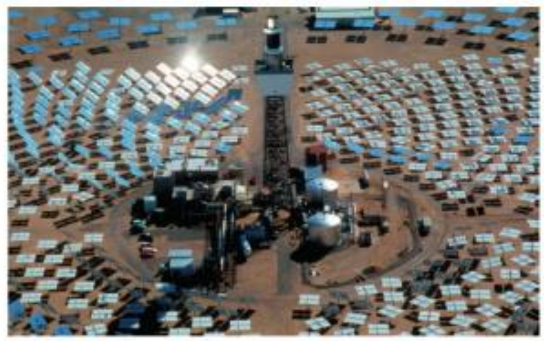
Solar power producing heat

Solar heating panels use Sun's heat to warm water, providing small quantities of hot water and reducing energy consumption from non-renewable resources. The design of these panels involves various heat transfer methods, absorbing thermal radiation to heat water. They are placed to receive maximum Sun's energy, facing south in the northern **hemisphere** and angled to allow direct light to fall on them. The typical solar heating panel structure is shown in Figure 17.15.



▲ Figure 17.15 Here is one type of solar heating panel. They are designed to transfer as much energy to the water passing through them as possible.

Water is pumped through copper pipes brazed onto a copper sheet, which is an excellent thermal conductor. The matt black finish absorbs heat radiation, while glass traps air to insulate the unit. The backing prevents heat escape. Solar heating panels are cost-efficient and widely used for water heating, making them a viable alternative to photovoltaic cells.



▲ Figure 17.16 A large number of mirrors focus heat from the Sun on a boiler in the tower at the centre. The steam produced drives a turbine to generate electricity.

Geothermal energy

Geothermal energy, stored deep within Earth, is produced by the decay of radioactive **elements** like uranium in volcanic activity regions. While volcanoes are not a reliable energy resource, ground-heated water from springs and geysers can be used safely for electricity generation and domestic heating. This renewable, non-polluting resource has a minimal environmental impact and is used in many areas, including Iceland, where geothermally heated springs are being used for energy.

Supply and demand

Electricity generation involves various energy resources with both advantages and disadvantages. Demand for electricity varies from hour to hour, day to day, and season to season, with some variations being predictable. Companies must be able to cope with these changes to avoid cutting off electricity to some consumers. Nuclear power stations cannot be turned on instantly due to the long process of starting the fission reaction and heating up the core. Fossil fuel-burning power stations can start quickly but take longer to produce electricity. Coal-fired and gas-fired stations can respond quickly to demand changes. Hydroelectric power stations can respond quickly to national demand changes and operate in reverse, using extra electricity to pump water back into high-level reservoirs.

Cost

Nuclear power generates electricity using cheap uranium fuel, but building a nuclear power station is expensive due to complex technology and safety standards. Decommissioning a nuclear power station is also costly due to radioactive materials. Despite low running costs, the pay-back time for nuclear power is long. On the other hand, wind farms have lower costs and no fuel costs, but their energy output is less, resulting in a longer pay-back time.

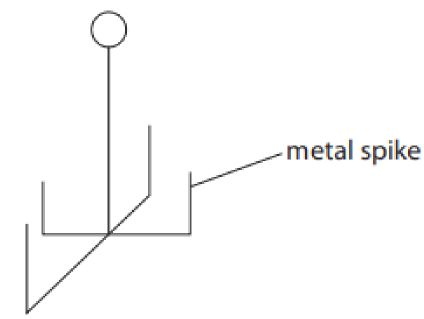
Revision questions

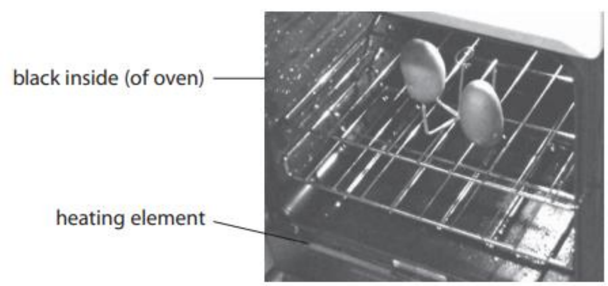
1) The diagram shows a metal device for cooking potatoes. Potatoes are pushed onto the metal spikes
The photograph shows two potatoes cooking in an electric oven.

The inside of the oven is black.

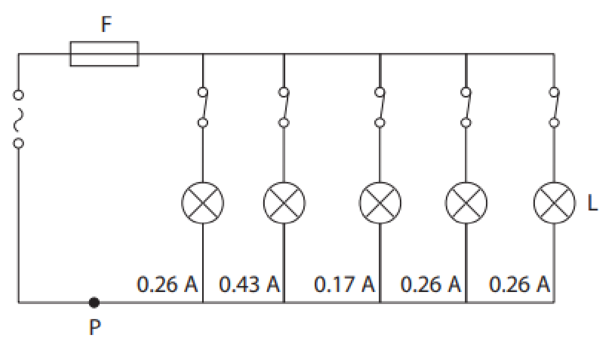
The heating element is at the bottom of the oven

Describe the different ways in which energy is transferred to cook the potatoes



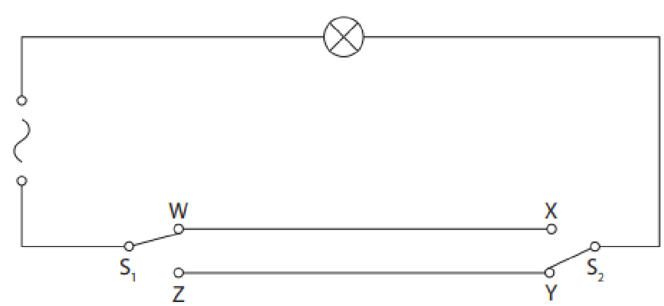


(2) The diagram shows part of a lighting circuit in a house.
The circuit is protected by fuse F



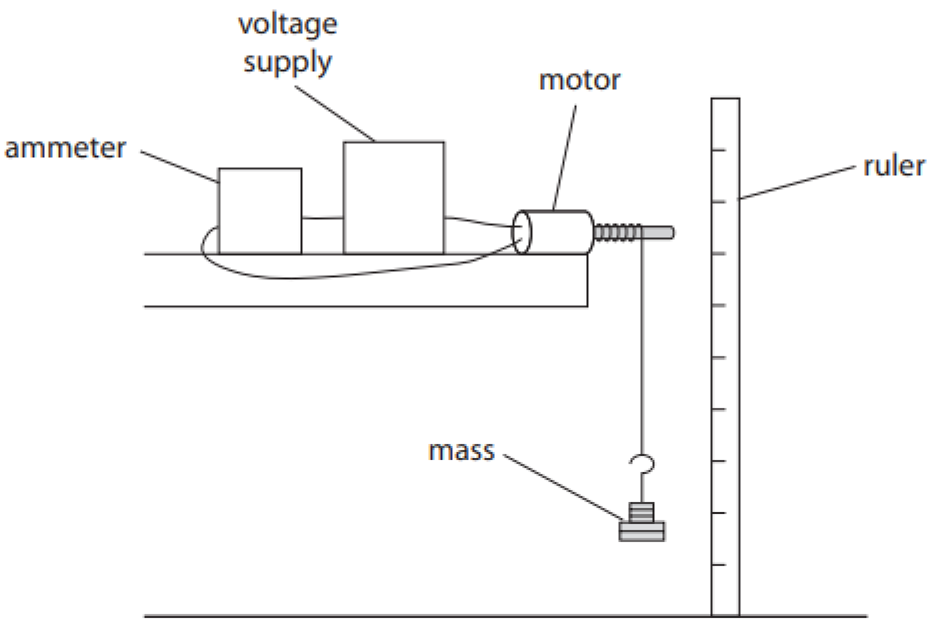
(a) Give two reasons why the lamps are wired in parallel.
(b) What is the current at P?
(c) Explain how the fuse protects the circuit.
(d) (i) State the equation linking power, current and voltage.
(ii) Calculate the power of lamp L. [assume the mains voltage is 230 V]
(iii) Calculate the amount of energy transferred by lamp L in 3 minutes. Give the unit
(e) This diagram shows another lighting circuit
(i) Complete the table by putting a tick (9) in the box if the lamp is lit and a cross (8) in the box if the lamp is not lit.

S_1 position	S_2 position	lamp lit (✓ or ×)
W	X	
W	Y	
Z	X	
Z	Y	



(ii) Suggest where this circuit would be useful in a house.

(3) (a) The diagram shows a motor lifting a 130 g mass



The current in the motor is 2.1A and the voltage across it is 12 V. The motor takes 1.5 s to lift the mass.

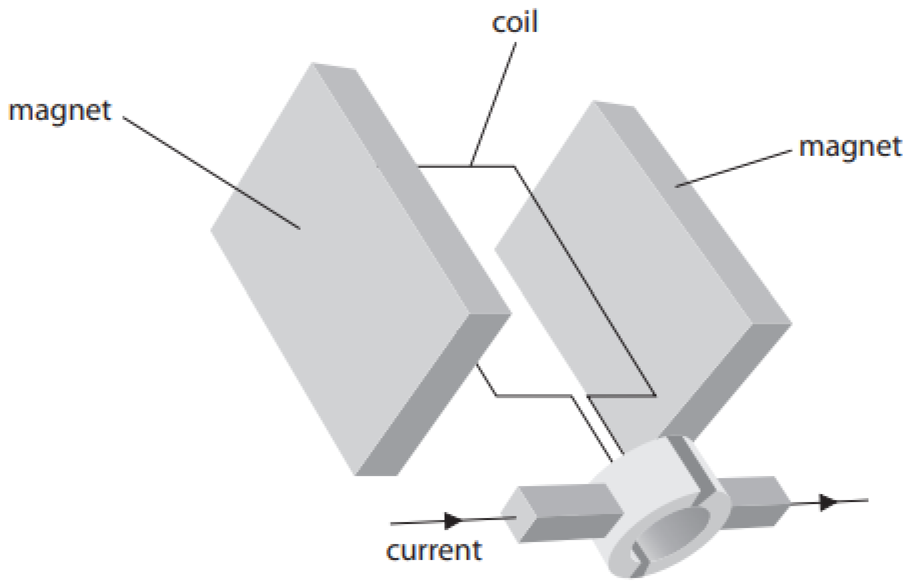
(i) Calculate the electrical energy transferred to the motor as it lifts the mass. Give your answer to two significant figures.

ii) State the equation linking gravitational potential energy, mass, g and height.

(iii) The motor lifts a 130 g mass to a height of 63 cm. Calculate the gravitational potential energy (GPE) gained by the 130 g mass.

(iv) Why is the amount of GPE gained by the mass less than the amount of electrical energy transferred to the motor?

(b) The diagram shows an electric motor and the direction of current



Explain how the current produces movement of the coil.

(4) The photograph shows a solar-powered battery charger connected to a mobile phone.

When the battery charger is used, it transfers light energy from the Sun to the battery of the mobile phone.

(a) Complete the energy transfer diagram

(b) It takes 3.5 hours to recharge the battery fully. The average current supplied by the charger is 400 mA.

(i) State the equation linking charge, current and time

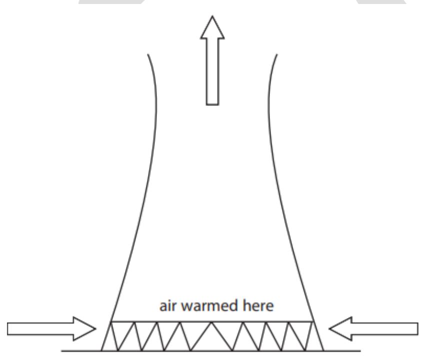
light energy from the Sun	→	.... energy in the charger and the cable	→	.... energy in the battery of the mobile phone

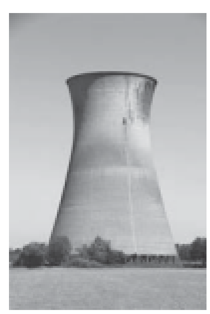
(ii) Calculate the amount of charge needed to recharge the battery fully, and give the unit

(c) If the charger is moved into the shade, the output power decreases. The voltage across the charger stays the same. Explain how moving the charger into the shade affects the time needed to recharge the battery fully.

(5) A cooling tower is designed to transfer thermal energy away from a power station

(a) Thermal energy from the power station warms the air inside the cooling tower.

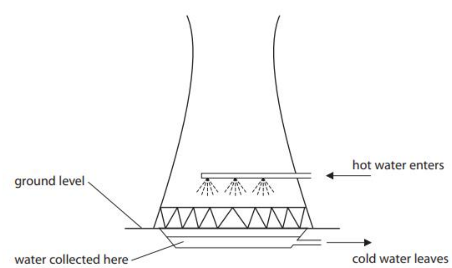




Air enters through holes at the bottom of the cooling tower and leaves through the top.

Explain why the air moves as shown by the arrows.

(b) Hot water from the power station is sprayed into the cooling tower, as shown. As it falls through the air, some of the hot water evaporates. The rest of the water is collected and returned as cold water to the power station. Explain how evaporation cools the water.



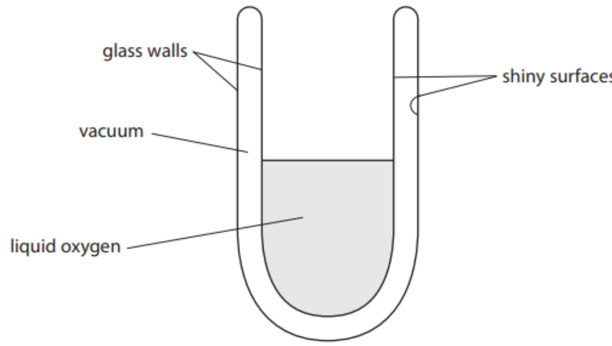
(6) James Dewar was a scientist who investigated liquid oxygen.

(a) He discovered that the boiling point of liquid oxygen is –183 °C.

(i) Convert –183 °C to a temperature on the Kelvin scale.

(ii) Use ideas about particles to describe the changes that happen when a liquid boils to form a gas.

(b) Dewar invented a special flask for storing liquid oxygen in the laboratory.



It was designed to reduce heat flow from the air outside to the liquid oxygen inside.

The flask had two glass walls with a vacuum between them.

The inside glass surfaces were each covered with a thin layer of shiny metal.

The diagram shows a cross section of the flask

(i) Explain how the shiny surfaces reduce the thermal energy transferred to the liquid oxygen from the laboratory.

(ii) Explain how the vacuum reduces the thermal energy transferred to the liquid oxygen from the laboratory.

(c) Dewar's flask did not have a lid when it was holding liquid oxygen. Suggest why a lid was not needed.

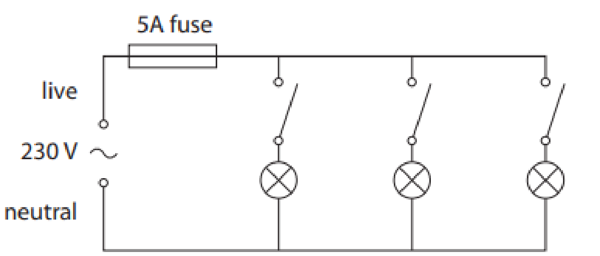
(7) The diagram shows the lighting circuit in an office.

(a) (i) State two advantages of connecting lamps in parallel rather than in series.

(ii) What is the purpose of the 5A fuse?

(iii) Explain how a fuse works

(b) A label on one of the office computers includes this information



230 V	0.25 kW

(i) State the equation linking power, current and voltage.

(ii) Use the information on the label to calculate the current in the computer

(iii) Fuses are available with values of 1A, 3A, 10A and 13A.

Suggest the most suitable fuse value for the computer.

Give a reason for your answer

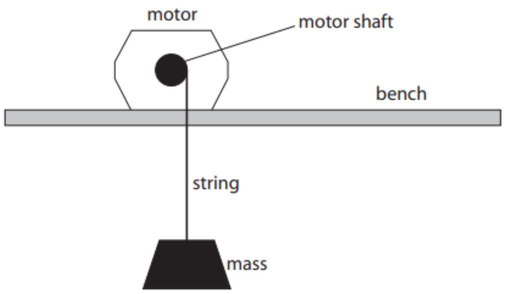
(iv) Some circuits use a circuit breaker instead of a fuse. State two advantages of using a circuit breaker instead of a fuse.

(8) A student investigates the efficiency of an electric motor

She uses the motor to lift a mass.

The table shows her measurements

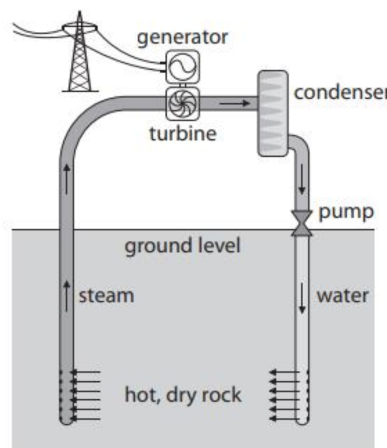
(a) Calculate the electrical energy supplied to the motor during this time



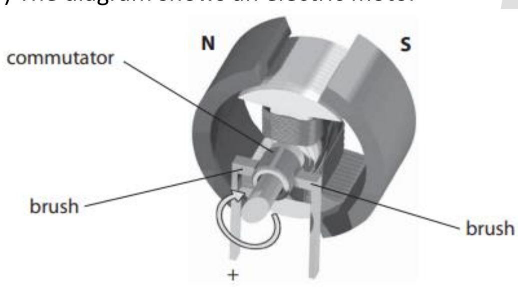
Current in motor	1.3 A
Voltage across motor	10.3 V
Time taken to lift mass	4.7 s
Force needed to lift mass	20 N
Distance the mass was lifted	0.85 m

(b) (i) State the equation linking work done, force and distance moved.
(ii) Calculate the work done on the mass
(iii) State the useful energy transferred to the mass.
(c) (i) State the equation linking efficiency, useful energy output and total energy input
(ii) Calculate the efficiency of the motor

(9) The diagram shows a type of power station used to generate electricity.
(a) (i) What type of renewable resource does this power station use?
(ii) Name another renewable resource.
(b) Cold water is pumped down into the hot, dry rock. Describe the energy transfers at each stage of electricity generation from this resource



(b) The diagram shows an electric motor



(a) This electric motor needs a direct current (d.c).
(i) Explain what is meant by the term direct current.
(ii) Explain the purpose of the brushes and the commutator in a d.c. motor.
(iii) The motor turns clockwise when the direction of the current goes from + to – . State what happens to the motor when both the magnetic field and the current are reversed.