Unit 2: Energy transfer systems

Unit 2 is assessed by completing a 1.5 hour external examination. The examination consists of a series of compulsory short answer, structured questions.

It is supported by two types of resource material:

- **supporting activities** which develop and provide opportunities to cover the practical aspects of the unit (enclosed in this pack); and
- a **revision guide** which covers and tests students' understanding of the unit content (available seperately).

Unlike portfolio-assessed units, there are fewer opportunities for practical work. However, in the exam students will be expected to show they can plan and evaluate investigations to make sure the outcomes are valid and reliable. These could include laboratory investigations or investigations that mimic professionals working in a scientific environment.

In Unit 2 students learn about:

- the structure and function of the circulatory and respiratory systems, including the processes involved in respiration
- some methods of taking physiological measurements related to the circulatory and respiratory systems, and the uses of these in monitoring health and diagnosing illness
- examples of imaging methods used in monitoring health and in diagnosis, the advantages and disadvantages of using these methods, and which are best suited to particular situations
- ethical issues relating to the monitoring, diagnosis and treatment of the circulatory and respiratory systems
- relating information from measurements or monitoring to what is happening in the organs and systems involved
- some applications of energy transfer both in the body and in wider contexts
- the meaning of the term efficiency, how to calculate the efficiency of a system and know that there is a fundamental limit to efficiency.

The supporting activities

The following supporting activities give students experience of and an opportunity to demonstrate their ability to:

- plan and carry out investigations to find out about physiological status through monitoring of the circulatory and respiratory systems
- discuss ethical issues relating to the monitoring, diagnosis and treatment of the circulatory and respiratory systems
- interpret data
- investigate applications of energy transfer.

The activity summaries below provide more opportunities than students are likely to have the time for and so suitable ones will need to be selected.

Note: The activity summaries refer to those aspects that link directly to the specification. All are set in context.

A Pressure and pulse

Students:

- use standard procedures to measure the pulse and blood pressure of a selected group of subjects before, during and after a measured period of exercise
- carry out a data interpretation exercise which asks then to interpret Electrocardiogram (ECG) traces
- take part in a debate to discuss the ethical issues which relate to monitoring, diagnosis and heart patient treatment.

B Lung capacity and health

Students:

- use standard procedures to carry out lung capacity measurements using a spirometer
- carry out a technique to measure peak flow
- plan an investigation to see how tidal volume and vital capacity vary with height and weight
- read a case study and consider some of the ethical issues associated with lung transplants.

C Energy efficiency

Students:

- use and manipulate the formulae for kinetic energy, potential energy and efficiency
- calculate the cost of using various electrical appliances
- find out about the different methods of generating electricity
- research the problems caused by wasteful energy transfer, both large scale and small scale
- discuss practical methods of reducing wasteful energy transfer
- consider the social, environmental and financial consequences of using energy efficiently.

D Heat transfer

Students:

- carry out an investigation into heat transfer through different types of materials and heat loss from different types of surface
- watch the practical demonstrations or video clips showing conduction, convection and radiation and make notes
- find out about U values and how they are used in the construction industry
- describe how automatic feedback can control the temperature of a system.

AQA
AS GCE APPLIED SCIENCE
UNIT 2: ENERGY TRANSFER SYSTEMS

ENERGY EFFICIENCY

Specification links

This investigation relates to the following sections of Unit 2: Energy transfer systems

Content

- Applications of energy transfer

Assessment evidence

- 1.5 hour external examination marked out of 80 consisting of compulsory short answer, structured questions

4 science

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ENERGY EFFICIENCY

Is there science behind a seance? Back in the 1800s Michael Faraday - a leading scientist of the day - went to two seances and devised an experiment to see if there was a rational explanation. He decided that "yes" there was, and dismissed the supernatural causes as nonsense ...

... but he's probably a little more well known for discovering how to make electricity using wire and a magnet. The advantages of a clean and easily transportable source of energy were quickly recognised. His discovery led to the development of generators powered by turbines.

Contents

The science at work

Producing electricity

There are many ways of generating electricity but more than 85 % of the world's electricity is generated by burning fossil fuels (gas, oil and coal) in thermal power stations.

Scientists and engineers are working on ways to generate power using renewable energy resources and those which don't release greenhouse gases into the atmosphere.

Geographical and climatic features have been harnessed to produce electricity. Large volumes of fresh water flowing to the sea have been dammed and are used to generate hydro-electric power. Waves, wind and geothermal energy are used to drive small turbines. Nuclear power stations use the energy stored in the nuclei of uranium atoms to produce steam which can drive large turbines.

Impact on the environment

Scientists monitor the use of energy and the consequent impact on the environment.

Burning fossil fuels, whether for heating, transport or electricity generation produces waste gases which have a negative effect on our surroundings. There is also the environmental cost of extracting and transporting hydrocarbon fossil fuels - coal, gas or oil.

There are hazards in disposing of the waste products from nuclear power generation. And there is a visual impact and potential disruption of community life with any renewable energy generation (hydro-electric, barrage, geothermal, wind farm, and so on). Scientists have to deal with all these issues.

Conservation of energy

Fossil fuels are finite resources which will become increasingly scarce and expensive. As well as developing renewable energy resources, scientists and engineers are trying to help people to use energy as efficiently as possible. If scientists don't succeed - think of the consequences.

Your brief

Your brief is to learn about the different types of energy transfer and the efficiency of the energy transfer process. This includes:

- using and manipulating the formulae for kinetic energy, potential energy and efficiency;
- calculating the cost of using various electrical appliances;
- finding out about the different methods of generating electricity;
- being aware of the problems caused by wasteful energy transfer, both large scale and small scale;
- discussing practical methods of reducing wasteful energy transfer;
- recognising the social, environmental and financial consequences of using energy inefficiently.

For all analytical work record your observations and interpretations, and answer the questions that come with each task.

The investigation

Energy transfer

Lifting heavy weights is hard work! To do it you need plenty of energy in the form of food, which is our fuel. For a machine to do the work for us it needs a source of energy or a supply of fuel. In fact, to do any mechanical work you need some form of energy and the work that is done will be equal to the energy transferred. Work and all types of energy have the same S.I. unit, the joule (J).

The energy that an object has because of its movement or motion is called **kinetic energy** and may be calculated using the formula:

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

where

E_k = kinetic energy (J)

m = mass (kg)

v = velocity (m s^{-1}).

Potential energy is the energy that an object has due to its position in the gravitational field of the Earth. If we raise an object from the ground we must do work against the force of gravity. The work done in raising the object is transferred to potential energy stored in the object. The potential energy stored is calculated using the formula:

$E_p = mgh$

where

E_p = potential energy (J)

m = mass (kg)

g = acceleration due to gravity (9.8 m s^{-2})

h = vertical height lifted (m)

If an object is raised above the ground and then allowed to fall, the stored potential energy will be transferred to kinetic energy as the object falls. There may be other energy transfers as well. For example, there may be some **sound** energy and **heat** energy transferred to the surroundings. If water is allowed to fall from a height the kinetic energy of the moving water may be used to turn a turbine and therefore generate **electrical** energy.

Electricity can also be generated in a coal fired power station which uses the **chemical** energy stored in the coal. **Nuclear** and **light** are two other forms of energy.

Questions

You will need to keep your answers to all the questions so you can use them for revision.

1 List all the forms of energy mentioned above.

2 State the energy transfers that take place in the following:

(a) a television set

(b) a light bulb

(c) a microphone

(d) a hairdryer

(e) muscles of the body

(f) a petrol engine

(g) fireworks

(h) a waterfall

(i) a pendulum

3 Calculate the kinetic energy, in joules, of a stone of mass 10g travelling at 5.0 m s^{-1}. (Don't forget to change the mass into kg!)

4 A 10 g stone is lifted 5.0 m above the ground.

(a) Calculate its gain in potential energy.

(b) How much kinetic energy will it have, just before it hits the ground?

(c) What have you assumed to do this calculation?

(d) With what speed will it hit the ground?

5 A girl of mass 55 kg climbs the 10 metre diving board in preparation for making her dive.

How much potential energy does she have at the top? How much work has she done in order to reach the top? She now jumps from the 10 metre board, what is the maximum amount of kinetic energy she can have just before she enters the water? What other forms of energy transfer may take place as she moves through the air?

Energy efficiency

We know from the Principle of Conservation of Energy that energy cannot be created or destroyed but that it may be transferred from one form into another.

This means that the **total** amount of energy, before and after the change, is always the same.
No energy is lost. This is the good news! However, not all the energy changes taking place are useful ones.

A light bulb transfers electrical energy into light energy and heat energy. Usually it's only the light energy that's useful: the heat energy isn't needed and so is wasted. Similarly, an electric motor converts electrical energy into useful mechanical or kinetic energy - but there's some heat energy and sound energy produced too and that's not needed to drive the motor.

In many mechanical systems, we want to know the efficiency of the conversion from the energy source into mechanical work. To calculate the efficiency of energy transfers we use the equation:

$$\boxed{\textbf{efficiency = useful energy out} \div \textbf{total energy in}}$$

As this equation is a ratio, efficiency has no units.

Work and energy have the same unit, the joule (J), so we can write:

efficiency = useful work out ÷ total energy in

Power is defined as the rate of doing work, or the rate of transferring energy:

energy = power x time or work = power x time

Power is measured in watts (W) and time is measured in seconds (s).

Energy is measured in joules **and** one watt is one joule per second.

Remember: you can rearrange the equation to power = energy ÷ time, or 1 W = 1 J per second.

Going back to efficiency, we can write the equation in another way, in terms of power.

efficiency = useful power out ÷ total power in

Although the SI unit of energy is the joule there are many other units that may be used. The kilowatt hour (kW h) and British thermal unit (Btu) are two of them. There is no need to change the units for energy (or power) as long as the two numbers that you put into the equation **have the same unit.** In other words, useful energy out and total energy in are both in joules or both in kilowatt hours or both in whatever unit you want to use. And don't mix up power and energy in the same equation.

Often efficiency is given as a percentage (%) in which case multiply the efficiency equations by 100.

efficiency (%) = (useful energy out ÷ total energy in) x 100 %

efficiency (%) = (useful power out ÷ total power in) x 100 %

Remember that you can never end up with more energy than you started with. The answer you get for efficiency can never be more than 1 or 100 %. If your calculation gives an answer greater than this you have gone wrong somewhere!

Questions

1 A dishwasher has a heating element of power rating 2.5 kW. It heats the water to the required temperature in 400 s.

(a) Calculate the total electrical energy supplied.

(b) If the actual energy required to heat the water is 750 kJ calculate the efficiency of the process.

2 A hydroelectric power station has an output power of 6.0 MW when water passes through its turbines. The water is supplied from a reservoir which is vertically above the power station turbines. If the potential energy lost per second of the water flowing from the reservoir to the turbines is 1.1×10^7 J, calculate the efficiency of the power station.

3 The turbines of a power station drive generators that produce an electrical supply. If the power input to the generators is 6.0 MW and the generator is 80 % efficient, calculate the electrical power produced by the generator.

4 A microwave oven has an output power of 600 W. If the electrical power input to the oven is 1.6 kW calculate the efficiency of the microwave oven.

5 An electric motor is 60 % efficient. If 2500 J of electrical energy is supplied to the motor how much energy is wasted?

6 A student of mass 74 kg runs up a flight of stairs in 5.9 seconds. If the total height of the staircase is 4.2 m calculate the power developed by the student.

Cost of electrical energy

Petrol is sold by the litre, milk is sold by the pint and electricity is sold by the unit. One unit of electricity is one kilowatt hour (kW h). The kilowatt hour is a power of 1 kW or 1000 W used for one hour.

Cost (pence) = power (kW)* x *time (hours)* x *cost per unit (pence)

Questions

1 How many joules of energy equals 1 kilowatt hour?

2 How many kilowatt hours of electricity are consumed when the following appliances are used

(a) 2.0 kW electric fire for 2 hours

(b) 1500 W hairdryer for 20 minutes

(c) 100 W lamp for 4 hours

3 If the cost per kilowatt hour is 13.8 pence, calculate the cost of using the following electrical appliances

(a) 3 kW kettle for 10 minutes

(b) 375 W stereo player for 2 hours

(c) 1600 W iron for 45 minutes

(d) 750 W toaster for 5 minutes

(e) 110 W television for 3.5 hours

4 Calculate the annual cost of using a fridge of capacity 338 litres. In one year it uses 190 kW h of electricity per 100 litres. The average cost per unit is 10.6 pence.

5 An upright freezer of capacity 262 litres uses 376 kW h per 100 litres per year compared to a chest freezer of capacity 257 litres which uses 292 kW h per 100 litres per year.

Which freezer is more economical to run?

6 A tumble drier has a motor of power rating 250 W and a heater of 2000 W. Calculate the cost of using the tumble drier for one hour if the heater is switched on for 75 % of the time.

Use 13.8 pence per kW h.

7 A television set left on standby uses 10 W of electricity. If the television is on standby mode for 20 hours a day calculate the extra energy used in one year compared with switching off the set.

The efficiency of a motor

Use *Standard Procedure: Efficiency of an electric motor* to find the efficiency of an electric motor that you will be given.

Draw an energy flow diagram to show the different forms of energy transfers that take place starting from the electrical energy input to the motor and ending with the potential energy of the raised mass.

Questions

1 What is the efficiency of the electric motor you used?

2 What percentage of electrical energy to the electric motor is wasted?

3 What form(s) does this wasted energy take?

4 How could you improve the efficiency of the motor?

5 Write a modified standard procedure for a situation where a mass is pulled up a slope or ramp rather than vertically through the air.

(a) Does this improve the efficiency of the energy transfer?

(b) What type of surface would give the best efficiency?

6 **Plan** a procedure to show how the efficiency of the motor changes when the load (or mass) lifted is varied. Remember to keep all the other factors constant whilst you change the value of the mass.

Limits to efficiency

Obviously it's important financially and environmentally for machines and heating systems to be as efficient as possible.

Energy conversions are never 100 % efficient as some energy is wasted in the transfer process, often as heat. However, processes that convert heat energy into mechanical energy are particularly inefficient. The devices that do this are called heat engines and these include the steam turbine (used in some power stations as part of the electricity generation process), petrol and diesel engines.

The efficiency of a heat engine is governed by the second law of thermodynamics which may be stated as the equation:

efficiency = useful work out ÷ total heat put in

Work and heat are both measured in joules.

Not surprisingly, the amount of heat on each of the output and the input sides of a heat engine is related to temperature. The efficiency of a heat engine can, therefore, be written in terms of temperature:

efficiency = temperature difference ÷ hot temperature

$$\text{efficiency (\%)} = \frac{T_H - T_C}{T_H} \times 100$$

where

T_H = hot temperature (K)

T_C = cold temperature (K)

Notice that both temperatures must be in Kelvin (K) and not °C.

Remember: temperature in K = temperature in °C + 273

Heat naturally flows from a high temperature to a lower one. If we want heat to flow in the opposite direction then some mechanical work must be done. Heat pumps and refrigerators work in this way. It's the reverse of a heat engine.

In the **heat engine** heat flows from a hot place to a colder place and produces work.

In the **heat pump** and **refrigerator** heat is made to flow from a cold place to a hotter place by doing work.

When referring to refrigerators and heat pumps the term ***coefficient of performance*** is often used rather than efficiency.

Questions

1 Look at the equation above for efficiency of a heat engine. What must the temperature of the cold side of the heat engine be for the efficiency to be 100 %? Is this possible?

2 What is the maximum possible efficiency of a heat engine using steam at 100 ºC when the ambient temperature is 15 ºC? Will this engine be more or less efficient on a hot summer day? Explain your answer.

Generating electricity

Electricity is generated in a variety of ways using a variety of energy sources.

You need to find out about the different types of energy transfers that might be present in the process of generating electricity.

Make detailed notes (including diagrams and charts) describing these, following the points below.

Although your notes won't be used as part of your portfolio you need this knowledge for the examination. The notes will help you to learn and, later on, to revise.

What to do

Working in a group, look for the best sources of information about generating electricity and share your suggestions with each other. Then, work on the first two questions, either by yourself or by sharing the work between members of the group.

1 Find out about the generation of electricity using coal, nuclear power, hydroelectric power, biogas and solar power.

2 Make a labelled drawing to show the principal energy transfers that take place - from the source of the energy to the end product, the electricity. Use Sankey diagrams as well.

In your group compare your findings using the next five questions.

3 Which methods use finite resources that will eventually run out? Which use renewable sources of energy? What are the different sources?

4 Do all of the methods use a heat engine (a steam or gas turbine) to turn the generator and produce the electricity?

5 What are the problems when generating electricity from each source? Think about the amount of electrical energy produced for the effort used (the efficiency), the effect on the environment, the availability of fuel, the cost and where the plant can be sited.

6 What are the advantages of each type of electricity generation?

7 What are the problems, both large and small scale, caused by wasteful energy transfer? How could this waste be reduced?

In your group, devise some charts that will describe and compare the different ways of generating electricity. Make sure that each member of the group has a copy of all of the charts.

Now write up any other details that aren't on the charts.

Your findings

Don't forget to …

- check your answers to the calculations are correct;
- make sure your written notes on methods of generating electricity cover the points 1 to 7 above;
- record your practical work and your plan to find the efficiency of an electric motor;
- keep your notes, your calculations and the record of your practical work to aid your revision.

Useful resources

www.cat.org.uk
www.le.ac.uk/se/centres/sci/selfstudy/egy.htm
www.ace.mmu.ac.uk/eae/Sustainability/Older/Energy.html
www.darvill.clara.net/altenerg/fossil.htm
www.npower.com/education/
A good overview on all methods of generating electricity can found at
www.classroom-energy.org/teachers/energy_tour/pg5.html

Standard Procedure: Efficiency of an electric motor

1 Scope

This procedure is used to determine the efficiency of a small electric motor.

2 Definitions

Efficiency: a measure of how well energy is transferred from one form to another.

Efficiency (%) = (useful energy transferred ÷ total energy put in) x 100

3 Principle

An electric motor lifts a mass through a vertical height. The total energy put in is the electrical energy supplied to the motor. The useful energy transferred will be the potential energy gained by the raised mass.

4 Equipment and materials

- low voltage dc power supply with variable voltage
- small electric motor with spindle
- dc ammeter
- dc voltmeter
- mass 100 g
- length of string about 70 cm long
- G clamp
- connecting wires
- switch
- metre rule
- base clamp
- stop clock
- balance weighing to 0.1 g

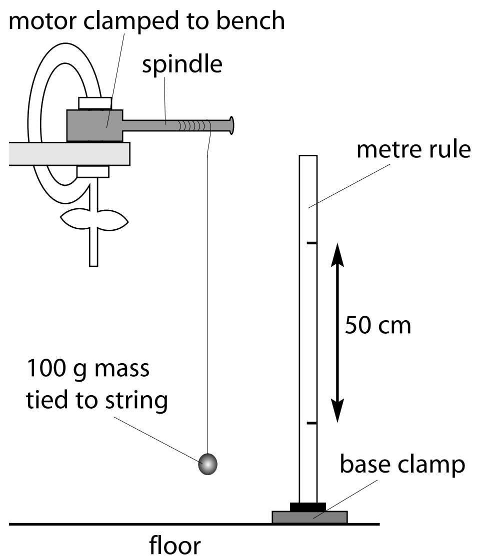
5 Procedure

1 Consult a risk assessment for this procedure and consider whether it needs to be adapted to suit the particular conditions under which you are working. Implement the control measures identified, modifying them as necessary, but first ask your teacher to check your risk assessment.

2 Use the G-clamp to clamp the electric motor to the edge of the table or bench so the spindle hangs over the side. Tie the string securely to the spindle and wind a little of the string onto it. Allow the rest of the string to hang down.

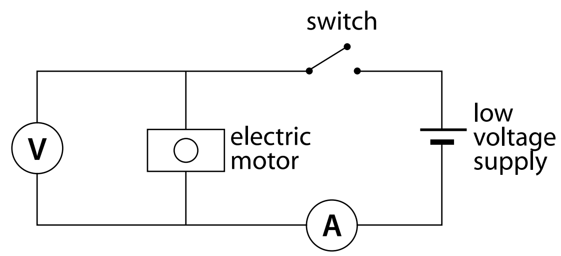
3 Weigh the 100 g mass and record its mass to 0.1 g. Tie the mass to the free end of the string.

4 Use the base clamp to set up the metre rule vertically alongside the mass and string. See diagram, below.



5 Mark two points on the metre rule 50 cm apart. Start with the mass below the bottom mark.

6 Set up the electric circuit as shown below.



7 Close the switch and allow the motor to raise the mass. Start the stop clock when the mass passes the lower mark and stop the clock when it passes the higher mark. Note the time taken (t) for the mass to be raised 50 cm.

8 Record the current (*I*) on the ammeter and potential difference (*V*) on the voltmeter whilst the mass is being lifted.

9 Repeat steps 7 and 8 until consistent results are obtained.

10 Change the potential difference supplied to the motor if you are using a variable power supply. Repeat the experiment to find the efficiency using a different energy input. Change one factor (the potential difference) at one time.

6 Calculations

1 Calculate the total electrical energy (in joules) given to the motor.

Total energy = $I \times V \times t$

2 Calculate the useful energy (in joules) transferred to the mass.

Energy transferred = mass (kg) x *9.81* x *height (m).*

The mass used was 100 grams which must be changed to kg. The height must be in metres.

3 Calculate the efficiency of the electric motor.

Efficiency (%) = (useful energy transferred ÷ total energy put in) x 100

7 Test Report

The test report should include:

- tables of your readings of:
  - current;
  - potential difference;
  - time.
- clearly laid out calculations of:
  - the mean energy supplied to the motor;
  - the useful energy transferred to the mass;
  - the efficiency of the electric motor.
- comments on the accuracy and reliability of your data, including a note of the main sources of error in the practical procedure.

Datasheet: Energy efficiency formulae

Efficiency (%) = (useful energy out ÷ total energy in) x 100 %
Efficiency (%) = (useful work out ÷ total energy in) x 100 %
Efficiency (%) = (useful power out ÷ total power in) x 100 %

Cost = power x time x cost per unit

$E = Pt$
where
E = energy (J)
P = power (W)
t = time (s)

$P = \frac{E}{t}$
where
P = power (W)
E = energy (J)
t = time (s)

$P = IV$
where
P = electrical power (P)
I = current (A)
V = potential difference (V)

$E_p = mgh$
where
E_p = potential energy (J)
m = mass (kg)
g = acceleration due to gravity (9.81 m s^{-1})
h = vertical height moved (m)

$E_k = ½mv^2$
where
E_k = kinetic energy (J)
m = mass (kg)
v = velocity (m s^{-1})

$E = IVt$
where
E = electrical energy (J)
I = current (A)
V = potential difference (V)
t = time (s)

Maximum possible efficiency of a heat engine = $\frac{T_H - T_C}{T_H}$ x 100 %

where
T_H = temperature of hot side (K)
T_C = temperature of cold side (K)

Temperature in K = temperature in ^oC + 273

1 kW = 1000 W = 10^3 W
1MW = 1000 000 W = 10^6 W

1 kJ = 1000 J = 10^3 J
1MJ = 1000 000 J = 10^6 J

1 W = 1 joule per second = 1 J s^{-1}

General

This unit will be assessed by an external exam of 1.5 hours and not portfolio evidence. It is therefore important that the students have a full set of accurate notes for their revision of this topic. The notes should include correct solutions (and working) to the numerical questions and details of the experiment to find the efficiency of an electric motor.

Generating electricity

Depending on the number of students in the group or class the research on the section "Generating Electricity" could be divided up amongst the students. The briefing gives one method of group working. It is important that each student has a full set of notes at the end.

Alternatively, the research could be divided between the whole class: groups of two or three students could each research one particular method of generating electricity. They then present their findings to the rest of the class using a PowerPoint presentation or interactive quiz. This should encourage a discussion with the audience on the advantages and problems associated with that particular method of power generation. At the end of the presentation the group of students **must** provide a set of notes for the other members of the class to use for revision.

A visit to a local power station, if it could be arranged, would give the students more idea of how the power station operates and also give an opportunity to ask questions. A useful web site which shows the location of different power stations is

www.npower.com/education/Power_station_visits.html

Efficiency of an electric motor

An electric supply with variable voltage is not essential for this procedure. There are two options if a variable supply is not available: the procedure can be repeated using a different, but fixed, voltage supply, or it can be repeated using a different mass.

In the student briefing, it is suggested that students should plan a procedure, based on incremental changes in the mass lifted by the motor. There may be a need for emphasis on keeping other variables the same and guidance on the way that the mean value is calculated.

Answers to numerical questions

Energy transfer

3 0.125 J

4 0.49 J, 0.49 J, that all the PE at the top is transferred to KE at the ground with no other energy transfers taking place

5 10 m s^{-1}

6 PE = 5390 J, work done = 5390 J, max KE = 5390 J, heat transferred to air and sound

Energy efficiency

1 0.75 or 75 %

2 0.55 or 55 %

3 4.8 MW

4 0.38 or 38 %

5 1000 J

6 516 W

Cost of electrical energy

1 3.6×10^6 J or 3.6 MJ

2 (a) 4.0 kW h

(b) 0.5 kW h

(c) 0.4 kW h

3 (a) 6.9 p

(b) 10.35 p

(c) 16.56 p

(d) 0.86 p

(e) 5.31 p

4 £68.07

5 the chest freezer

6 24.15 p

7 73 kW h

The efficiency of a motor

1 0 K or absolute zero

2 0.23 or 23 % less efficient as T_C will be higher

Equipment and materials

Standard Procedure: Efficiency of an electric motor

- low voltage dc power supply with variable voltage
- small electric motor with spindle
- dc ammeter
- dc voltmeter
- mass 100 g
- length of string about 70 cm long
- G clamp
- connecting wires
- switch
- metre rule
- base clamp
- stop clock
- balance weighing to 0.1 g

Note: Two different fixed voltage supplies could be used if a variable power supply is not available. If only a single voltage supply is available, students could vary the mass. This additional mass will depend on the power of the motor.