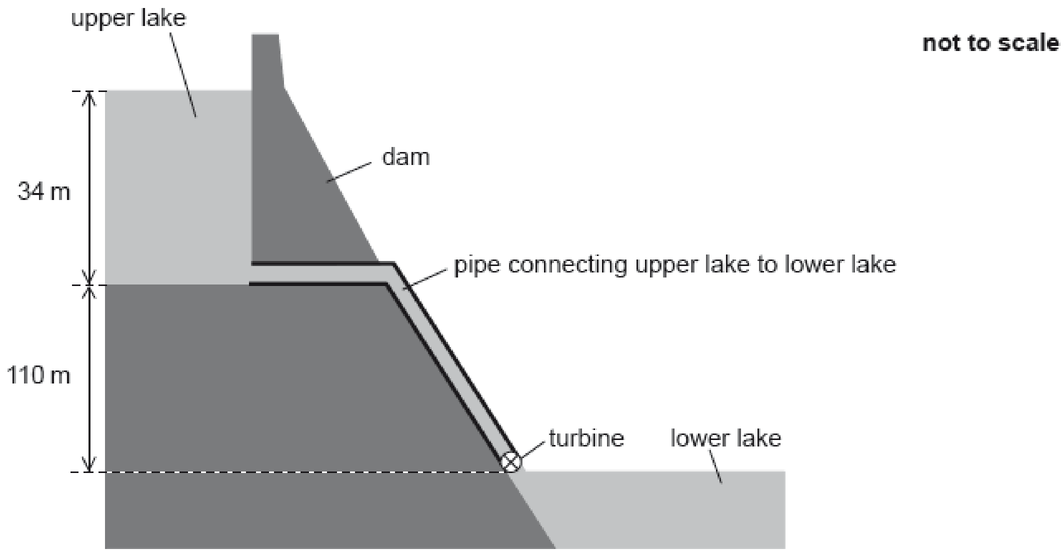
SL Paper 2

In a pumped storage hydroelectric system, water is stored in a dam of depth 34 m.



The water leaving the upper lake descends a vertical distance of 110 m and turns the turbine of a generator before exiting into the lower lake.

Water flows out of the upper lake at a rate of 1.2×10^5 m^3 per minute. The density of water is 1.0×10^3 kg m^{-3}.

a.i. Estimate the specific energy of water in this storage system, giving an appropriate unit for your answer. [2]

a.ii. Show that the average rate at which the gravitational potential energy of the water decreases is 2.5 GW. [3]

a.iii. The storage system produces 1.8 GW of electrical power. Determine the overall efficiency of the storage system. [1]

b. After the upper lake is emptied it must be refilled with water from the lower lake and this requires energy. Suggest how the operators of this storage system can still make a profit. [1]

Markscheme

a.i. Average height = 127 «m»

Specific energy «= $\frac{mg\bar{h}}{m} = g\bar{h}$ = 9.81 × 127» = 1.2×10^3 J kg^{-1}

Unit is essential

Allow g = 10 gives 1.3×10^3 J kg^{-1}

Allow ECF from 110 m

(1.1×10^3 J kg^{-1}) or 144 m

(1.4×10^3 J kg^{-1})

[2 marks]

a.ii. mass per second leaving dam is $\frac{1.2\times10^5}{60}$ × 10^3 = «2.0×10^6 kg s^{-1}»

rate of decrease of GPE is = $2.0 \times 10^6 \times 9.81 \times 127$

= 2.49×10^9 «*W*» /2.49 «*GW*»

Do not award ECF for the use of 110 m or 144 m

Allow 2.4 GW if rounded value used from (a)(i) or 2.6 GW if g = 10 is used

[3 marks]

a.iii. efficiency is «$\frac{1.8}{2.5}$ =» 0.72 / 72%

[1 mark]

b. water is pumped back up at times when the demand for/price of electricity is low

[1 mark]

Examiners report

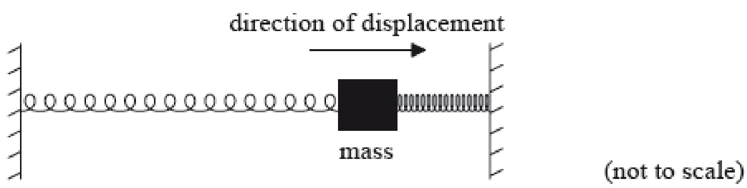
a.i. [N/A]
a.ii. [N/A]
a.iii. [N/A]
b. [N/A]

This question is in **two** parts. **Part 1** is about the oscillation of a mass. **Part 2** is about nuclear fission.

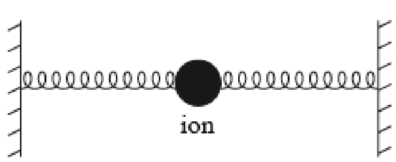
Part 1 Oscillation of a mass

A mass of 0.80 kg rests on a frictionless surface and is connected to two identical springs both of which are fixed at their other ends. A force of 0.030 N is required to extend or compress each spring by 1.0 mm. When the mass is at rest in the centre of the arrangement, the springs are not extended.

The mass is displaced to the right by 60 mm and released.



The motion of an ion in a crystal lattice can be modelled using the mass–spring arrangement. The inter-atomic forces may be modelled as forces due to springs as in the arrangement shown.



The frequency of vibration of a particular ion is 7×10^{12} Hz and the mass of the ion is 5×10^{-26} kg. The amplitude of vibration of the ion is 1×10^{-11} m.

Part 2 Nuclear fission

A reaction that takes place in the core of a particular nuclear reactor is as shown.

$$^{235}_{92}\mathrm{U} + ^{1}_{0}\mathrm{n} \rightarrow ^{144}_{56}\mathrm{Ba} + ^{89}_{36}\mathrm{Kr} + 3^{1}_{0}\mathrm{n}$$

In the nuclear reactor, 9.5×10^{19} fissions take place every second. Each fission gives rise to 200 MeV of energy that is available for conversion to electrical energy. The overall efficiency of the nuclear power station is 32%.

In addition to the U-235, the nuclear reactor contains a moderator and control rods. Explain the function of the

a.i. Determine the acceleration of the mass at the moment of release. [3]

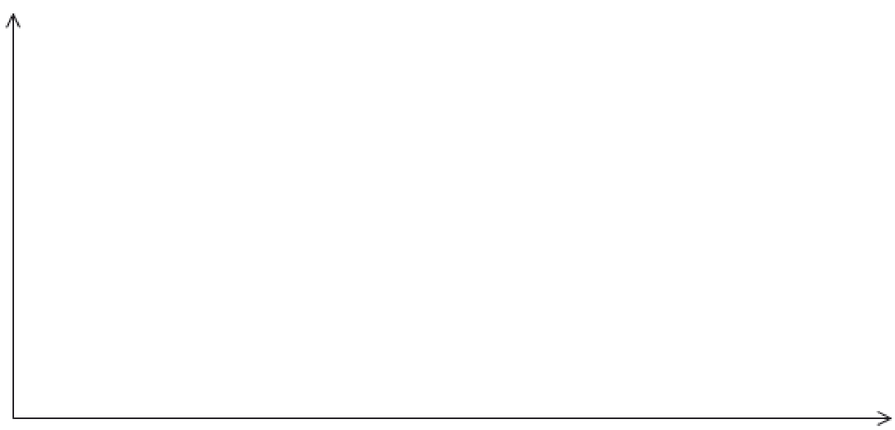
a.ii. Outline why the mass subsequently performs simple harmonic motion (SHM). [2]

a.iii. Calculate the period of oscillation of the mass. [2]

b.i. Estimate the maximum kinetic energy of the ion. [2]

b.ii. On the axes, draw a graph to show the variation with time of the kinetic energy of mass and the elastic potential energy stored in the springs. [3]

You should add appropriate values to the axes, showing the variation over one period.



c.i. Calculate the wavelength of an infrared wave with a frequency equal to that of the model in (b). [1]

d.i. Determine the mass of U-235 that undergoes fission in the reactor every day. [3]

d.ii. Calculate the power output of the nuclear power station. [2]

e.i. moderator. [3]

e.ii. control rods. [2]

Markscheme

a.i. force of 1.8 N for each spring so total force is 3.6 N;

acceleration $= \frac{3.6}{0.8} = 4.5\ \mathrm{ms}^{-2}$; *(allow ECF from first marking point)*

to left/towards equilibrium position / negative sign seen in answer;

a.ii.force/acceleration is in opposite direction to displacement/towards equilibrium position;

and is proportional to displacement;

a.iii.$\omega = \left(\sqrt{\left(\frac{a}{x}\right)} =\right) \sqrt{\frac{4.5}{60\times10^{-3}}}\ (= 8.66\ \mathrm{rad\,s^{-1}})$;

$T = 0.73\ \mathrm{s}$;

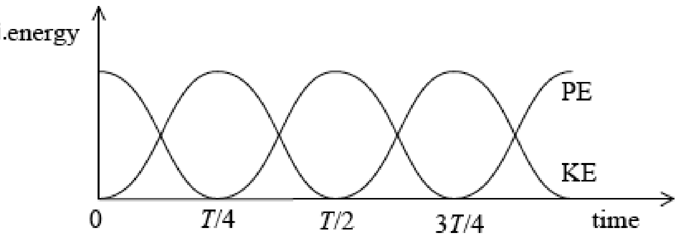
*Watch out for ECF from (a)(i) eg award **[2]** for $T = 1.0\ s$ for $a = 2.25\ \mathrm{m\,s^{-2}}$.*

b.i.$\omega = 2\pi \times 7 \times 10^{12} (= 4.4 \times 10^{13} Hz)$;

$5 \times 10^{-21}\ \mathrm{J}$;

Allow answers in the range of 4.8 to $4.9 \times 10^{-21}\ \mathrm{J}$ if 2 sig figs or more are used.

b.ii.



KE and PE curves labelled – very roughly $\cos^2$ and $\sin^2$ shapes; } *(allow reversal of curve labels)*

KE and PE curves in anti-phase and of equal amplitude;

at least one period shown;

either $E_{\max}$ marked correctly on energy axis, or T marked correctly on time axis;

c.i. $7.0 \times 10^{12}\ \mathrm{Hz}$ is equivalent to wavelength of $4.3 \times 10^{-5}\ \mathrm{m}$;

d.i.number of fissions in one day $= 9.5 \times 10^{19} \times 24 \times 3600\ (= 8.2 \times 10^{24})$;

mass of uranium atom $= 235 \times 1.661 \times 10^{-27}\ (= 3.9 \times 10^{-25}\ \mathrm{kg})$;

mass of uranium in one day $(= 8.2 \times 10^{24} \times 3.9 \times 10^{-25}) = 3.2\ \mathrm{kg}$;

d.ii.energy per fission $= 200 \times 10^{6} \times 1.6 \times 10^{-19}\ (= 3.2 \times 10^{-11}\ \mathrm{J})$;

power output $= (9.5 \times 10^{19} \times 3.2 \times 10^{-11} \times 0.32 =)\ 9.7 \times 10^{8}\ \mathrm{W}$;

*Award **[1]** for an answer of $6.1 \times 10^{27}\ \mathrm{eVs^{-1}}$.*

e.i. neutrons have to be slowed down (before next fission);

because the probability of fission is (much) greater (with neutrons of thermal energy);

neutrons collide with/transfer energy to atoms/molecules (of the moderator);

e.ii.have high neutron capture cross-section/good at absorbing neutrons;

(remove neutrons from the reaction) thus controlling the rate of nuclear reaction;

Examiners report

a.i. This is a slightly different situation. Most candidates at SL did not use F and m to find acceleration. Very few added the force due to each spring and ECF was frequently applied.

a.ii. [N/A]

a.iii. [N/A]

b.i. [N/A]

b.ii. Care was needed in showing the constant and equal amplitudes. Many poor answers were seen.

c.i. [N/A]
d.i. [N/A]
d.ii. [N/A]
e.i. Mostly good answers although it was rare to find a candidate who stated that the probability of further fusion is increased with thermal neutrons.

e.ii. Too many answers lacked precision referring only to the use of control rods in avoiding an explosion or meltdown.

This question is in **two** parts. **Part 1** is about energy resources. **Part 2** is about thermal physics.

Part 1 Energy resources

Electricity can be generated using nuclear fission, by burning fossil fuels or using pump storage hydroelectric schemes.

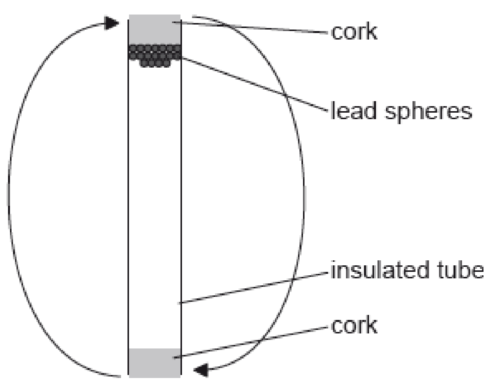
In a nuclear reactor, outline the purpose of the

Fission of one uranium-235 nucleus releases 203 MeV.

This question is in **two** parts. **Part 1** is about energy resources. **Part 2** is about thermal physics.

Part 2 Thermal physics

A mass of 0.22 kg of lead spheres is placed in a well-insulated tube. The tube is turned upside down several times so that the spheres fall through an average height of 0.45 m each time the tube is turned. The temperature of the spheres is found to increase by 8 °C.



a. Outline which of the three generation methods above is renewable. [2]

b.i. heat exchanger. [1]

b.ii. moderator. [2]

c.i. Determine the maximum amount of energy, in joule, released by 1.0 g of uranium-235 as a result of fission. [3]

d.i. Describe the main principles of the operation of a pump storage hydroelectric scheme. [3]

d.ii. A hydroelectric scheme has an efficiency of 92%. Water stored in the dam falls through an average height of 57 m. Determine the rate of flow of water, in $\mathrm{kg\,s^{-1}}$, required to generate an electrical output power of 4.5 MW. [3]

e. Distinguish between specific heat capacity and specific latent heat. [2]

f.i. Discuss the changes to the energy of the lead spheres. [2]

f.ii. The specific heat capacity of lead is $1.3 \times 10^2\ \mathrm{J\,kg^{-1}K^{-1}}$. Deduce the number of times that the tube is turned upside down. [4]

Markscheme

a. pump storage;

renewable as can be replaced in short time scale / storage water can be pumped back up to fall again / source will not run out; } *(do not accept "because water is used")*

b.i. (allows coolant to) transfer thermal/heat (energy) from the reactor/(nuclear) reaction to the water/steam;

Must see reference to transfer – "cooling reactor/heating up water" is not enough.

b.ii. reduces speed/kinetic energy of neutrons; *(do not allow "particles")*

improves likelihood of fission occurring/U-235 capturing neutrons;

c.i. (203 MeV is equivalent to) 3.25×10^{-11} (J);

6.02×10^{23} nuclei have a mass of 235 (g) / evaluates number of nuclei;

(2.56×10^{21} nuclei produce) 8.32×10^{10} (J) / multiplies two previous answers;

*Award **[3]** for bald correct answer.*

*Award **[1]** for correct conversion from eV to J even if rest is incorrect.*

d.i. water flows between water masses/reservoirs at different levels;

flow of water drives turbine/generator to produce electricity;

at off peak times the electricity produced is used to raise water from lower to higher reservoir;

d.ii. use of $\frac{mgh}{t}$;

$\frac{m}{t} = \frac{4.5\times10^6}{0.92\times9.81\times57}$; *(t is usually ignored, assume 1 s if not seen)*

$8.7 \times 10^3\ (\mathrm{kg\,s^{-1}})$;

*Award **[3]** for a bald correct answer.*

e. specific heat capacity is/refers to energy required to change the temperature (without changing state);

specific latent heat is energy required to change the state/phase without changing the temperature;

If definitions are given they must include salient points given above.

f.i. gravitational potential energy $\rightarrow$ kinetic energy;

kinetic energy $\rightarrow$ internal energy/thermal energy/heat energy;

Do not allow heat.

Two separate energy changes must be explicit.

f.ii. use of $mc\Delta T$;

use of $n \times mg\Delta h$;

equating $(c\Delta T = ng\Delta h)$;

236 ***or*** 240;

or

use of $\Delta U = mc\Delta T$;

$(0.22 \times 1.3 \times 10^2 \times 8 =)\ 229\ (\mathrm{J})$;

$n \times mg\Delta h = 229\ (\mathrm{J})$;

$n = \frac{229}{0.22 \times 9.81 \times 0.45} = 236$ ***or*** 240; } *(allow if answer is rounded up to give complete number of inversions)*

*Award **[4]** for a bald correct answer.*

Examiners report

a. [N/A]
b.i. [N/A]
b.ii. [N/A]
c.i. [N/A]
d.i. [N/A]
d.ii. [N/A]
e. The essential difference between specific heat capacity and specific latent heat is that the former refers to a change of temperature without changing state; whereas the latter refers to a change of state without changing temperature. Most candidates just wrote definitions which they had learnt by rote – and omitted the constant temperature for a substance changing state.

f.i. This is a question specifically about energy changes so candidates are expected to use accurate language and spell out the changes one by one. Common mistakes were omitting the “gravitational” in gravitational potential energy; referring to “heat” rather than thermal energy; and saying that gravitational potential energy changed to thermal and kinetic energy as if it were a single process.

f.ii. This was generally well done. There were four marks and the question asks the candidates to “deduce” so it is essential that the argument is transparent. The examiner cannot be expected to search through a mass of numbers in order to carry forward an error.

This question is in **two** parts. **Part 1** is about energy resources. **Part 2** is about electric fields.

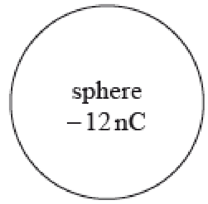
Part 1 Energy resources

A photovoltaic panel is made up of a collection (array) of photovoltaic cells. The panel has a total area of $1.3\ \mathrm{m}^2$ and is mounted on the roof of a house. The maximum intensity of solar radiation at the location of the panel is $750\ \mathrm{W\,m^{-2}}$. The panel produces a power output of 210 W when the solar radiation is at its maximum intensity.

The owner of the house chooses between photovoltaic panels and solar heating panels to provide 4.2 kW of power to heat water. The solar heating panels have an efficiency of 70%. The maximum intensity of solar radiation at the location remains at $750\ \mathrm{W\,m^{-2}}$.

Part 2 Electric fields

An isolated metal sphere is placed in a vacuum. The sphere has a negative charge of magnitude 12 nC.



Outside the sphere, the electric field strength is equivalent to that of a point negative charge of magnitude 12 nC placed at the centre of the sphere.

The radius r of the sphere is 25 mm.

An electron is initially at rest on the surface of the sphere.

a. The Sun is a renewable energy source whereas a fossil fuel is a non-renewable energy source. Outline the difference between renewable and non-renewable energy sources. [2]

b. With reference to the energy transformations and the operation of the devices, distinguish between a photovoltaic cell and a solar heating panel. [2]

c.i. Determine the efficiency of the photovoltaic panel. [2]

c.ii. State **two** reasons why the intensity of solar radiation at the location of the panel is not constant. [2]

1.

2.

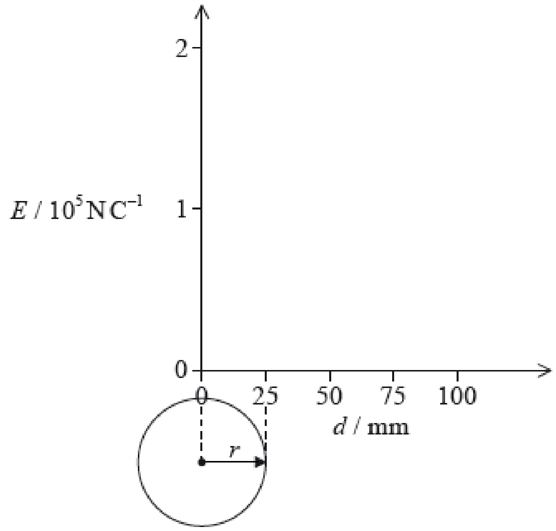
d.i. Calculate the minimum area of solar heating panel required to provide this power. [2]

d.ii. Comment on whether it is better to use a solar heating panel rather than an array of photovoltaic panels for the house. Do not consider the installation cost of the panels in your answer. [2]

f. Using the diagram, draw the electric field pattern due to the charged sphere. [2]

g.i. Show that the magnitude of the electric field strength at the surface of the sphere is about $2 \times 10^5 \text{ N C}^{-1}$. [2]

g.ii. On the axes, draw a graph to show the variation of the electric field strength E with distance d from the centre of the sphere. [2]



h.i. Calculate the initial acceleration of the electron. [2]

h.ii. Discuss the subsequent motion of the electron. [2]

Markscheme

a. *renewable sources*:

rate of use/depletion of energy source;

is less than rate of production/regeneration of source;

Accept equivalent statement for non-renewable sources.

or

mention of rate of production / usage;

comparison of sources in terms of being used up/depleted/lasting a long time *etc*;

*Award **[1]** if answer makes clear the difference but does not address the rate of production.*

b. solar heating panel converts solar/radiation/photon/light energy into thermal/heat energy <u>and</u> photovoltaic cell converts solar/radiation/photon/light energy into electrical energy; } *(both needed)*

in solar heating hot liquid is stored/circulated <u>and</u> photovoltaic cell generates emf/pd; } *(both needed)*

c.i. (power available at roof) $= 1.3 \times 750\ (= 975\ \mathrm{W})$;

efficiency $= \left(\frac{210}{975} =\right)\ 0.22$ ***or*** 22%;

c.ii. depends on time of day;

depends of time of year;

depends on weather (*eg* cloud cover) at location;

power output of Sun varies;

Earth-Sun distance varies;

d.i. area of panel $= \frac{4200}{0.7 \times 750}$;

$8\ \mathrm{m}^2$;

d.ii. calculates area of photovoltaic panels needed as about $26\ \mathrm{m}^2$ / makes a quantitative comparison;

solar heating takes up less area/more efficient/faster;

further energy conversion needed, from electrical to thermal, with photovoltaic panels, involving further losses / *OWTTE*;

Allow ECF from (d)(i) with appropriate reverse argument.

f. radial field with arrows <u>and</u> direction correct towards the sphere; *(both needed)*

no field inside sphere;

At least four lines of force to be shown on diagram.

g.i. use of $E = \frac{kQ}{r^2}$;

$1.73 \times 10^5\ \mathrm{N\,C^{-1}}$; *(must see answer to 2+ significant figures)*

g.ii. <u>line drawn</u> showing zero field strength inside sphere;

decreasing in inverse square-like way from a value of $2 \times 10^5\ \mathrm{N\,C^{-1}}$ ***or*** $1.7 \times 10^5\ \mathrm{N\,C^{-1}}$ at the surface, $d = 25\ \mathrm{mm}$;

h.i. force $= 1.7 \times 10^5 \times 1.6 \times 10^{-19}$; *(allow use of* $2 \times 10^5\ \mathrm{NC^{-1}}$*)*

acceleration $= \left(\frac{2.7 \times 10^{-14}}{9.1 \times 10^{-31}} =\right)\ 3.0 \times 10^{16}\ \mathrm{m\,s^{-2}}$;

h.ii. <u>radially</u> away from sphere / away from <u>centre</u> of sphere;

velocity increasing but at a decreasing rate / accelerating with decreasing acceleration;

because (electric) field (strength) is decreasing;

Examiners report

a. [N/A]
b. [N/A]
c.i. [N/A]
c.ii. [N/A]
d.i. [N/A]
d.ii. [N/A]
f. It was disappointing to see some candidates sketching very imprecise lines. Most fields were radial, but often with incorrect direction.

g.i. Another “show that” question which often elicited a jumble of numbers. Line of reasoning needs to be clear. Although there were many arithmetic/POT mistakes the field strength was often given correctly.

g.ii. It was extremely rare to find a zero line for the field inside of the sphere. The inverse square drop-off was often very approximate and did not always start from the surface of the sphere. The line should not touch the x-axis, but often did.

h.i. This was done correctly by a minority of candidates with many arithmetic and POT errors.

h.ii. Some candidates clearly do not fully understand the difference between velocity and acceleration. It was rare to find that direction of motion was given with precision. Some candidates said that the electron would stop as the field strength approached zero.

This question is in **two** parts. **Part 1** is about a nuclear reactor. **Part 2** is about simple harmonic oscillations.

b. The reactor produces 24 MW of power. The efficiency of the reactor is 32 %. In the fission of one uranium-235 nucleus 3.2×10^{-11}J of energy is released. [4]

Determine the mass of uranium-235 that undergoes fission in one year in this reactor.

c. Explain what would happen if the moderator of this reactor were to be removed. [3]

d. During its normal operation, the following set of reactions takes place in the reactor. [3]

$^{1}_{0}\mathrm{n} + ^{238}_{92}\mathrm{U} \rightarrow ^{239}_{92}\mathrm{U}$ (I)

$^{239}_{92}\mathrm{U} \rightarrow ^{239}_{93}\mathrm{Np} + ^{0}_{-1}e + \bar{v}$ (II)

$^{239}_{93}\mathrm{Np} \rightarrow ^{239}_{94}\mathrm{Pu} + ^{0}_{-1}e + \bar{v}$ (III)

(i) State the name of the process represented by reaction (II).

(ii) Comment on the international implications of the product of these reactions.

Markscheme

b. power produced $\left(\frac{24}{0.32}\right)$=75MW;

energy produced in a year ($75\times10^{6}\times365\times24\times60\times60$=)$2.37\times10^{15}$J;

number of reactions required in one year $\left(\frac{2.37\times10^{15}}{3.2\times10^{-11}}\right) = 7.39 \times 10^{25}$;

mass used ($7.39\times10^{25}\times235\times1.66\times10^{-27}$)≈29kg;

or

mass used $\left(\frac{7.39\times10^{25}}{6.02\times10^{23}} \times 235 \times 10^{-3}\right) = 29\mathrm{kg}$;

c. the neutrons would not be slowed down;

therefore they would not be/have less chance of being captured/induce fission;

so (much) less/no power would be produced;

d. (i) beta decay;

(ii) the reactions end up producing plutonium (from uranium 238);
(this isotope of) plutonium may be used to manufacture nuclear weapons / can be used as fuel in other reactors / plutonium is extremely toxic;

or

the products of the reactions are radioactive for long periods of time / *OWTTE*;
therefore posing storage/safety problems;

Examiners report

b. [N/A]
c. [N/A]
d. [N/A]

Part 2 Melting of the Pobeda ice island

a. The Pobeda ice island forms regularly when icebergs run aground near the Antarctic ice shelf. The "island", which consists of a slab of pure ice, breaks apart and melts over a period of decades. The following data are available. [8]

Typical dimensions of surface of island = 70 km × 35 km
Typical height of island = 240 m
Average temperature of the island = –35°C
Density of sea ice = 920 kg m^{-3}
Specific latent heat of fusion of ice = 3.3×10^{5}J kg^{-1}
Specific heat capacity of ice = 2.1×10^{3}J $kg^{-1}K^{-1}$

(i) Distinguish, with reference to molecular motion and energy, between solid ice and liquid water.

(ii) Show that the energy required to melt the island to form water at 0°C is about 2×10^{20}J. Assume that the top and bottom surfaces of the island are flat and that it has vertical sides.

(iii) The Sun supplies thermal energy at an average rate of 450 W m^{-2} to the surface of the island. The albedo of melting ice is 0.80. Determine an estimate of the time taken to melt the island assuming that the melted water is removed immediately and that no heat is lost to the surroundings.

b. Suggest the likely effect on the average albedo of the region in which the island was floating as a result of the melting of the Pobeda ice island. [2]

Markscheme

a. (i) in water, molecules are able to move relative to other molecules, less movement possible in ice / in water, vibration and translation of molecules possible, in ice only vibration;

in liquid there is sufficient energy/vibration (from latent heat) to break and re-form inter-molecular bonds;

(ii) mass of ice=70000×35000×240×920(=5.4×10^{14}kg);
energy to raise ice temperature to 0°C=$5.4\times10^{14}\times2.1\times10^{3}\times35$(= 3.98×10^{19}J);
energy to melt ice=$5.4\times10^{14}\times3.3\times10^{5}$(=$1.8\times10^{20}$J);
total= 2.2×10^{20}J

(iii) energy incident=450×70000×35000(=1.1×10^{12}J$s^{-1}m^{-2}$);
energy available for melting=$1.1\times10^{12}\times0.2$(=$2.2\times10^{11}$J);
time $= \left(\frac{2.2\times10^{20}}{2.2\times10^{11}} =\right) 9.9\times10^{8}\text{s}$ ***or*** 32 years;

b. average albedo of ocean much smaller than (snow and) ice;

so average albedo (of Earth) is reduced;

Examiners report

a. [N/A]
b. [N/A]

The Sun has a radius of 7.0×10^{8}m and is a distance 1.5×10^{11} m from Earth. The surface temperature of the Sun is 5800 K.

a. Show that the intensity of the solar radiation incident on the upper atmosphere of the Earth is approximately 1400Wm^{-2}. [2]

b. The albedo of the atmosphere is 0.30. Deduce that the average intensity over the entire surface of the Earth is 245Wm^{-2}. [2]

c. Estimate the average surface temperature of the Earth. [2]

Markscheme

a. $I = \frac{\sigma A T^4}{4\pi d^2}$

$= \frac{5.67\times10^{-8}\times\left(7.0\times10^{8}\right)^{2}\times5800^{4}}{\left(1.5\times10^{11}\right)^{2}}$

OR $\frac{5.67\times10^{-8}\times4\pi\times\left(7.0\times10^{8}\right)^{2}\times5800^{4}}{4\pi\times\left(1.5\times10^{11}\right)^{2}}$

I=1397 Wm^{-2}

In this question we must see 4SF to award MP3.
Allow candidate to add radius of Sun to Earth–Sun distance. Yields 1386 Wm^{-2}.

b. «transmitted intensity =» 0.70 × 1400 «= 980Wm^{-2}»

$\frac{\pi R^2}{4\pi R^2} \times 980\mathrm{Wm}^{-2}$

245Wm^{-2}

c. 5.67 × 10^{-8} × T^4 = 245

T = 256K

Examiners report

a. [N/A]
b. [N/A]
c. [N/A]

Two renewable energy sources are solar and wind.

An alternative generation method is the use of wind turbines.

The following data are available:

Length of turbine blade = 17 m
Density of air = 1.3 kg m^{-3}
Average wind speed = 7.5 m s^{-1}

a. Describe the difference between photovoltaic cells and solar heating panels. [1]

b. A solar farm is made up of photovoltaic cells of area 25000 m^2. The average solar intensity falling on the farm is 240 W m^{-2} and the average power output of the farm is 1.6MW. Calculate the efficiency of the photovoltaic cells. [2]

c.i. Determine the minimum number of turbines needed to generate the same power as the solar farm. [3]

c.ii. Explain **two** reasons why the number of turbines required is likely to be greater than your answer to (c)(i). [2]

Markscheme

a. solar heating panel converts solar/radiation/photon/light energy into thermal **energy** ***AND*** photovoltaic cell converts solar/radiation/photon/light energy into electrical **energy**

Accept internal energy of water.

b. power received = 240 × 25000 = «6.0 MW»

efficiency «$= \frac{1.6}{6.0}$ = 0.27 / 27%

c.i. area = π × 17^2 «= 908m^2»

power = $\frac{1}{2} \times 908 \times 1.3 \times 7.5^3$ «= 0.249 MW»

number of turbines «$= \frac{1.6}{0.249} = 6.4$» = 7

Only allow integer value for MP3.

Award ***[2 max]*** *for* ***25 turbines*** *(ECF from incorrect power)*

Award ***[2 max]*** *for* ***26 turbines*** *(ECF from incorrect radius*)

c.ii. «efficiency is less than 100% as»

not all KE of air can be converted to KE of blades

OR

air needs to retain KE to escape

thermal energy is lost due to friction in turbine/dynamo/generator

Allow velocity of air after turbine is not zero.

Examiners report

a. [N/A]
b. [N/A]
c.i. [N/A]
c.ii. [N/A]

This question is in **two** parts. **Part 1** is about the production of energy in nuclear fission. **Part 2** is about collisions.

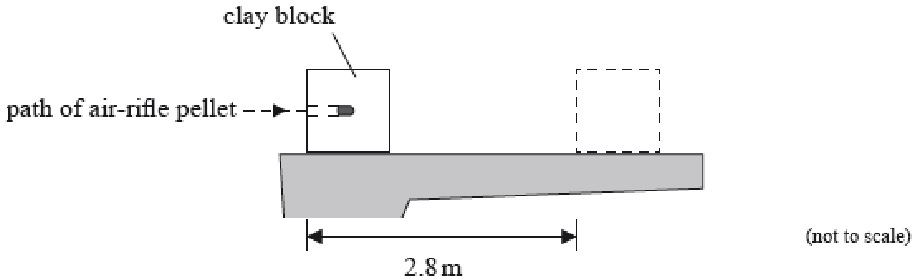
Part 1 Production of energy in nuclear fission

A possible fission reaction is

$$^{235}_{92}U + ^{1}_{0}n \rightarrow ^{92}_{36}Kr + ^{141}_{56}Ba + x^{1}_{0}n.$$

Part 2 Collisions

In an experiment, an air-rifle pellet is fired into a block of modelling clay that rests on a table.



The air-rifle pellet remains inside the clay block after the impact.

As a result of the collision, the clay block slides along the table in a straight line and comes to rest. Further data relating to the experiment are given below.

Mass of air - rifle pellet	$= 2.0$ g
Mass of clay block	$= 56$ g
Velocity of impact of air - rifle pellet	$= 140 \text{ m s}^{-1}$
Stopping distance of clay block	$= 2.8$ m

Part 1.a. (i) State the value of x. [6]

(ii) Show that the energy released when one uranium nucleus undergoes fission in the reaction in (a) is about 2.8×10^{-11} J.

Mass of neutron	$= 1.00867$ u
Mass of U - 235 nucleus	$= 234.99333$ u
Mass of Kr - 92 nucleus	$= 91.90645$ u
Mass of Ba - 141 nucleus	$= 140.88354$ u

(iii) State how the energy of the neutrons produced in the reaction in (a) is likely to compare with the energy of the neutron that initiated the reaction.

Part 1.b. Outline the role of the moderator. [2]

Part 1.c. A nuclear power plant that uses U-235 as fuel has a useful power output of 16 MW and an efficiency of 40%. Assuming that each fission of U-235 gives rise to 2.8×10^{-11} J of energy, determine the mass of U-235 fuel used per day. [4]

Part 2.a. State the principle of conservation of momentum. [2]

Part 2.b. (i) Show that the initial speed of the clay block after the air-rifle pellet strikes it is 4.8 m s^{-1}. [6]

(ii) Calculate the average frictional force that the surface of the table exerts on the clay block whilst the clay block is moving.

Part 2.c. Discuss the energy transformations that occur in the clay block and the air-rifle pellet from the moment the air-rifle pellet strikes the block until the clay block comes to rest. [3]

Part 2.d. The clay block is dropped from rest from the edge of the table and falls vertically to the ground. The table is 0.85 m above the ground. Calculate the speed with which the clay block strikes the ground. [2]

Markscheme

Part 1.a. (i) 3;

(ii) $\Delta m = 234.99333 - 91.90645 - 140.88354 - [2 \times 1.00867]$;

$= 0.186$ (u);

energy released $= 0.186 \times 931 = 173$ (MeV);

$173 \times 10^{6} \times 1.6 \times 10^{-19}$;

$(= 2.768) \approx 2.8 \times 10^{-11}$ (J)

or

$\Delta m = 234.99333 - 91.90645 - 140.88354 - [2 \times 1.00867]$;

$= 0.186$ (u);

mass converted $= 0.186 \times 1.66 \times 10^{-27}$ $(= 3.09 \times 10^{-28})$;

(use of $E = mc^{2}$) energy $= 3.09 \times 10^{-28} \times 9 \times 10^{-16}$;

$(= 2.77) \approx 2.8 \times 10^{-11}$ (J)

*Award **[2 max]** if mass difference is incorrect.*

If candidate carries forward an incorrect value from (a)(i) [2 is common], treat this as ecf in (a)(ii).

*Award **[3 max]** if the candidate uses a value for x inconsistent with (a)(i).*

(iii) greater/higher energy;

Part 11.b. reduces neutron speed to (thermal) lower speeds;

so that chance of initiating fission is higher;

Accept "fast neutrons cannot cause fission" for 2nd marking point.

Part 11.c. 40% efficient so 40 (MW) required;

$\frac{40 \times 10^{6}}{2.8 \times 10^{-11}} = 1.43 \times 10^{18}$ per second;

number of fissions per day $= 1.23 \times 10^{23}$;

$\left(= \frac{1.23 \times 10^{23} \times 235}{6 \times 10^{23}}\right) = 48 \text{ g per day}$;

Part 12.a. the total momentum of a system is constant;

provided external force does not act;

or

the momentum of an isolated/closed system;

is constant;

*Award **[1]** for momentum before collision equals collision afterwards.*

Part 12.b. (i) initial momentum $= 2.0 \times 10^{-3} \times 140$;

final speed $\frac{2.0 \times 10^{-3} \times 140}{5.6 \times 10^{-2} + 2.0 \times 10^{-3}}$;

$= 4.8 \text{ m s}^{-1}$

Watch for incorrect mass values in equation.

(ii) initial kinetic energy of pellet + clay block $= \frac{1}{2}mv^{2}$;

$0.5 \times 0.058 \times 4.8^{2}$ $(= 0.67 \text{ J})$;

$\text{force} = \frac{\text{work done}}{\text{distance travelled}}$;

$= 0.24 \text{ N}$;

or

use of appropriate kinematic equation with consistent sign usage *e.g.* $a = \frac{u^2 - v^2}{2s}$;

$a = \frac{4.8^2}{2 \times 2.8}$;

$F = \frac{0.058 \times 4.8^2}{2 \times 2.8}$;

$= 0.24\ \text{N}$;

Part 2.c. Kinetic energy of pellet is transferred to kinetic energy of clay block;

and internal energy of pellet and clay block;

clay block loses kinetic energy as thermal energy/heat;

Part 2.d. $v = \sqrt{2gs}$;

$= 4.1\ \text{m s}^{-1}$;

Allow $g = 10\ \text{m s}^{-2}$ *answer* $4.1\ \text{m s}^{-2}$

Award ***[2]*** *for bald correct answer.*

Examiners report

Part 1.a. (i) A common incorrect answer was 2.

(ii) Candidates were often able to carry this calculation through to a correct conclusion. It was a “show that” and a high level of explanation was required by examiners and was – in many cases – demonstrated.

(iii) Reponses here were mostly correct. However, the answer “It has a higher energy” was common. Candidates need to be reminded of the imprecision of such a statement. Is “It” the initiating neutron or the emitted neutron?

Part 1.b. Weaker candidates could not distinguish between the role of the moderator and that of the control rods.

Part 1.c. Many good calculations were seen but weaker candidates usually arrived at recognition that the required power from the reactor is 40 MW and could go no further.

Part 2.a. When the question is “State the principle of conservation of momentum.” an answer of “momentum is conserved” will attract no marks. The examiner needs to know what “conserved” means. Many omitted the statement that external forces do not act (or similar)

Part 2.b. (i) Careful examination of solutions showed that about one-third of candidate forgot to add the mass of the pellet to the final total mass of the block.

(ii) This two-stage calculation attracted the same error as part (i) and many power of ten errors through a failure to note the units of mass in the question.

Part 2.c. Descriptions of the energy transformations were incomplete and poorly described. There was a general failure to recognise that the pellet transfers its kinetic energy into a number of distinct forms. Candidates are too quick to ascribe energy loss to “friction” without indicating the seat of this energy loss.

Part 2.d. Most candidates were able to complete this calculation or to get close to it. Some forgot to evaluate the square root having arrived at the speed squared.

This question is about the use of energy resources.

Electrical energy is obtained from tidal energy at La Rance in France.

Water flows into a river basin from the sea for six hours and then flows from the basin back to the sea for another six hours. The water flows through turbines and generates energy during both flows.

The following data are available.

Area of river basin $= 22\ \text{km}^2$

Change in water level of basin over six hours $= 6.0\ \text{m}$

Density of water $= 1000\ \text{kg}\,\text{m}^{-3}$

Nuclear reactors are used to generate energy. In a particular nuclear reactor, neutrons collide elastically with carbon-12 nuclei $\left({}^{12}_{6}\text{C}\right)$ that act as the moderator of the reactor. A neutron with an initial speed of $9.8 \times 10^6\ \text{m}\,\text{s}^{-1}$ collides head-on with a stationary carbon-12 nucleus. Immediately after the collision the carbon-12 nucleus has a speed of $1.5 \times 10^6\ \text{m}\,\text{s}^{-1}$.

a. State the difference between renewable and non-renewable energy sources. [1]

b. (i) The basin empties over a six hour period. Show that about $6000\ \text{m}^3$ of water flows through the turbines every second. [10]

(ii) Show that the average power that the water can supply over the six hour period is about 0.2 GW.

(iii) La Rance tidal power station has an energy output of $5.4 \times 10^8\ \text{kW}\,\text{h}$ per year. Calculate the overall efficiency of the power station. Assume that the water can supply 0.2 GW at all times.

Energy resources such as La Rance tidal power station could replace the use of

fossil fuels. This may result in an increase in the average albedo of Earth.

(iv) State **two** reasons why the albedo of Earth must be given as an average value.

d. (i) State the principle of conservation of momentum. [10]

(ii) Show that the speed of the neutron immediately after the collision is about $8.0 \times 10^6\ \text{m}\,\text{s}^{-1}$.

(iii) Show that the fractional change in energy of the neutron as a result of the collision

is about 0.3.

(iv) Estimate the minimum number of collisions required for the neutron to reduce its initial energy by a factor of 10^6.

(v) Outline why the reduction in energy is necessary for this type of reactor to function.

Markscheme

a. only non-renewable is depleted/cannot re-generate whereas renewable can / consumption rate of non-renewables is greater than formation rate and consumption rate of renewables is less than formation rate;

Do not allow "cannot be used again".

b. (i) volume released = $(22 \times 10^6 \times 6 =)\ 1.32 \times 10^8\ (\text{m}^3)$;

volume per second $\frac{1.32\times10^8}{6\times3600}$ $(= 6111\ \text{m}^3)$;

(ii) use of average depth for calculation (3 m);

gpe lost $6100 \times 1000 \times 9.81 \times 3$;

0.18 (GW);

Accept g = 10 m s^{-2}*.*

*Award **[1 max]** if 6 m is used and an "average" is used at end of solution without mention of average depth.*

(iii) converts/states output with units; } *(allow values quoted from question without unit)*

converts/states input with units; } *(allow values quoted from question without unit)*

calculates efficiency from $\frac{\text{output}}{\text{input}}$ as 0.31;

*Award **[3]** for bald correct answer.*

eg:

power output $\frac{5.4\times10^{8}}{365\times24\times3600}$ $(= 17\ \text{kW h s}^{-1})$;

$= 17 \times 3600000 = 6.16 \times 10^{7}\ (\text{W})$;

efficiency = $\left(\frac{6.16\times10^{7}}{2.0\times10^{8}} =\right)$ 31% ***or*** 0.31;

or

0.2 GW is $1.752 \times 10^{9}\ (\text{kW h year}^{-1})$;

$\frac{5.4\times10^{8}}{1.752\times10^{9}}$;

efficiency $= 0.31$;

(iv) cloud cover / weather conditions;

latitude;

time of year / season;

nature/colour of surface;

d. (i) (total) momentum unchanged before and after collision / momentum of a system is constant; } *(allow symbols if explained)*

no external forces / isolated system / closed system;

Do not accept "conserved".

(ii) final momentum of neutron $=$ neutron mass $\times\ 9.8 \times 10^{6} - 1\text{u} \times 12 \times 1.5 \times 10^{6}$; } *(allow any appropriate and consistent mass unit)*

final speed of neutron $= 8.0$ ***or*** $8.2 \times 10^{6}\ (\text{m s}^{-1})$;

$(\approx 8.0 \times 10^{6}\ (\text{m s}^{-1}))$

Allow use of 1 u for both masses giving an answer of 8.2 $\times$ *10*^{6} *(m s*$^{-1}$*).*

(iii) initial energy of neutron $= 8.04 \times 10^{-14}\ (\text{J})$ <u>and</u> final energy of neutron $= 5.36 \times 10^{-14}\ (\text{J})$; } *(both needed)*

fractional change in energy $= \left(\frac{(8.04-5.36)}{8.04} =\right)\ 0.33$;

or

fractional change $= \left(\frac{\frac{1}{2}mv_{\text{i}}^{2}-\frac{1}{2}mu_{\text{f}}^{2}}{\frac{1}{2}mv_{\text{i}}^{2}}\right)$; }*(allow any algebra that shows a subtraction of initial term from final term divided by initial value)*

$\left(= \frac{(9.8\times10^{6})^{2}-(8.0\times10^{6})^{2}}{(9.8\times10^{6})^{2}}\right)$ *(allow omission of 10*^{6}*)*

$= 0.33$; *(allow 0.30 if 8.2 used)*

Do not allow ECF if there is no subtraction of energies in first marking point.

(iv) $(0.33)^{n} = 10^{-6}$;

$n = 13$; *(allow n = 12 if 0.3 is used)*

(v) neutrons produced in fission have large energies;

greatest probability of (further) fission/absorption (when incident neutrons have thermal energy or low energy);

Do not accept "reaction" for "fission reaction".

Examiners report

a. Many candidates continue to give weak responses to questions in which they are asked to compare renewable and non-renewable resources.

Although the "it cannot be used again" answer has largely disappeared, many candidates still fail to appreciate that the issue is about the rate at which the resource can be replaced.

b. (i) This was often well done, although occasional recourse was made to inappropriate physics (see bii). Candidates should note that in questions where the final answer is quoted (typically "Show that ….." questions) candidates are strongly advised to quote answers to one more significant figure than in the question.

(ii) The rare candidate who understood the physics here was able to give a clear account of the solution. Many failed to spot the factor of a half in the water level change and introduced a factor of two later and arbitrarily. Others completely misunderstood the (simple) nature of the problem and used a random equation from the data booklet (usually $1/3\rho Av^3$). This of course gained no marks. A simple initial diagram would have helped many to avoid errors.

(iii) As in question 1 there were far too many candidates who clearly do not understand and have not practised the problem of converting between energy units. Effective use of units would have made this an easy calculation. Explanations were few and candidates were clearly struggling with this aspect of energy.

(iv) Many candidates were able to give one coherent reason but two distinct answers were rare.

d. (i) As is often the case with this question, candidates state that "momentum is conserved" and fail to explain what this means. There was much confusion with energy conservation rules.

(ii) Calculations of the final speed of the neutron were confused with little or no explanation of the equations. It was often not clear what mass values (if any) were being used in the solution.

(iii) There were few clear solutions to this problem. Some candidates did not appreciate the meaning of fractional energy change and others were still travelling along the momentum route from an earlier part, scoring few, if any, marks.

(iv) Candidates had evidently not considered the mechanical issues of moderation in their learning. There was little recognition that the change in fractional energy is 0.33n where n is the number of collisions. The most frequent answer was that the change is 0.33n.

(v) There was more clarity about the reasons for moderation but even so, answers were poorly expressed. Only a minority recognised that the probability of absorption is greatest at low neutron incident energy.

This question is in **two** parts. **Part 1** is about solar power and climate models. **Part 2** is about gravitational fields and electric fields.

Part 1 Solar power and climate models

a. Distinguish, in terms of the energy changes involved, between a solar heating panel and a photovoltaic cell. [2]

b. State an appropriate domestic use for a [2]

(i) solar heating panel.

(ii) photovoltaic cell.

c. The radiant power of the Sun is 3.90 $\times 10^{26}$W. The average radius of the Earth's orbit about the Sun is 1.50 $\times 10^{11}$ m. The albedo of the atmosphere is 0.300 and it may be assumed that no energy is absorbed by the atmosphere. [3]

Show that the intensity incident on a solar heating panel at the Earth's surface when the Sun is directly overhead is 966 Wm^{-2}.

d. Show, using your answer to (c), that the average intensity incident on the Earth's surface is 242 Wm^{-2}. [3]

e. Assuming that the Earth's surface behaves as a black-body and that no energy is absorbed by the atmosphere, use your answer to (d) to show that the average temperature of the Earth's surface is predicted to be 256 K. [2]

Markscheme

a. a solar heating panel converts the (radiation) energy of the Sun into thermal/heat energy;

(allow "solar energy" but do not allow "heat")

a photovoltaic cell converts the (radiation) energy of the Sun into electrical energy;

b. (i) water heater / any specific use such as swimming pool/bath;

(ii) powering TV/radio/lighting/any low energy electrical appliance;

c. surface area of sphere at 1.5×10^{11}m from Sun $=4\pi\times1.50^2\times10^{22}$;

power per m^2=$\frac{3.90\times10^{26}}{4\times3.14\times1.50^2\times10^{22}} = 1.38 \times 10^3$;
(presence of the substitution allows inference of first marking point)

power per m^2 at surface = $0.7\times1.38\times10^3$Wm^{-2};
(=966Wm^{-2})

d. Earth appears, to the Sun, like a disc of radius R; *(must be explicit)*

intensity=power incident per unit area; *(must be explicit in words or equation)*

(power incident per unit area)=$\frac{966\pi R^2}{4\pi R^2}$;

(=242Wm^{-2})

e. (power absorbed) 242 = (power emitted) σT^4 ;

$T = \left[\frac{242}{5.67\times10^{-8}}\right]^{\frac{1}{4}}$ ***or*** 255.5;

(=256K)

Examiners report

a. In an easy opener, candidates were asked for the energy changes in solar heating panels and photovoltaic cells. Sometimes the word "energy" did not appear in the answer. It is important for candidates to give a clear statement of the initial and the final energy forms expressed in scientific language.

b. (i) and (ii) There was a wide variety of correct responses here. However some are clearly confused about the uses of solar heating panels and photovoltaics.

c. This was done well with many correctly showing the intensity arriving from the Sun and incorporating the effect of albedo appropriately.

d. This was not so impressive (as (c)) with many inclusions of the factor of 4 with no explanation of its origin. This was not acceptable.

e. This was straightforward but a clear manipulation of Stefan"s Law was required, ideally with a calculation with significant figures quoted to better than the quoted answer. Many failed in this respect by giving an initial substitution and nothing else. Examiners needed to see correct handling of the fourth root to award full credit.

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a. Outline, with reference to energy changes, the operation of a pumped storage hydroelectric system. [2]

b. The hydroelectric system has four 250 MW generators. The specific energy available from the water is 2.7 kJ kg^{-1}. Determine the maximum time for which the hydroelectric system can maintain full output when a mass of 1.5 x 10^{10} kg of water passes through the turbines. [2]

c. Not all the stored energy can be retrieved because of energy losses in the system. Explain **one** such loss. [1]

d. At the location of the hydroelectric system, an average intensity of 180 W m^{-2} arrives at the Earth's surface from the Sun. Solar photovoltaic (PV) cells convert this solar energy with an efficiency of 22 %. The solar cells are to be arranged in a square array. Determine the length of one side of the array that would be required to replace the

hydroelectric system. [2]

Markscheme

a. PE of water is converted to KE of moving water/turbine to electrical energy «in generator/turbine/dynamo»

idea of pumped storage, *ie:* pump water back during night/when energy cheap to buy/when energy not in demand/when there is a surplus of energy

b. total energy = «2.7 x 10^3 x 1.5 x 10^{10} =» 4.05 x 10^{13} «J»

time = «$\frac{4.0\times10^{13}}{4\times2.5\times10^{8}}$» 11.1h ***or*** 4.0 x 10^4 s

*For MP2 the unit **must** be present.*

c. friction/resistive losses in walls of pipe/air resistance/turbulence/turbine and generator bearings

thermal energy losses, in electrical resistance of components

water requires kinetic energy to leave system so not all can be transferred

Must see "seat of friction" to award the mark.
Do not allow "friction" bald.

d. area required $= \frac{1\times10^{9}}{0.22\times180}$ «= 2.5 x 10^7 m^2»

length of one side $= \sqrt{area} = 5.0$ k«m»

Examiners report

a. [N/A]
b. [N/A]
[N/A]

d. [N/A]

This question is about a tidal power station.

A tidal power station is built for a coastal town. Sea water is stored in a tidal basin behind a dam at high tide and released in a controlled manner between high tides, so that it passes through turbines to generate electricity.

The following data are available.

Difference between high and low tide water level = 1.8m
Density of sea water = $1.1\times10^{3}kgm^{-3}$
Surface area of basin = $1.4\times10^{5}m^{2}$
Overall efficiency of power station = 24%

a. (i) Show that the mass of sea water released between successive high and low tides is about 2.8×10^{8} kg. [5]

(ii) Calculate the electrical energy produced between successive high and low tides.

b. (i) Identify **one** mechanism through which energy is transferred to the surroundings during the electricity generation process. [2]

(ii) State why the energy transferred to the surroundings is said to be degraded.

Markscheme

a. (i) $m = \varrho\Delta V = \varrho A\Delta h$;

$=1.1\times10^{3}\times1.4\times10^{5}\times1.8$;

$(\approx 2.8\times10^{8}\text{ kg})$

(ii) difference in height of centre of mass of water$=\frac{1.8}{2}=0.9$(m)
$\Delta E_P \left(= mg\Delta h = 2.8\times10^{8}\times9.8\times0.9\right) = 2.5\times10^{9}$ (J)
electrical energy $(=0.24\times2.5\times10^{9})=5.9\times10^{8}$ (J)(=590MJ);
Allow ECF for ***[2 max]*** *if candidate omits factor of 2 in first marking points. Accept g=10ms*$^{-2}$ *giving an answer of* 6.0×10^{8} *(J).*

b. (i) friction/turbulence of flowing water / friction in turbine/generator / resistive heating in wires;

Do not allow bald statement of "heating".

(ii) it can no longer be used to do work / not available in useful form;
Do not accept "it is more spread out" or similar.

Examiners report

a. ai) Many candidates provided a simple calculation with no explanation to show why the values were multiplied together. This did not provide sufficient evidence to show how the data provided lead to the given value.

aii) Few candidates realized that the energy produced by a water storage is dependent on half the height between the upper and lower water levels.

b. bi) Many candidates provided a general response such as "friction" without identifying the mechanism that caused the frictional losses.

bii) Few candidates could adequately explain the concept of degraded energy.

Part 2 Wind power and the greenhouse effect

a. A coal-fired power station has a power output of 4.0GW. It has been suggested that a wind farm could replace this power station. Using the data below, determine the area that the wind farm would occupy in order to meet the same power output as the coal-fired power station. [4]

Radius of wind turbine blades = 42 m
Area required by each turbine = 5.0×10^4 m^2
Efficiency of a turbine = 30%
Average annual wind speed = 12 m s^{-1}
Average annual density of air = 1.2 kg m^{-3}

b. Wind power does not involve the production of greenhouse gases. Outline why the surface temperature of the Earth is higher than would be expected without the greenhouse effect. [3]

c. The average solar intensity incident at the surface of the Earth is 238 W m^{-2}. [5]

(i) Assuming that the emissivity of the surface of the Earth is 1.0, estimate the average surface temperature if there were no greenhouse effect.

(ii) The enhanced greenhouse effect suggests that in several decades the predicted temperature of the atmosphere will be 250 K. The emissivity of the atmosphere is 0.78. Show that this atmospheric temperature increase will lead to a predicted average Earth surface temperature of 292 K.

Markscheme

a. power output of a turbine=$0.3\times½\rho Av^3$=$0.3\times0.5\times1.2\times3.14\times[42]^2\times[12]^3$(=1723kW);

number of turbines needed $= \frac{4\times10^9}{1.723\times10^6} (= 2322)$;

area needed = $2322\times5.0\times10^4$;

=1.2×10^8(m^2);

*Award **[4]** for a bald correct answer.*

Note: Answers sometimes start with calculating power input from wind which is 5743 kW and incorporate 0.3 at a later stage.

b. *look for these main points:*

the surface of Earth re-radiates the Sun's radiation;

greenhouse gases (in atmosphere) readily absorb infrared;

mention of resonance;

the absorbed radiation is re-emitted (by atmosphere) in all directions;

(some of) which reaches the Earth and further heats the surface;

*Award **[1 max]** for responses along the lines that greenhouse gases trap infrared radiation.*

c. (i) total absorbed radiation= total emitted radiation =238(Wm $^{-2}$);

temperature of Earth= $\left[\frac{238}{5.67\times10^{-8}}\right]^{\frac{1}{4}}$ =255(K);

*Award **[2]** for a bald correct answer.*

(ii) total absorbed radiation at surface=238+[($\varepsilon\delta T^4$)0.78×5.67×10^{-8}×250^4];
=410.8(Wm^{-2});

temperature of surface= $\left[\frac{410.8}{5.67\times10^{-8}}\right]^{\frac{1}{4}}$ =291.7(K);

≈292K

Examiners report

a. This was another calculation in which candidates are becoming well versed. There are a number of steps and many were able to negotiate them with ease. Failures included omitting the efficiency or getting it the wrong way up in the equation. Although full marks were given for the correct answer candidates would be well advised in such questions, to fully explain each step in their argument so that part-credit can be obtained. A jumble of arithmetic with the wrong answer will score zero.

b. A sizeable majority talked about the infrared radiation being trapped in the atmosphere. This did not attract full credit as it fails to grasp the nettle of the interaction between the earth's surface and the atmosphere. A generous number of points were available on the scheme but most gained two out of three marks. This question was poorly answered by Spanish-speaking candidates.

c. (i) temperature of surface

(ii)This was another "show that" question. Candidates need to display reasoning - more able candidates could satisfy examiners on this point.

This question is in **two** parts. **Part 1** is about a lightning discharge. **Part 2** is about fuel for heating.

Part 1 Lightning discharge

The magnitude of the electric field strength E between two infinite charged parallel plates is given by the expression

$$E = \frac{\sigma}{\varepsilon_0}$$

where σ is the charge per unit area on one of the plates.
A thundercloud carries a charge of magnitude 35 C spread over its base. The area of the base is $1.2 \times 10^7\ \mathrm{m}^2$.

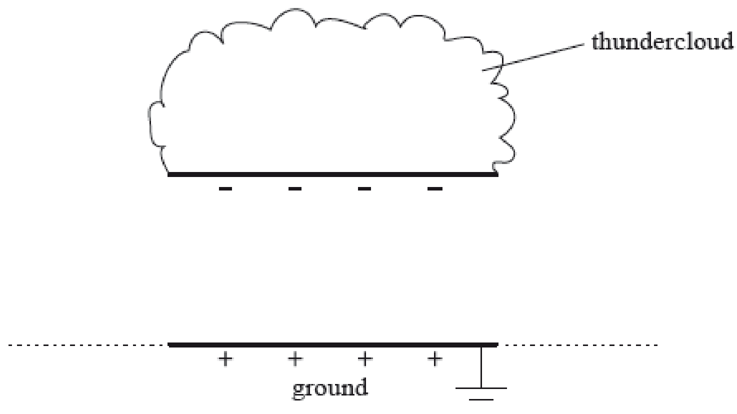
Part 2 Fuel for heating

A room heater burns liquid fuel and the following data are available.

Density of liquid fuel	$= 8.0 \times 10^2 \text{ kg m}^{-3}$
Energy produced by 1 m^3 of liquid fuel	$= 2.7 \times 10^{10}$ J
Rate at which fuel is consumed	$= 0.13 \text{ g s}^{-1}$
Latent heat of vaporization of the fuel	$= 290 \text{ kJ kg}^{-1}$

Part 1.a. Define *electric field strength*. [2]

Part 1.b. A thundercloud can be modelled as a negatively charged plate that is parallel to the ground. [3]



The magnitude of the charge on the plate increases due to processes in the atmosphere. Eventually a current discharges from the thundercloud to the ground.

On the diagram, draw the electric field pattern between the thundercloud base and the ground.

Part 1.c. (i) Determine the magnitude of the electric field between the base of the thundercloud and the ground. [12]

(ii) State **two** assumptions made in (c)(i).

1.

2.

(iii) When the thundercloud discharges, the average discharge current is 1.8 kA. Estimate the discharge time.

(iv) The potential difference between the thundercloud and the ground before discharge is 2.5×10^8 V. Determine the energy released in the discharge.

Part 2.a. Define the *energy density* of a fuel. [1]

Part 2.b. (i) Use the data to calculate the power output of the room heater, ignoring the power required to convert the liquid fuel into a gas. [5]

(ii) Show why, in your calculation in (b)(i), the power required to convert the liquid fuel into a gas at its boiling point can be ignored.

Part 2.c. State, in terms of molecular structure and their motion, **two** differences between a liquid and a gas. [2]

1.

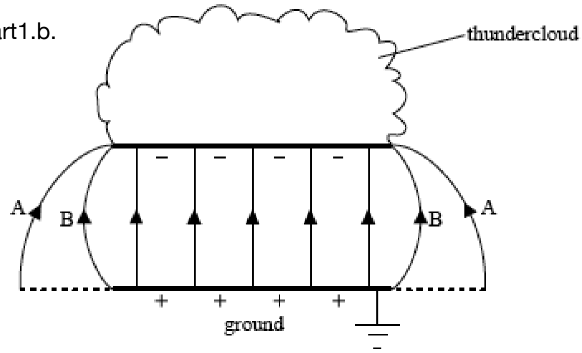
2.

Markscheme

Part 1.a. force acting per unit charge;

on positive test / point charge;

Part1.b.



lines connecting plate and ground equally spaced in the central region of thundercloud <u>and</u> touching both plates; *(judge by eye)*

edge effects shown; *(accept either edge effect A or B shown on diagram)*

field direction correct;

Part1.c. (i) $\sigma = \left(\frac{35}{1.2\times10^{7}} =\right)\ 2.917 \times 10^{-6}\ (\mathrm{C\,m^{-2}})$;

$E = \frac{2.917\times10^{-6}}{8.85\times10^{-12}}$;

$= 3.3 \times 10^{5}\ \mathrm{N\,C^{-1}}$ ***or*** $\mathrm{V\,m^{-1}}$;

*Award **[3]** for bald correct answer.*

(ii) edge of thundercloud parallel to ground;

thundercloud and ground effectively of infinite length;

permittivity of air same as vacuum;

(iii) $t = \frac{Q}{I}$;

$t = \frac{35}{1800}$;

$= 20\ \mathrm{m\,s}$;

(iv) use of energy $= \text{p.d.} \times \text{charge}$;

$\text{average p.d.} = 1.25 \times 10^{8}\ (\mathrm{V})$;

$\text{energy released} = 1.25 \times 10^{8} \times 35$;

$= 4.4 \times 10^{9}\ \mathrm{J}$;

*Award **[3 max]** for 8.8 GJ if average p.d. point omitted.*

Accept solution which uses average current $\left(from \frac{charge}{time}\right)$.

Allow ecf from (c)(ii).

Part2.a. energy (released) per unit mass;

Accept per unit volume or per kg or per m^3.

Do not accept per unit density.

Part2.b. (i) volume of fuel used per second $= \frac{\text{rate}}{\text{density}}\ \left(= 1.63 \times 10^{-7}\ (\mathrm{m^{3}})\right)$;

$\text{energy} = 2.7 \times 10^{10} \times 1.63 \times 10^{-7}$;

$= (4.3875 =)\ 4.4\ \mathrm{kW}$;

*Award **[3]** for bald correct answer.*

(ii) power required $= (2.9 \times 10^{5} \times 0.13 \times 10^{-3} =)\ 38\ \mathrm{W}$;

small fraction/less than 1% of overall power output / *OWTTE*;

Part2.c. sensible comment comparing molecular structure;

e.g. liquid molecular structure (more) ordered than that of a gas.

in gas molecules far apart/about 10 molecular spacings apart / in liquid molecules close/touching.

sensible comment comparing motion of molecules;

e.g. in liquid: molecules interchange places with neighbouring molecules / no long distance motion.
in gases: no long-range order / long distance motion.

Examiners report

Part 1.a. Many omitted the reference to a test charge that is positive.

Part 1.b. Common errors were to draw the field lines in the wrong direction, to omit edge effects, and to fail to draw field lines that touch the plates.

Part 1.c. (i) This part was well done.

(ii) Most candidates could only identify one assumption made in the calculation.

(iii) The estimation of discharge time was well done.

(iv) There was a general failure to recognise that the average pd during the discharge is half the maximum (starting) value and this lost a mark.

Part 2.a. A handful of candidates defined energy density as energy converted per unit density, but most gave energy released per unit mass with a minority quoting energy released per unit volume.

Part 2.b. (i) Again, this was done well by the majority with the usual smattering of significant figure penalties and mistakes in handling powers of ten.

(ii) Arguments were weak and poorly supported by calculation.

Part 2.c. Candidates found great difficulty in stating the differences between liquids and gases. They often focused on either molecular structure or motion, but not both as required in the question.

This question is in **two** parts. **Part 1** is about power production and global warming. **Part 2** is about electric charge.

Part 1 Power production and global warming

b. A nuclear power station uses uranium-235 (U-235) as fuel. Outline the [7]
(i) processes and energy changes that occur through which thermal energy is produced.

(ii) role of the heat exchanger of the reactor and the turbine in the generation of electrical energy.

e. The Drax power station produces an enormous amount of carbon dioxide, a gas classified as a greenhouse gas. Outline, with reference to the vibrational behaviour of molecules of carbon dioxide, what is meant by a greenhouse gas. [3]

Markscheme

b. (i) U-235 fissions / neutrons are produced;

nuclei/neutrons have high energy/are fast moving;

nuclei transfer (kinetic) energy to (reactor) core / neutrons transfer (kinetic) energy to moderator;

names energy of moving nuclei/neutrons as <u>kinetic</u>;

core/moderator energy transferred to coolant/named coolant/surroundings;

(ii) heat exchanger allows transfer of (thermal) energy between reactor and coolant; coolant transfers (thermal) energy to steam/other

named fluid;
steam/fluid allows turbine to drive generator/dynamo;

e. frequency of vibration is close to that of the frequency of infrared radiation; (atmospheric) carbon dioxide absorbs the infrared radiated by the surface of Earth; the part of the radiation that is re-radiated back to Earth will cause the temperature of the surface to rise / re-radiated at a different frequency / *OWTTE*;

Examiners report

b. (i) Outlines of the processes and energy changes in a nuclear power station were very poor. Examiners had to give the benefit of the doubt on many occasions. Some candidates thought that the U-235 is burnt (in the same way as a fossil fuel) to convert the energy for the process. Only rarely were there an attempt to describe the processes consistently and many answers focussed only on the operation of the turbines.

(ii) Equally, the heat exchanger and the turbine roles were poorly described and often simply repeated material from (b)(i).

e. As in part (d) it was rare to find a well-expressed solution and in the case of incorrect evaluations, examiners found it difficult to understand what the candidate was attempting to do.

This question is in **two** parts. **Part 1** is about Newton's laws and momentum. **Part 2** is about the greenhouse effect.

Part 1 Newton's laws and momentum

Part 2 The greenhouse effect

a. State the condition for the momentum of a system to be conserved. [1]

b. A person standing on a frozen pond throws a ball. Air resistance and friction can be considered to be negligible. [5]

(i) Outline how Newton's third law and the conservation of momentum apply as the ball is thrown.

(ii) Explain, with reference to Newton's second law, why the horizontal momentum of the ball remains constant whilst the ball is in flight.

c. The maximum useful power output of a locomotive engine is 0.75 M W. The maximum speed of the locomotive as it travels along a straight horizontal track is 44 m s^{-1}. Calculate the frictional force acting on the locomotive at this speed. [2]

d. The locomotive engine in (c) gives a truck X a sharp push such that X moves along a horizontal track and collides with a stationary truck Y. As a result of the collision the two trucks stick together and move off with speed *v*. The following data are available. [4]

Mass of truck X=3.7×10^3 kg
Mass of truck Y=6.3×10^3 kg
Speed of X just before collision=4.0 m s^{-1}

(i) Calculate *v*.

(ii) Determine the kinetic energy lost as a result of the collision.

e. The trucks X and Y come to rest after travelling a distance of 40 m along the horizontal track. Determine the average frictional force acting on X and Y. [3]

f. Nuclear fuels, unlike fossil fuels, produce no greenhouse gases. [5]

(i) Identify **two** greenhouse gases.

(ii) Discuss, with reference to the mechanism of infrared absorption, why the temperature of the Earth's surface would be lower if there were no greenhouse gases present in the atmosphere.

g. Outline how an increase in the amount of greenhouse gases in the atmosphere of Earth could lead to an increase in the rate at which glaciers melt and thereby a reduction of the albedo of the Earth's surface. [3]

Markscheme

a. the net (external) force acting on the system is zero / no force acting on system / system is isolated;

b. (i) no external force/system is isolated so change in momentum is zero; { *(do not accept momentum is conserved/constant)*

force on ball must be equal and opposite to force on the person;

so ball and person/Earth/pond move in opposite directions;

(ii) Newton's second law states that the rate of change of momentum is equal/proportional/directly proportional to the force acting;
the horizontal force acting on the ball is zero therefore the momentum must be constant/the rate of change of momentum is zero;

or

Newton's second law can be expressed as the force acting is equal to the product of mass and acceleration;
the horizontal force acting on the ball is zero therefore the acceleration is zero so velocity is constant (and therefore momentum is constant);

c. $F = \frac{P}{v}$ ***or*** $\frac{0.75 \times 10^6}{44}$;

17kN;

d. (i) $3.7 \times 4.0 = 10 \times v$;

$v = 1.5 \text{ms}^{-1}$;

(ii) KE lost$= \frac{1}{2}\left[3.7 \times 10^3 \times 4.0^2\right] - \frac{1}{2}\left[10 \times 10^3 \times 1.5^2\right]$;
=18kJ;

e. initial KE$= \left(\frac{1}{2}\left[10 \times 10^3 \times 1.5^2\right] =\right) 11250\text{J}$;

friction$= \frac{11250}{40}$;

=280 N;

or

use of kinematic equation to give $a = 0.274 \text{ms}^{-1}$;
use of $F(=ma) = 10 \times 10^3 a$;
270/280 N;

f. (i) methane/CH_4, water vapour/H_2O, carbon dioxide/CO_2, nitrous oxide/N_2O;

*Award **[1]** for any two of the above.*

(ii) *mechanism:*
mention of resonance;
natural frequency of (resonating) greenhouse gas molecules is same as that of infrared radiation from Earth;

or

mention of energy level differences;
differences between energy levels of greenhouse gas molecules matches energy of infrared radiation from Earth;

explanation:
less infrared trapped if absorption is reduced;
so more infrared is transmitted through atmosphere;

or

more infrared is trapped if absorption is increased;
so more infrared is re-radiated back to Earth;
Allow only one variant for each alternative.

g. more greenhouse gas therefore more infrared radiated back to Earth;

leading to an increase in temperature of glaciers/surface;

less glacier area so less reflection from glacier surface / *OWTTE*;

albedo defined as $\frac{\text{amountofradiationreflected}}{\text{amountofradiationabsorbed}}$ therefore albedo reduced;

Examiners report

a. [N/A]
b. [N/A]
c. [N/A]
d. [N/A]
e. [N/A]
f. [N/A]
g. [N/A]

This question is about nuclear power production.

State **two** advantages of power production using fossil fuels compared to using nuclear fuels.

Markscheme

no radioactive waste;

no radiation risks to users;

lower expense of decommissioning / easier to decommission / easier to install / lower set-up cost;

transportation and storage less hazardous/safer;

simpler technology;

cannot be used for military purposes;

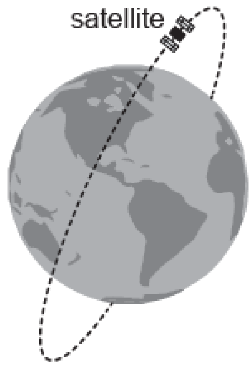
fossil fuels can be extracted/found more easily;

no chance of catastrophic accident/meltdown/Chernobyl;

Examiners report

[N/A]

A satellite powered by solar cells directed towards the Sun is in a polar orbit about the Earth.



The satellite is orbiting the Earth at a distance of 6600 km from the centre of the Earth.

The satellite carries an experiment that measures the peak wavelength emitted by different objects. The Sun emits radiation that has a peak wavelength λ_S of 509 nm. The peak wavelength λ_E of the radiation emitted by the Earth is 10.1 μm.

a. Determine the orbital period for the satellite. [3]

Mass of Earth = 6.0 x 10^{24} kg

b.i. Determine the mean temperature of the Earth. [2]

b.ii. Suggest how the difference between λ_S and λ_E helps to account for the greenhouse effect. [3]

c. Not all scientists agree that global warming is caused by the activities of man. [1]

Outline how scientists try to ensure agreement on a scientific issue.

Markscheme

a. $\frac{mv^2}{r} = G\frac{Mm}{r^2}$

leading to $T^2 = \frac{4\pi^2 r^3}{GM}$

T = 5320 «s»

Alternative 2

«$v = \sqrt{\frac{GM_E}{r}}$» = $\sqrt{\frac{6.67\times10^{-11}\times6.0\times10^{24}}{6600\times10^3}}$ ***or*** 7800 «ms^{-1}»

distance = $2\pi r$ = 2π x 6600 x 10^3 «m» or 4.15 x 10^7 «m»

«$T = \frac{d}{v} = \frac{4.15\times10^7}{7800}$» = 5300 «s»

Accept use of ω instead of v

b.i. T = «$\frac{2.90\times10^{-3}}{\lambda_{max}} =$» $\frac{2.90\times10^{-3}}{10.1\times10^{-6}}$

= 287 «K» ***or*** 14 «°C»

*Award **[0]** for any use of wavelength from Sun*

Do not accept 287 °C

b.ii. wavelength of radiation from the Sun is shorter than that emitted from Earth «and is not absorbed by the atmosphere» infrared radiation emitted from Earth is absorbed by greenhouse gases in the atmosphere

this radiation is re-emitted in all directions «including back to Earth»

c. peer review

international collaboration

full details of experiments published so that experiments can repeated

[Max 1 Mark]

Examiners report

a. [N/A]
b.i. [N/A]
b.ii. [N/A]
c. [N/A]

The following data are available for a natural gas power station that has a high efficiency.

Rate of consumption of natural gas	= 14.6 kg s^{-1}
Specific energy of natural gas	= 55.5 MJ kg^{-1}
Efficiency of electrical power generation	= 59.0 %
Mass of CO_2 generated per kg of natural gas	= 2.75 kg
One year	= 3.16×10^7 s

a. Calculate, with a suitable unit, the electrical power output of the power station. [1]

b. Calculate the mass of CO_2 generated in a year assuming the power station operates continuously. [1]

c. Explain, using your answer to (b), why countries are being asked to decrease their dependence on fossil fuels. [2]

d. Describe, in terms of energy transfers, how thermal energy of the burning gas becomes electrical energy. [2]

Markscheme

a. **«**$55.5 \times 14.6 \times 0.59$**»** = 4.78×10^8 W

A unit is required for this mark. Allow use of J s^{-1}.

No sf penalty.

b. «$14.6 \times 2.75 \times 3.16 \times 10^7$ =» 1.27×10^9 «kg»

If no unit assume kg

c. CO_2 linked to greenhouse gas OR greenhouse effect

leading to «enhanced» global warming
OR
climate change
OR
other reasonable climatic effect

d. Internal energy of steam/particles OR KE of steam/particles

«transfers to» KE of turbine

«transfers to» KE of generator ***or*** dynamo «producing electrical energy»

Do not award mark for first and last energies as they are given in the question.

Do not allow "gas" for "steam"

Do not accept reference to moving OR turning generator

Examiners report

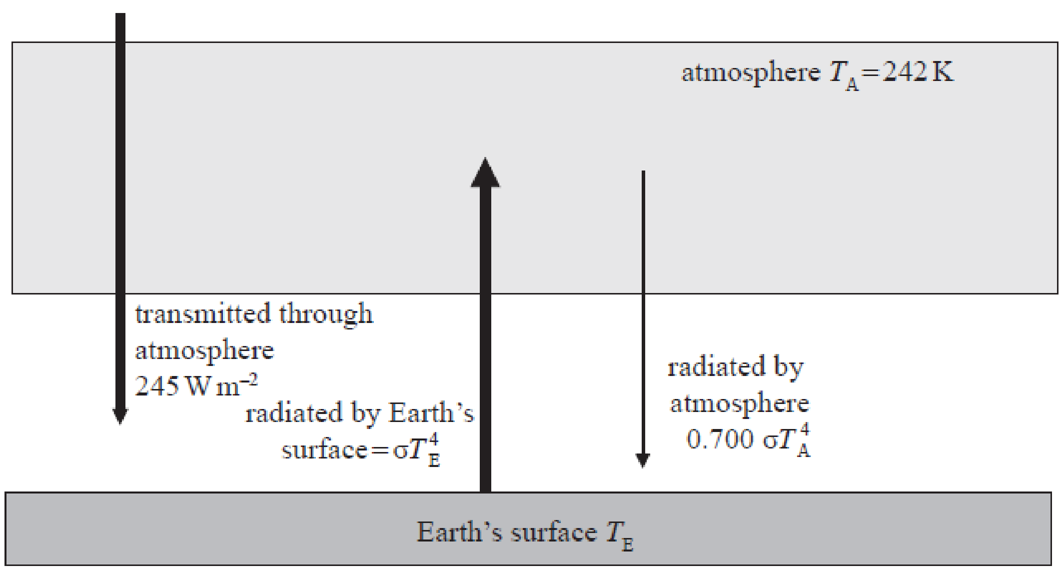
a. [N/A]
b. [N/A]
c. [N/A]
d. [N/A]

Part 2 Energy balance of the Earth

a. The intensity of the Sun's radiation at the position of the Earth is approximately 1400 W m^{-2}. [2]

Suggest why the average power received per unit area of the Earth is 350 W m^{-2}.

b. The diagram shows a simplified model of the energy balance of the Earth's surface. The diagram shows radiation entering or leaving the Earth's surface only. [4]



The average equilibrium temperature of the Earth's surface is T_E and that of the atmosphere is T_A = 242K.

(i) Using the data from the diagram, state the emissivity of the atmosphere.

(ii) Show that the intensity of the radiation radiated by the atmosphere towards the Earth's surface is 136Wm^{-2}.

(iii) By reference to the energy balance of the Earth's surface, calculate T_E.

c. (i) Outline a mechanism by which part of the radiation radiated by the Earth's surface is absorbed by greenhouse gases in the atmosphere. [7]

(ii) Suggest why the incoming solar radiation is not affected by the mechanism you outlined in (c)(i).

(iii) Carbon dioxide (CO_2) is a greenhouse gas. State **one** source and **one** sink (object that removes CO_2) of this gas.

Markscheme

a. the solar radiation is captured by a disc of area πR^2 where R is the radius of the Earth;

but is distributed (when averaged) over the entire Earth's surface which has an area four times as large;

*Award **[1]** for reference to absorption/reflection.*

b. (i) 0.700;

(ii) $I(=e\sigma T_a^{\,4})=0.70\times5.67\times10^{-8}\times242^4$;
$=136\text{Wm}^{-2}$

(iii) $\sigma T_e^{\,4}=136+245\text{Wm}^{-2}$;
hence $T_e\left(=\sqrt[4]{\frac{381}{5.67\times10^{-8}}}\right)=286\text{K};$

c. (i) the Earth radiates radiation in the infrared region of the spectrum; the greenhouse gases have energy level differences (in their molecular energy levels) corresponding to infrared energies;

and so the infrared photons are absorbed;

or

the Earth radiates photons of infrared frequency;

the greenhouse gas molecules oscillate/vibrate with frequencies in the infrared region;

and so because of resonance the photons are absorbed;

(ii) most incoming radiation consists of photons in the visible/ultraviolet region /photons of much shorter wavelength than those radiated by the Earth / photons of different wavelength of that radiated by Earth;
and so these cannot be absorbed;

(iii) *Source:* emissions from volcanoes/burning of fossil fuels in power plants/cars/breathing;
Sink: oceans / rivers / lakes / seas / trees;

Examiners report

a. [N/A]
b. [N/A]
c. [N/A]

---

a. A nuclide of deuterium $\left({}_1^2\text{H}\right)$ and a nuclide of tritium $\left({}_1^3\text{H}\right)$ undergo nuclear fusion. [5]

(i) Each fusion reaction releases 2.8×10^{-12}J of energy. Calculate the rate, in kg s^{-1}, at which tritium must be fused to produce a power output of 250 MW.

(ii) State **two** problems associated with sustaining this fusion reaction in order to produce energy on a commercial scale.

b. Tritium is a radioactive nuclide with a half-life of 4500 days. It decays to an isotope of helium. [3]

Determine the time at which 12.5% of the tritium remains undecayed.

Markscheme

a. (i) number of fusions required per second $= \frac{2.5\times10^{8}}{2.8\times10^{-12}} (= 8.93 \times 10^{19})$;

1 tritium nucleus has mass of 3 amu=$3.0\times1.67\times10^{-27}$(kg)(=$5.0\times10^{-27}$);

total tritium mass required = 4/4.4/4.5/4.48×10^{-7}(kgs^{-1});

*Award **[3]** for a bald correct answer.*

(ii) *Award any two appropriate problems e.g.*:
difficulty in maintaining high temperature for long periods;
difficulty in maintaining high density of plasma for long periods;
difficulty in enclosing plasma for long periods;
difficulty in controlled removal of heat from plasma;
difficulty in maintaining magnetic fields;

b. one-eight remains / 87.5 decayed;

3 half lives;

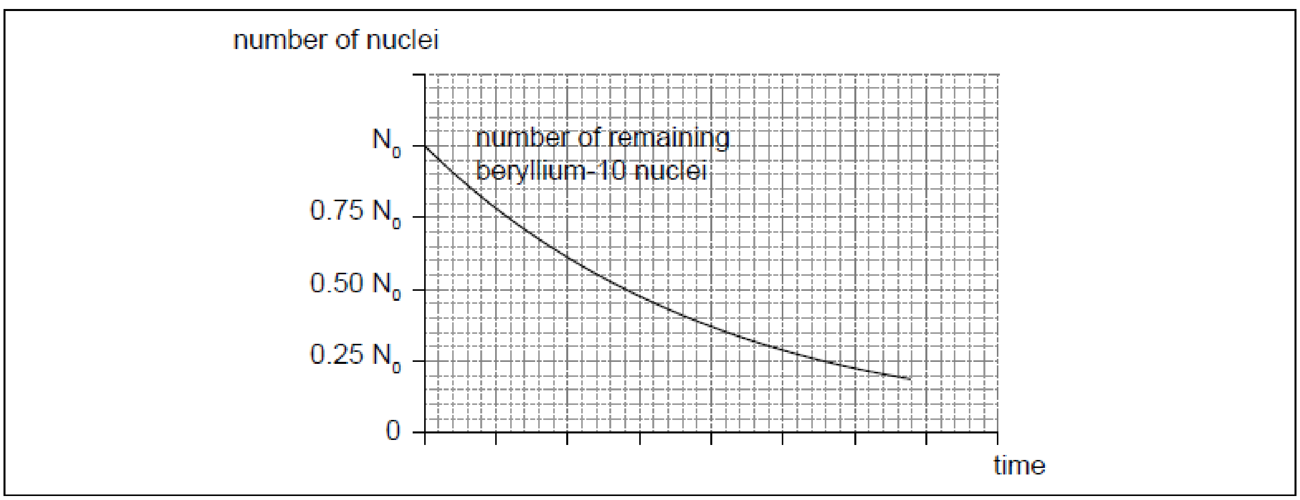
13500 (days);

Examiners report

a. [N/A]
b. [N/A]

The radioactive nuclide beryllium-10 (Be-10) undergoes beta minus (*β*–) decay to form a stable boron (B) nuclide.

The initial number of nuclei in a pure sample of beryllium-10 is N_0. The graph shows how the number of remaining **beryllium** nuclei in the sample varies with time.



An ice sample is moved to a laboratory for analysis. The temperature of the sample is –20 °C.

a. Identify the missing information for this decay. [1]

$$^{10}_{\square}\text{Be} \rightarrow {}^{\square}_{5}\text{B} + \beta + \overline{\upsilon}$$

b.i. On the graph, sketch how the number of **boron** nuclei in the sample varies with time. [2]

b.ii After 4.3 × 10^6 years, [3]

$$\frac{\text{number of produced boron nuclei}}{\text{number of remaining beryllium nuclei}} = 7.$$

Show that the half-life of beryllium-10 is 1.4 × 10^6 years.

b.iii Beryllium-10 is used to investigate ice samples from Antarctica. A sample of ice initially contains 7.6 × 10^{11} atoms of beryllium-10. State the number of remaining beryllium-10 nuclei in the sample after 2.8 × 10^6 years. [1]

c.i. State what is meant by thermal radiation. [1]

c.ii. Discuss how the frequency of the radiation emitted by a black body can be used to estimate the temperature of the body. [2]

c.iii Calculate the peak wavelength in the intensity of the radiation emitted by the ice sample. [2]

c.iv Derive the units of intensity in terms of fundamental SI units. [2]

Markscheme

a. $^{10}_{4}\text{Be} \rightarrow ^{10}_{5}\text{B} + \beta + \overline{\text{V}}_{\text{e}}$

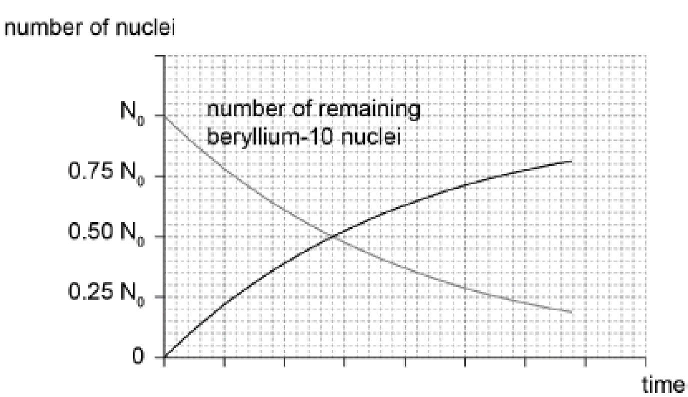
conservation of mass number ***AND*** charge $^{10}_{5}\text{B}$, $^{10}_{4}\text{Be}$

*Correct identification of both missing values required for **[1]**.*

[1 mark]

b.i. correct shape *ie* increasing from 0 to about 0.80 N_0

crosses given line at 0.50 N_0



[2 marks]

b.ii ***ALTERNATIVE 1***

fraction of Be = $\frac{1}{8}$, 12.5%, or 0.125

therefore 3 half lives have elapsed

$t_{\frac{1}{2}} = \frac{4.3\times10^6}{3} = 1.43 \times 10^6$ «≈ 1.4×10^6» «y»

ALTERNATIVE 2

fraction of Be = $\frac{1}{8}$, 12.5%, or 0.125

$\frac{1}{8} = \mathrm{e}^{-\lambda}(4.3 \times 10^6)$ leading to $\lambda = 4.836 \times 10^{-7}$ «y»$^{-1}$

$\frac{\ln 2}{\lambda} = 1.43 \times 10^6$ «y»

Must see at least one extra sig fig in final answer.

[3 marks]

b.iii. 1.9×10^{11}

[1 mark]

c.i. emission of (infrared) electromagnetic/infrared energy/waves/radiation.

[1 mark]

c.ii. the (peak) wavelength of emitted em waves depends on temperature of emitter/reference to Wein's Law

so frequency/color depends on temperature

[2 marks]

c.iii. $\lambda = \frac{2.90\times10^{-3}}{253}$

$= 1.1 \times 10^{-5}$ «m»

Allow ECF from MP1 (incorrect temperature).

[2 marks]

c.iv. correct units for Intensity (allow *W, Nms^{-1} OR Js^{-1} in numerator)*

rearrangement into proper SI units = kgs^{-3}

Allow ECF for MP2 if final answer is in fundamental units.

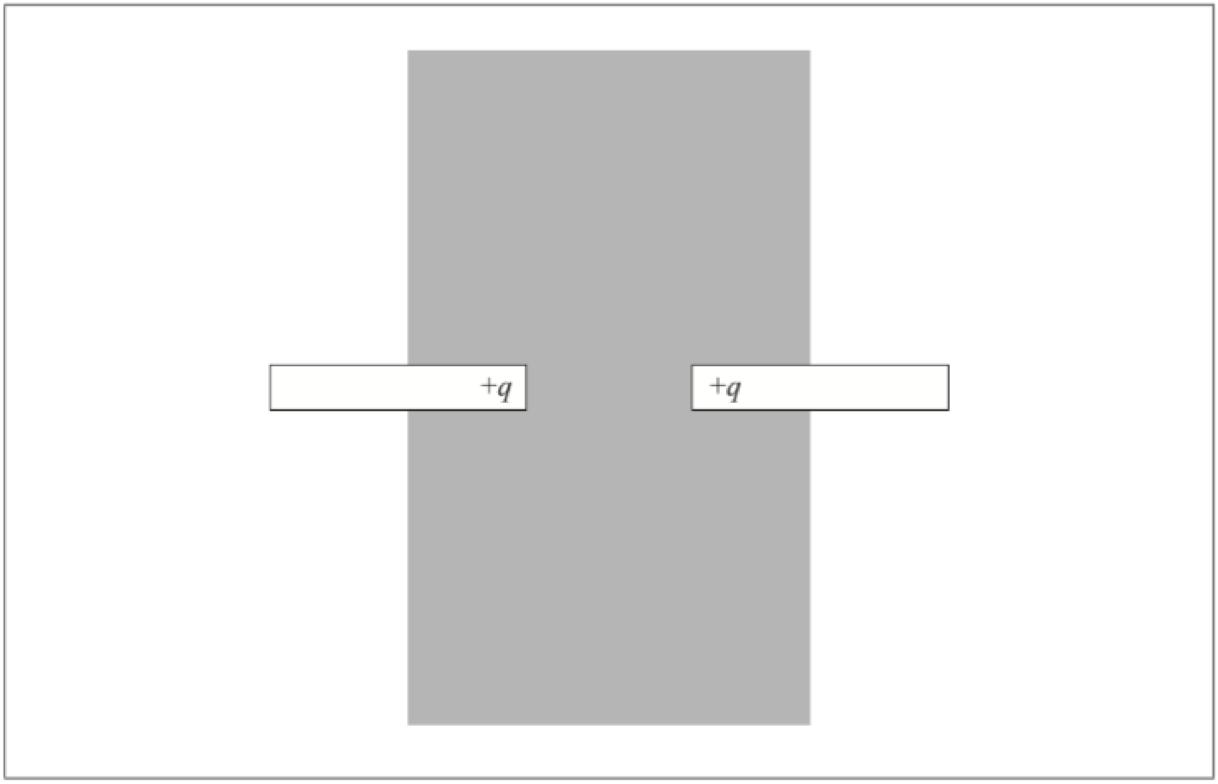
[2 marks]

Examiners report

a. [N/A]
b.i. [N/A]
b.ii. [N/A]
b.iii. [N/A]
c.i. [N/A]
c.ii. [N/A]
c.iii. [N/A]
c.iv. [N/A]

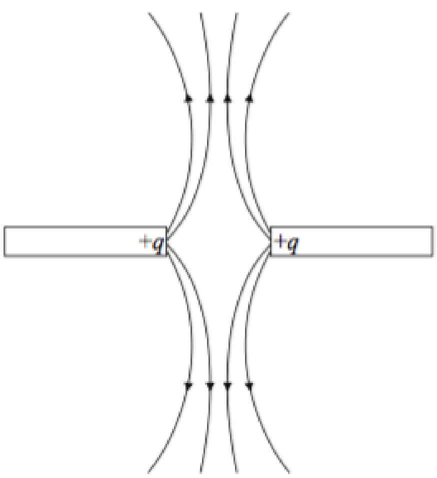
Part 2 Electric charge

Two plastic rods each have a positive charge +*q* situated at one end. The rods are arranged as shown.



Assume that the charge at the end of each rod behaves as a point charge. Draw, in the shaded area on the diagram, the electric field pattern due to the two charges.

Markscheme



at least four field lines (minimum two per rod) to show overall shape of pattern;

direction of lines all away from poles;

Ignore all working outside region.
Any field lines crossing loses first mark even if accidental.

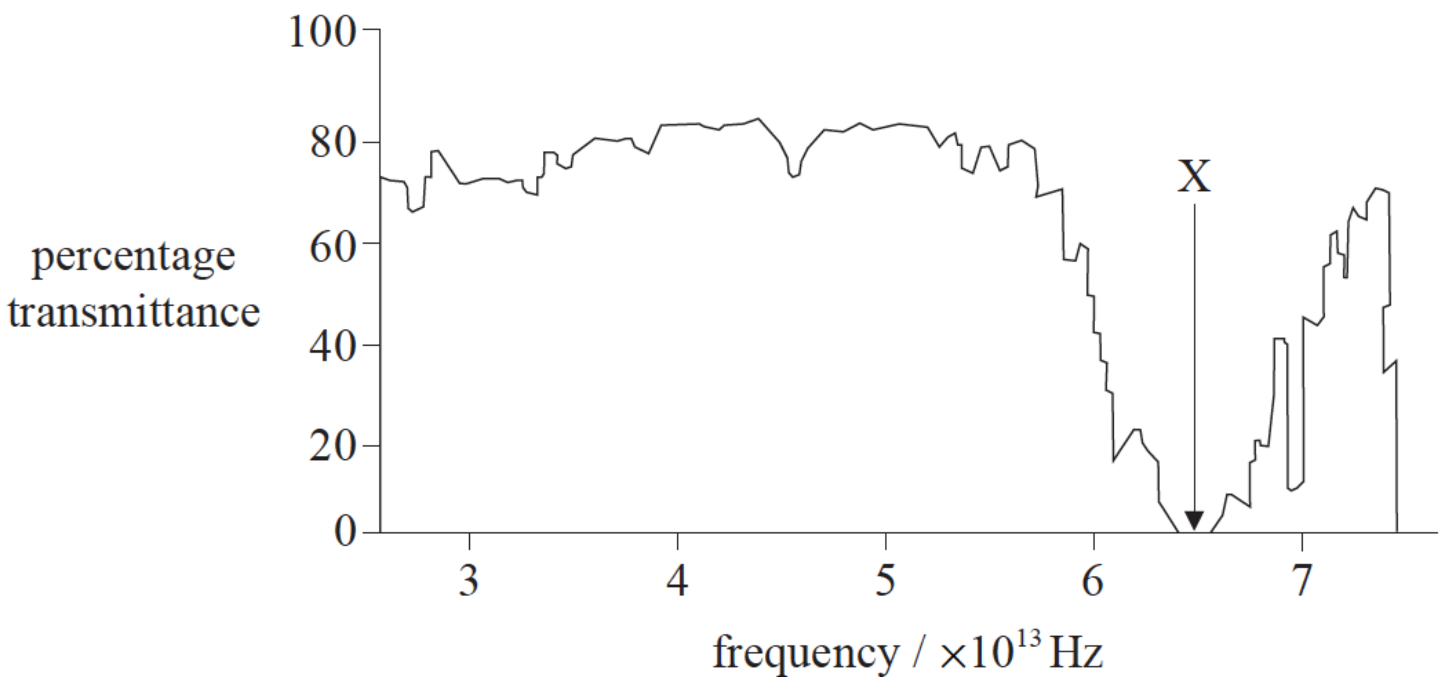
Examiners report

This question is in **two** parts. **Part 1** is about the greenhouse effect. **Part 2** is about an electric motor.

Part 1 Greenhouse effect

a. Describe what is meant by the greenhouse effect in the Earth's atmosphere. [3]

b. The graph shows the variation with frequency of the percentage transmittance of electromagnetic waves through water vapour in the atmosphere. [9]



(i) Show that the reduction in percentage transmittance labelled X occurs at a wavelength equal to approximately 5 μm.

(ii) Suggest, with reference to resonance, the possible reasons for the sharp reduction in percentage transmittance at a wavelength of 5 μm.

(iii) Explain how the reduction in percentage transmittance, labelled X on the graph opposite, accounts for the greenhouse effect.

(iv) Outline how an increase in the concentration of greenhouse gases in the atmosphere may lead to global warming.

Markscheme

a. effect caused by gas such as H_2O/NH_3/CH_4/CO_2/greenhouse gas in the atmosphere;

gas absorbs outgoing (long wave) radiation from Earth;

gas re-radiates some of the energy back to Earth;

b. (i) $\frac{3.0\times10^{8}}{6.5\times10^{13}} = 4.6\ (\mu m)$;

≈5(μm)

(ii) water vapour molecules have a natural frequency of oscillation;
if this frequency of oscillation is 6.5×10^{13} / reference to frequency at X;
due to resonance this radiation is readily absorbed by the molecules / the radiation matches the natural frequency of oscillation;

or

X is a natural frequency (of oscillation) of water molecule;
so resonance effects mean that molecules are excited at this frequency;
and energy is removed/less energy transmitted from electromagnetic waves at this (particular) frequency;

(iii) energy gained by absorption needs to be re-emitted (as molecules de-excite);
in other directions / some returns to Earth;

(iv) more greenhouse gases means that there is more absorption of outgoing radiation;
therefore more energy returns to Earth;
leading to a further/greater increase in the temperature of the surface (of Earth);

Examiners report

a. [N/A]
b. [N/A]

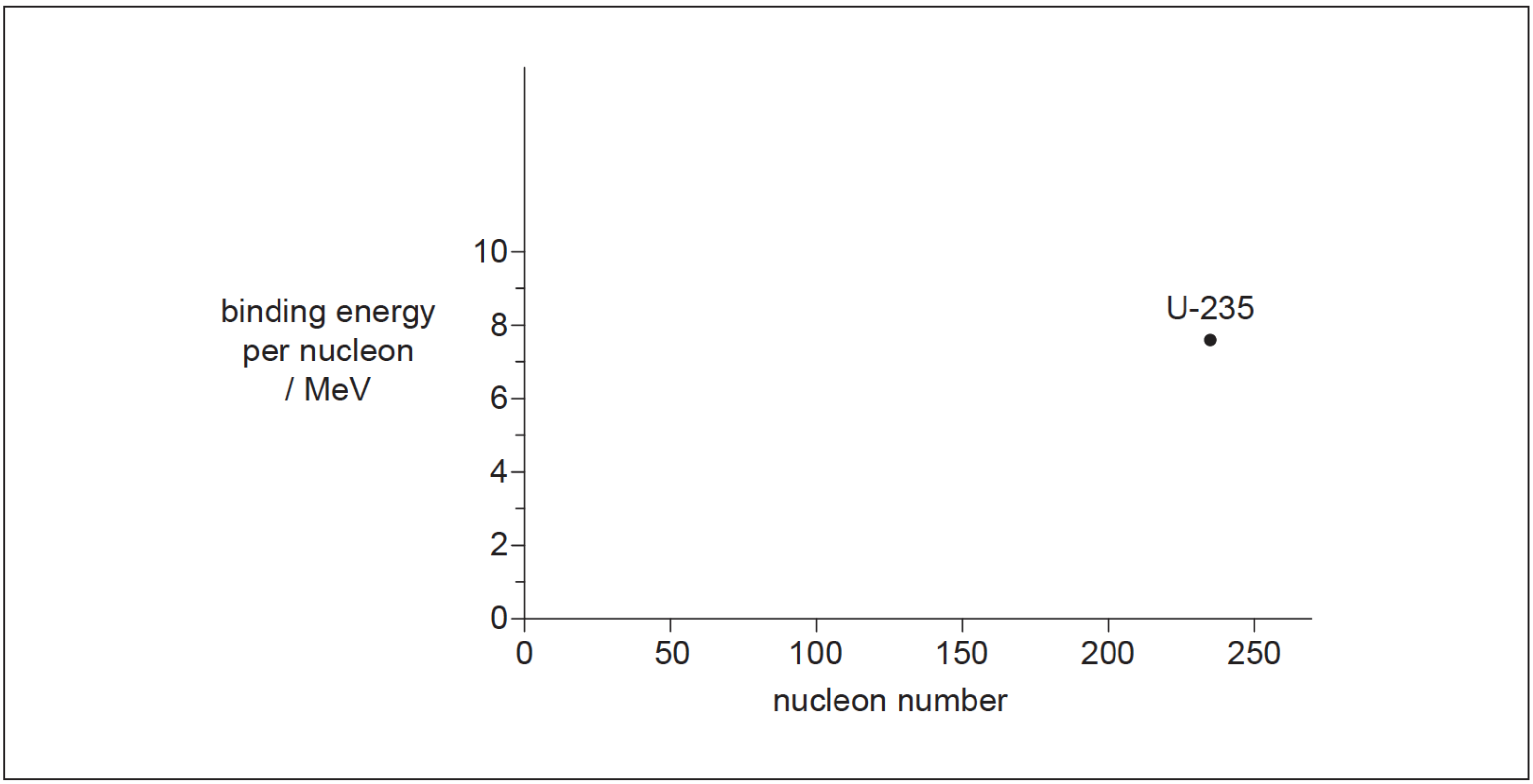
This question is in two parts. **Part 1** is about renewable energy. **Part 2** is about nuclear energy and radioactivity.

Part 1 Renewable energy

A small coastal community decides to use a wind farm consisting of five identical wind turbines to generate part of its energy. At the proposed site, the average wind speed is 8.5ms^{-1} and the density of air is 1.3kgm^{-3}. The maximum power required from the wind farm is 0.75 MW. Each turbine has an efficiency of 30%.

Part 2 Nuclear energy and radioactivity

The graph shows the variation of binding energy per nucleon with nucleon number. The position for uranium-235 (U-235) is shown.



a. (i) Determine the diameter that will be required for the turbine blades to achieve the maximum power of 0.75 MW. [8]

(ii) State **one** reason why, in practice, a diameter larger than your answer to (a)(i) is required.

(iii) Outline why the individual turbines should not be placed close to each other.

(iv) Some members of the community propose that the wind farm should be located at sea rather than on land. Evaluate this proposal.

b. Currently, a nearby coal-fired power station generates energy for the community. Less coal will be burnt at the power station if the wind farm is constructed. [7]

(i) The energy density of coal is 35 MJ kg^{-1}. Estimate the minimum mass of coal that can be saved every hour when the wind farm is producing its full output.

(ii) One advantage of the reduction in coal consumption is that less carbon dioxide will be released into the atmosphere. State **one** other advantage and **one** disadvantage of constructing the wind farm.

(iii) Suggest the likely effect on the Earth's temperature of a reduction in the concentration of atmospheric greenhouse gases.

c. State what is meant by the binding energy of a nucleus. [1]

d. (i) On the axes, sketch a graph showing the variation of nucleon number with the binding energy per nucleon. [5]

(ii) Explain, with reference to your graph, why energy is released during fission of U-235.

e. U-235 $\left({}^{235}_{92}\mathrm{U}\right)$ can undergo alpha decay to form an isotope of thorium (Th). [4]

(i) State the nuclear equation for this decay.

(ii) Define the term *radioactive half-life*.

(iii) A sample of rock contains a mass of 5.6 mg of U-235 at the present day. The half-life of U-235 is 7.0$\times$10^8 years. Calculate the initial mass of the U-235 if the rock sample was formed 2.1$\times$10^9 years ago.

Markscheme

a. (i) total wind power required $= \frac{750000}{0.3}$;

maximum wind power required per turbine, $P = \frac{750000}{5\times0.3} (= 500\mathrm{kW})$;

$d = \left(\frac{8P}{\rho\pi v^3} =\right)^{\frac{1}{2}} 40(\mathrm{m})$

*Award **[1 max]** for an answer of 48.9 (m) as it indicates 5 and 0.3 ignored.*
*Award **[2 max]** for 22 (m) as it indicates 0.3 ignored.*
*Award **[2 max]** for 89 (m) as it indicates 5 ignored.*

(ii) not all kinetic energy can be extracted from wind / losses in cables to community / turbine rotation may be cut off/"feathered" at high or low wind speeds;
Do not allow "wind speed varies" as question gives the average speed.

(iii) less kinetic energy available / wind speed less for turbines behind; turbulence/wake effect; *(do not allow "turbines stacked too close")*

(iv) *implications:* average wind speeds are greater / more space available;
limitations: installation/maintenance cost / difficulty of access / wave damage;
*Must see one each for **[2]**.*

b. (i) mass of coal per second (=0.0214 kg);

77.1 (kg);

or

energy saved per hour=0.75×3600 (=2700MJh^{-1}) ;

mass of coal saved $= \left(\frac{2700}{35} =\right) 77.1(\mathrm{kg});$

*Award **[2]** for a bald correct answer.*

(ii) *advantage:*
energy is free (apart from maintenance and start-up costs) / energy is renewable / sufficient for small community with predominance of wind / supplies energy to remote community / independent of national grid / any other reasonable advantage;
Answer must focus on wind farm not coal disadvantages.

disadvantage:
wind energy is variable/unpredictable / noise pollution / killing birds/bats / large open areas required / visual pollution / ecological issues / need to provide new infrastructure;

(iii) greenhouse gas molecules are excited by/absorbed by/resonate as a result of infrared radiations; { (must refer to infrared not "heat")
this radiation is re-emitted in all directions;
less greenhouse gas means less infrared/heat returned to Earth; { (consideration of return direction is essential for mark)
temperature falls (to reach new equilibrium);

c. energy released when a nucleus forms from constituent nucleons / (minimum) energy needed/work done to break a nucleus up into its constituent

nucleons;

*Award **[0]** for energy to assemble nucleus.*

Do not allow "particles" or "components" for "nucleons".

Do not accept "energy that binds nucleons together" OWTTE.

d. *(*i) generally correct shape with maximum shown, trending down to U-235;

maximum shown somewhere between 40 and 70;

*Award **[0]** for straight line with positive gradient from origin.*

*Award **[1]** if maximum position correct but graph begins to rise or flatlines beyond or around U-235.*

(ii) identifies fission as occurring at high nucleon number / at right-hand side of graph;
fission means that large nucleus splits into two (or more) smaller nuclei/nuclei to left of fissioning nucleus (on graph);
(graph shows that) fission products have higher (average) binding energy per nucleon than U-235;
energy released related to difference between initial and final binding energy;
*Award **[2 max]** if no reference to graph.*

e. (i) ${}^{235}_{92}\mathrm{U} \rightarrow {}^{231}_{90}\mathrm{Th} + {}^{4}_{2}\alpha$; *(allow He for α; treat charge indications as neutral)*

(ii) time taken for number of unstable nuclei/(radio)activity to halve;
Accept atom/isotope.
Do not accept mass/molecule/amount/substance.

(iii) three half-lives identified;
45 (mg);
*Award **[2]** for bald correct answer.*

Examiners report

a. [N/A]
b. [N/A]
c. [N/A]
d. [N/A]
e. [N/A]

This question is about the greenhouse effect.

The following data are available for use in this question:

Quantity	Symbol	Value
Power emitted by the Sun	P	3.8×10^{26} W
Distance from the Sun to the Earth	d	1.5×10^{11} m
Radius of the Earth	r	6.4×10^{6} m
Albedo of the Earth's atmosphere	α	0.31
Stefan–Boltzmann constant	σ	5.7×10^{-8} W m^{-2} K^{-4}

a. Explain why the power absorbed by the Earth is [3]

$$\frac{P}{4\pi d^2}\times(1-\alpha)\times\pi r^2$$

b. The equation in (a) leads to the following expression which can be used to predict the Earth's average surface temperature *T*. [4]

$$T=\sqrt[4]{\frac{(1-\alpha)\,P}{16\pi\sigma d^2}}$$

(i) Calculate the predicted temperature of the Earth.

(ii) Explain why the actual average surface temperature of the Earth is in fact higher than the answer to (b)(i).

Markscheme

a. intensity of the Sun's radiation at the Earth's orbit $=\frac{P}{4\pi d^2}$;

fraction absorbed by the Earth =(1-∝);

the surface area of the disc (absorbing the radiation) $=\pi r^2$;

Look for statements that correctly describe each term.

b. (i) correct substitution;

to get *T*=250 (K);

(ii) greenhouse gases in the atmosphere absorb some of the energy radiated by the Earth;
and radiate some of it back to the surface of the Earth;

Examiners report

a. [N/A]
b. [N/A]

This question is about alternative energy supplies.

A small island community requires a peak power of 850 kW. Two systems are available for supplying the energy: using wind power or photovoltaic cells.

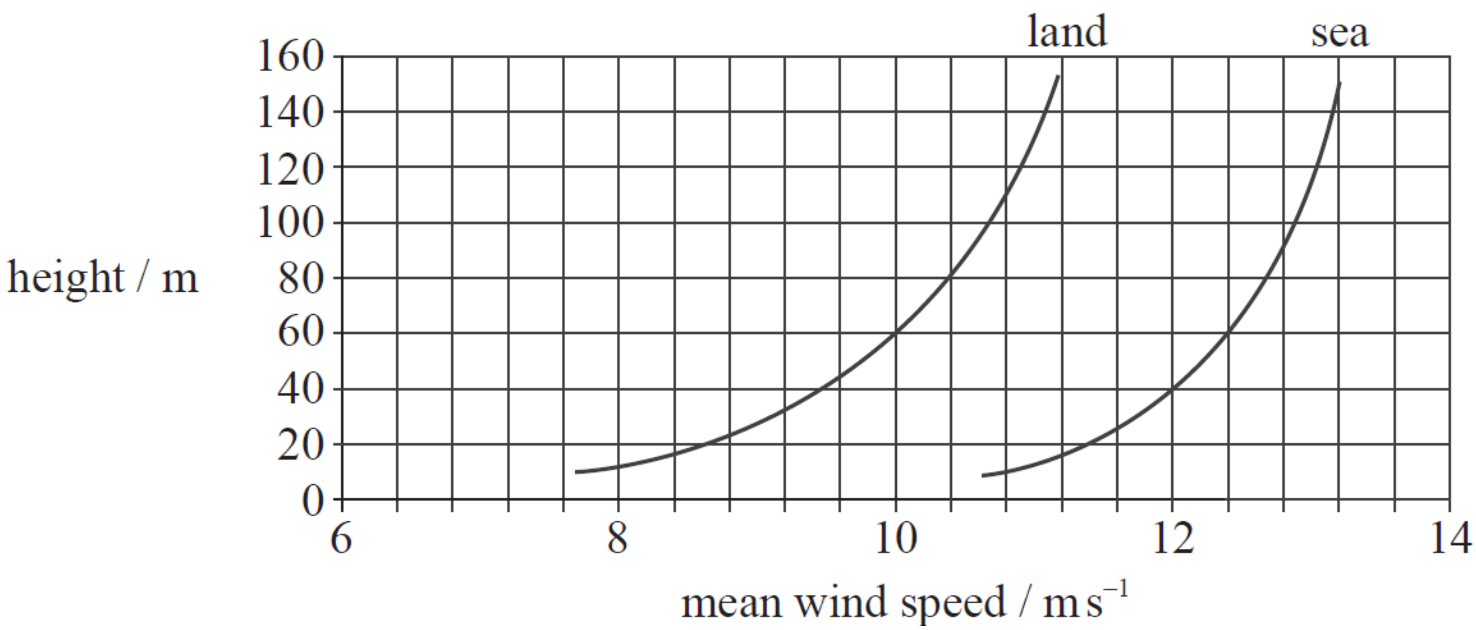
a. (i) Outline, with reference to the energy conversions in the machine, the main features of a conventional horizontal-axis wind generator. [7]

(ii) The mean wind speed on the island is 8.0 ms^{-1}. Show that the maximum power available from a wind generator of blade length 45 m is approximately 2 MW.

Density of air = 1.2 kg m^{-3}

(iii) The efficiency of the generator is 24%. Deduce the number of these generators that would be required to provide the islanders with enough power to meet their energy requirements.

b. The graph below shows how the wind speed varies with height above the land and above the sea. [3]



(i) Suggest why, for any given height, the mean wind speed above the sea is greater than the mean wind speed above the land.

(ii) There is a choice of mounting the wind generators either 60m above the land or 60m above the sea.

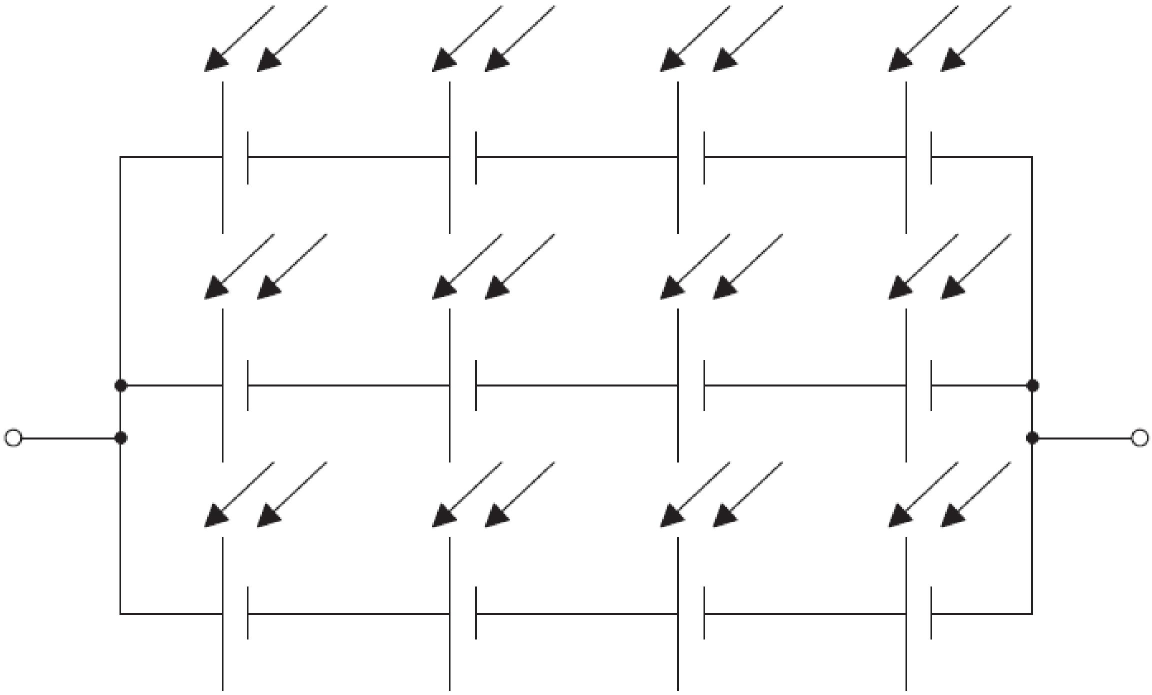
Calculate the ratio

$$\frac{\text{poweravailablefromaland} - \text{basedgenerator}}{\text{poweravailablefromasea} - \text{basedgenerator}}$$

at a height of 60m.

c. Distinguish between photovoltaic cells and solar heating panels. [2]

d. The diagram shows 12 photovoltaic cells connected in series and in parallel to form a module to provide electrical power. [8]

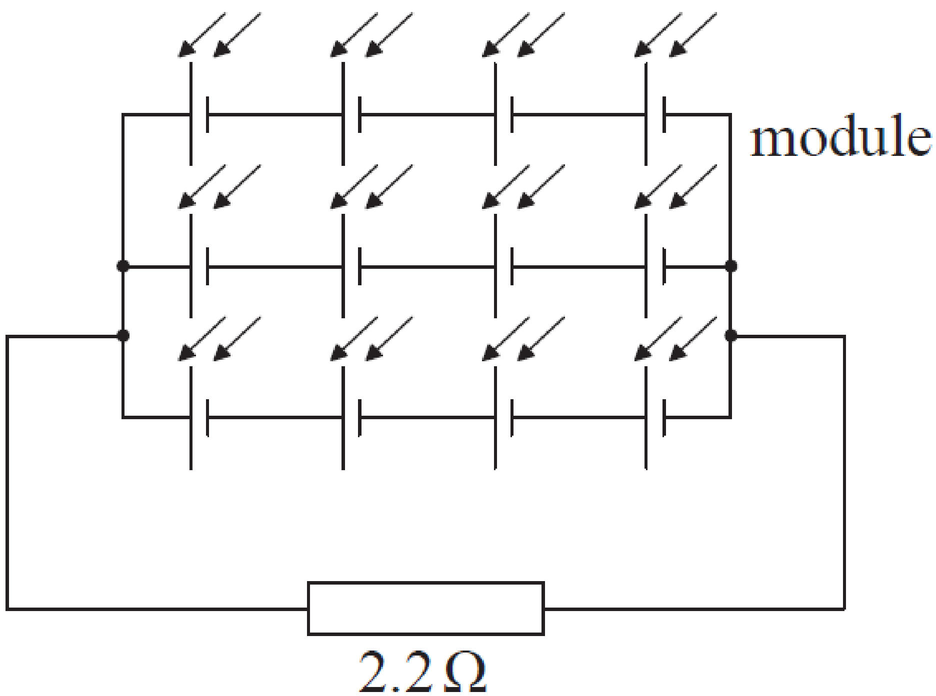


Each cell in the module has an emf of 0.75V and an internal resistance of 1.8Ω.

(i) Calculate the emf of the module.

(ii) Determine the internal resistance of the module.

(iii) The diagram below shows the module connected to a load resistor of resistance 2.2Ω.



Calculate the power dissipated in the load resistor.

(iv) Discuss the benefits of having cells combined in series and parallel within the module.

e. The intensity of the Sun's radiation at the position of the Earth's orbit (the solar constant) is approximately $1.4\times10^3 Wm^{-2}$. [5]

(i) Explain why the average solar power per square metre arriving at the Earth is 3.5×10^2 W.

(ii) State why the solar constant is an approximate value.

(iii) Photovoltaic cells are approximately 20% efficient. Estimate the minimum area needed to supply an average power of 850kW over a 24 hour period.

Markscheme

a. (i) mention of blades/propeller and turbine/generator/dynamo;

kinetic energy of wind → kinetic energy of turbine;

(rotational) kinetic energy → electricity/electrical energy;

*Award **[1 max]** for statement of (unqualified) kinetic energy to electrical energy*

(ii) $A(=\pi r^2)=6.4\times10^3(\text{m}^2)$;
(P=)1.95 MW;

(iii) 0.24×1.95MW (=0.47 MW/0.48 MW);
(0.47 MW = 470 kW thus) two generators would meet the maximum demand;
Allow only two generators for the second mark. Do not accept fractional generators.

b. (i) sea is smoother (does not interrupt wind flow) / no obstacles on sea / less friction / less turbulence (vice versa for land) / *OWTTE*; *Allow named obstacles, eg trees/buildings/hills, etc.*

(ii) $\frac{v_{land}}{v_{sea}}=\frac{10}{12.4}$;
$\frac{P_{land}}{P_{sea}}=\left[\frac{10}{12.4}\right]^3=0.52$;
*Award **[1 max]** for 1.9 due to inverted ratio.*

c. photovoltaic cells generate emf/electricity;

solar panels generate thermal energy/heat / *OWTTE*;

d. (i) emf=3.0 (V);

(ii) series combination of resistance=7.2(Ω);
use of parallel resistance formula;
2.4(Ω);
*Award **[3]** for a bald correct answer*

(iii) attempted use of IV, I^2R or $\frac{V^2}{R}$;
0.94 (W);
Allow ECF from (d)(i) and (d)(ii).
Must see values substituted to gain first mark as compensation.

(iv) (series) increases the total emf/voltage;
(parallel) increases the current/decreases internal resistance/ensures some power if single cell fails / *OWTTE*;

e. (i) the solar radiation is captured by a disc of area πR^2 where R is the radius of the Earth;

but is distributed (when averaged) over the entire Earth's surface which has an area four times as large;

or

rays make an angle θ with area of Earth's half-sphere and so average intensity is proportional to average of $\cos^2\theta$ i.e. $\frac{1}{2}$;
there is an additional factor of $\frac{1}{2}$ due to the other half of the sphere;

(ii) variation of solar emission / Earth's orbit is elliptical/not quite circular;

(iii) input power needed =(5×850(kW)=) 4.25×10^6 (W);

$\frac{4.25\times10^6(\mathrm{W})}{3.5\times10^2(\mathrm{Wm^{-2}})} = 1.2\times10^4\ (\mathrm{m^2})$;

*Award **[2]** for a bald correct answer.*

Examiners report

a. (i) Many did not mention the kinetic energy of the wind (often referring to 'wind energy'). All types of kinetic energy were referred to as 'mechanical' energy by many candidates. The general structure of this type of wind generator was generally well-known.

(ii) This part was generally well answered with those candidates completing the area calculation usually going on to gain both marks.

(iii) Again, this was well answered with nearly all candidates recognising that is not possible to have fractional generators and, therefore, rounding up their answers to 2 from the 1.7 calculation.

b. (i) Most candidates were able to suggest why the winds above the sea are higher than those above the land for the same height. A minority incorrectly answered this in terms of convection currents and sea versus land temperatures.

(ii) Nearly all candidates were able to correctly read the two values from the graph and a slight majority of these went on to correctly cube the ratio.

c. Most candidates knew the difference between photovoltaic cells and solar heating panels. A minority believed that both would normally produce electricity.

d. (i) This was not well known and many candidates simply added the emfs to give a value of 9.0 V rather than the correct 3.0 V.

(ii) Nearly all candidates correctly calculated the resistance of the series portions of the modules but there were frequent errors in combining these to find the total resistance – with the parallel formula often being incorrectly written in shorthand

(iii) Although many candidates recognised how they should use the power formula, very few were able to used the correct resistance and the correct voltage.

(iv) Many candidates knew that a failing cell would still allow current in other parallel branches, but few explained that the series combination increased the emf and the parallel combination increased the current in a module.

e. (i) A significant minority of candidates insisted that the reduction in the Sun's intensity was due to radiation reflected from atmosphere. Few went on to do the calculation to support their answer but there were a small number of very good answers to this part.

(ii) Here again, many mentioned radiation reflected by atmosphere rather than variations in solar emissions or the non-circularity of Earth's orbit.

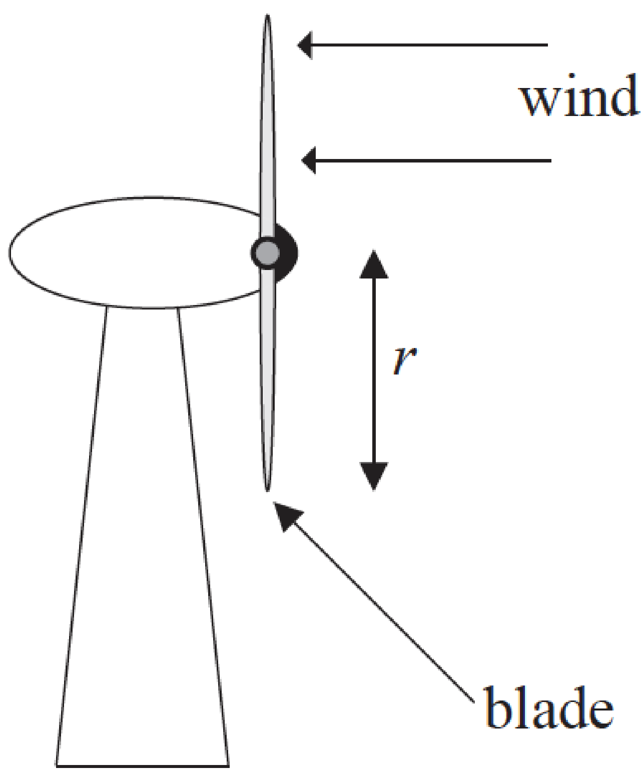
(iii) This part was generally poorly done. The '24-hour period' confused many candidates and few were able to follow the argument through to a logical conclusion.

This question is in **two** parts. **Part 1** is about wind power. **Part 2** is about radioactive decay.

Part 1 Wind power

a. Outline in terms of energy changes how electrical energy is obtained from the energy of wind. [2]

b. Air of density ρ and speed v passes normally through a wind turbine of blade length r as shown below. [5]



(i) Deduce that the kinetic energy per unit time of the air incident on the turbine is

$$\frac{1}{2}\pi\rho r^2 v^3$$

(ii) State **two** reasons why it is impossible to convert all the available energy of the wind to electrical energy.

c. Air is incident normally on a wind turbine and passes through the turbine blades without changing direction. The following data are available. [3]

Density of air entering turbine = 1.1 kg m^{-3}
Density of air leaving turbine = 2.2 kg m^{-3}
Speed of air entering turbine = 9.8 m s^{-1}
Speed of air leaving turbine = 4.6 m s^{-1}
Blade length = 25 m

Determine the power extracted from the air by the turbine.

d. A wind turbine has a mechanical input power of 3.0×10^5W and generates an electrical power output of 1.0×10^5W. On the grid below, construct and label a Sankey diagram for this wind turbine. [3]

e. Outline **one** advantage and **one** disadvantage of using wind turbines to generate electrical energy, as compared to using fossil fuels. [2]

Advantage:

Disadvantage:

Markscheme

a. <u>kinetic</u> energy of wind transferred to (rotational) kinetic energy of turbine/blades;

kinetic energy changed to electrical energy in generator/dynamo;

Generator/dynamo must be mentioned.

b. (i) volume of cylinder of air passing through blades per second $=v\pi r^2$;

mass of air incident per second$=\rho v\pi r^2$;

kinetic energy per second= $\frac{1}{2}mv^2$;

leading to $\frac{1}{2}\pi\rho r^2v^3$

*Award **[3]** for answers that combine one or more steps.*

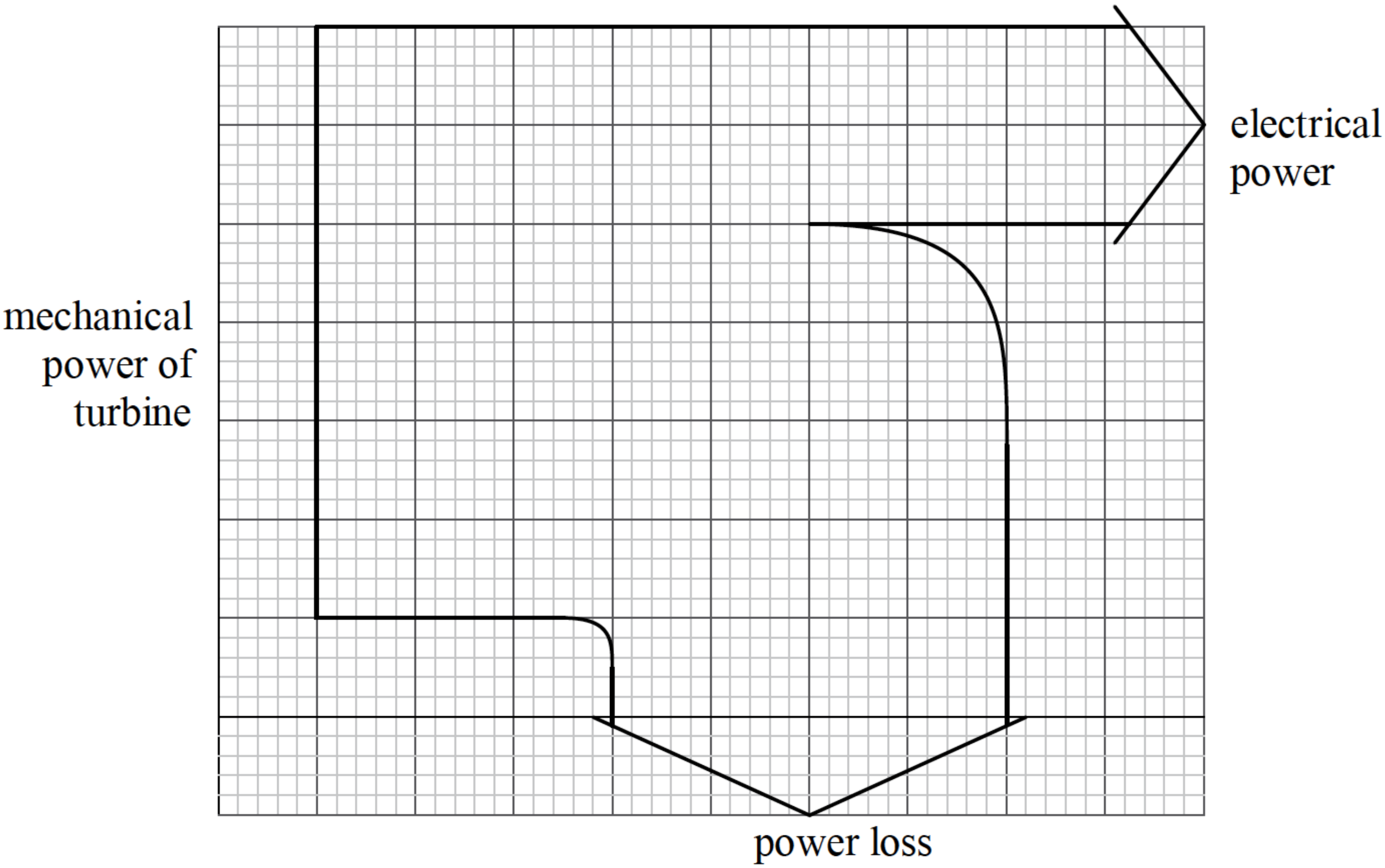
(ii) the speed of the air/wind cannot drop to zero;
wind turbulence / frictional losses in turbine/any moving part / resistive heating in wires;

c. kinetic energy per second of air entering turbine $= \frac{1}{2}\pi \times 1.1 \times 25^2 \times 9.8^3 = 1.016 \times 10^6$;

kinetic energy per second of air leaving turbine $= \frac{1}{2}\pi \times 2.2 \times 25^2 \times 4.6^3 = 2.102 \times 10^5$;

power extracted $= 1.0 \times 10^6 - 2.1 \times 10^5 = 8.062 \times 10^5 \approx 8.1 \times 10^5 \mathrm{W}$;

d.



correct shape of diagram (allow multiple arrows if power loss split into different components);
relative width of arrows correct;
labels correct;

e. *Advantage:*

wind is renewable so no resources used up / wind is free / no chemical pollution / no carbon dioxide emission / does not contribute to greenhouse effect / is "scalable" *i.e.* many sizes of turbine possible;

Disadvantage:
expensive initial cost / large land area needed / wind not constant / effect on movement of birds / aesthetically unpleasant / noise pollution / high maintenance costs / best locations far from population centres / low energy density;

Accept any other suitable advantage or disadvantage.

Examiners report

a. [N/A]
b. [N/A]
c. [N/A]
d. [N/A]
e. [N/A]

This question is about energy sources.

A small island is situated in the Arctic. The islanders require an electricity supply but have no fossil fuels on the island. It is suggested that wind generators should be used in combination with power stations using either oil or nuclear fuel.

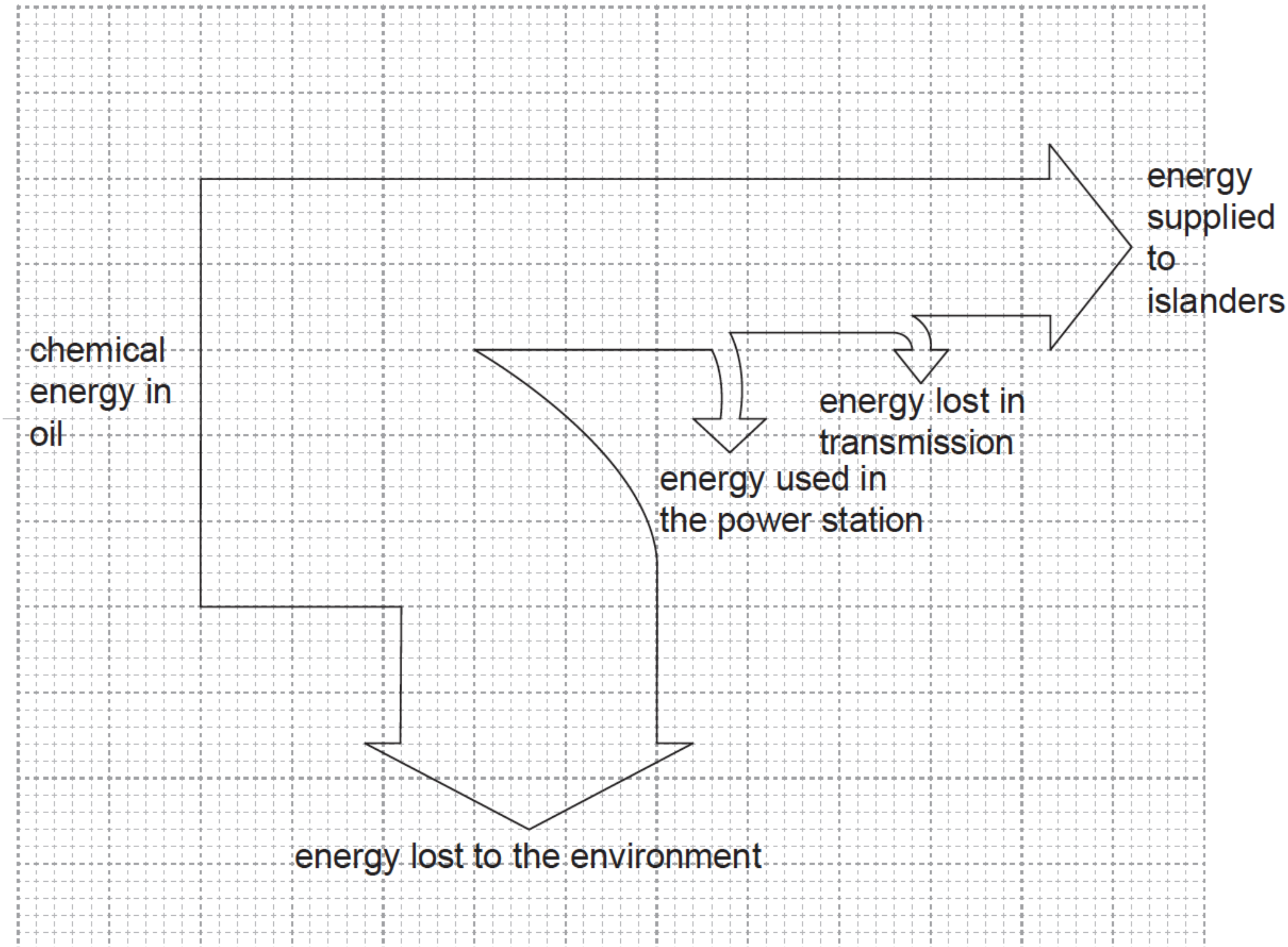
a. Suggest the conditions that would make use of wind generators in combination with either oil or nuclear fuel suitable for the islanders. [3]

b. Conventional horizontal-axis wind generators have blades of length 4.7m. The average wind speed on the island is $7.0 ms^{-1}$ and the average air density is $1.29 kgm^{-3}$. [5]

(i) Deduce the total energy, in GJ, generated by the wind generators in one year.

(ii) Explain why less energy can actually be generated by the wind generators than the value you deduced in (b)(i).

c. The energy flow diagram (Sankey diagram) below is for an oil-fired power station that the islanders might use. [4]



(i) Determine the efficiency of the power station.

(ii) Explain why energy is wasted in the power station.

(iii) The Sankey diagram in (c) indicates that some energy is lost in transmission. Explain how this loss occurs.

d. The emissions from the oil-fired power station in (c) are likely to increase global warming by the enhanced greenhouse effect. [3]

Outline the mechanism by which greenhouse gases contribute to global warming.

e. Nuclear fuel must be enriched before it can be used. Outline why fuel enrichment is needed. [2]

f. The nuclear equation below shows one of the possible fission reactions in a nuclear reactor. [3]

$$\left({}^{1}_{0}\mathrm{n} + {}^{\cdots}_{92}\mathrm{U} \rightarrow {}^{92}_{\ldots}\mathrm{Kr} + {}^{141}_{56}\mathrm{Ba} + \ldots {}^{1}_{0}\mathrm{n}\right)$$

Identify the missing numbers in the equation.

g. A nuclear reactor requires both control rods and a moderator to operate. Outline, with reference to neutrons, **one** similarity and **two** differences in the function of each of these components. [3]

Markscheme

a. needs to be windy/high average wind speeds; space/land/room for wind turbines;

ability to import oil/nuclear fuel;

ability to dispose of nuclear waste;

comment relating to need for geological stability;

b. (i) $\pi 4.7^2$ ***or*** 69.4 m^2;

power = 15300 to 15400 W;

470 to 490 GJ;

(ii) wind must retain kinetic energy to escape ***or*** not all KE of wind can be converted to KE of blades;

energy lost to thermal energy (due to friction) in generator/turbine/dynamo;

turbine will suffer downtime when no wind/too much wind;

Allow any two relevant factors.

c. (i) indication that energy supplied to islanders is output and chemical energy

input / $\frac{8}{25}$ used;

32% / 0.32;

(ii) energy/it is wasted due to inefficient burning of oil / thermal/heat energy loss to surroundings/environment / electrical energy is used to run the power station's systems / energy/it is wasted due to frictional losses in the turbine/generator;

(iii) heating of wires by electric current / inefficient transformers;

d. radiation emitted by Earth in (long wavelength) infrared region;

frequency corresponds to resonant frequency of greenhouse gases (either vibration or difference in energy levels);

radiation absorbed by greenhouse gases is (partly) re-radiated back to Earth;

e. percentage of U-235 in naturally occurring ores is too low to support fission ***or*** naturally occurring U-238 does not undergo fission;

percentage of U-235 (which can usefully capture thermal neutrons) is increased;

f. $\left({}^{1}_{0}\mathrm{n} + {}^{235}_{92}\mathrm{U} \rightarrow {}^{92}_{36}\mathrm{Kr} + {}^{141}_{56}\mathrm{Ba} + 3{}^{1}_{0}\mathrm{n}\right)$

235;
36;
3;

The number of neutrons must be consistent with chosen isotope of uranium.

g. control rods absorb neutrons;
moderators slow down neutrons;
both affect the rate of reaction;
both rely on the neutrons colliding with their atoms/nuclei;
Must see reference to collision/interaction for fourth marking point.

Examiners report

a. [N/A]
b. [N/A]
c. [N/A]
d. [N/A]
e. [N/A]
f. [N/A]
g. [N/A]

This question is in **two** parts. **Part 1** is about solar radiation and the greenhouse effect. **Part 2** is about a mass on a spring.

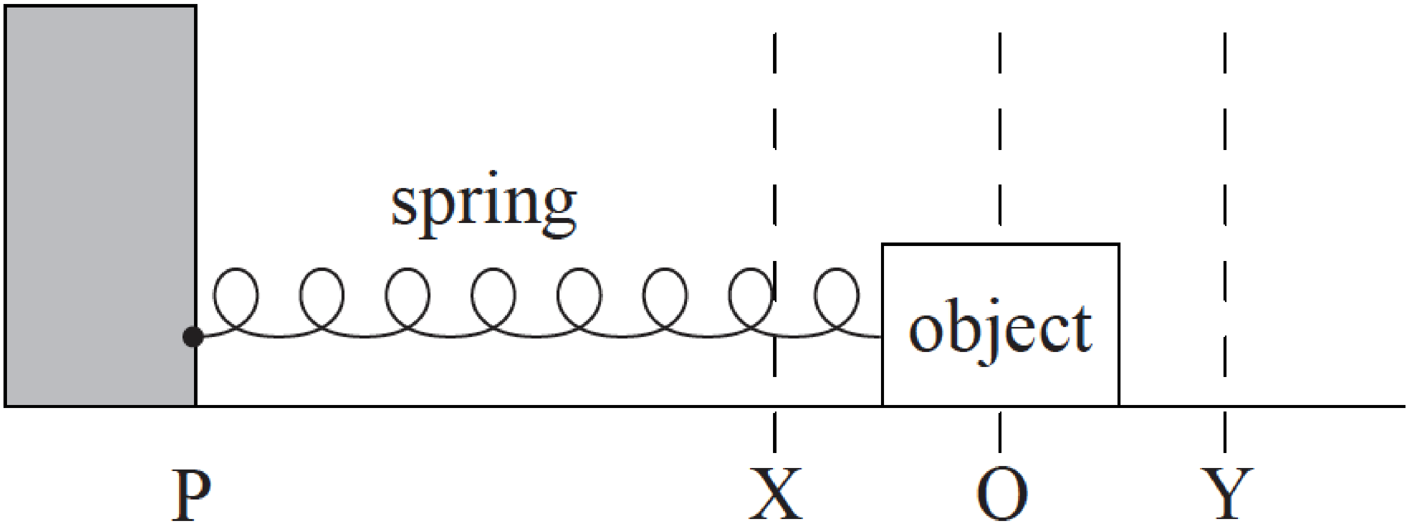
Part 1 Solar radiation and the greenhouse effect

The following data are available.

Quantity	Symbol	Value
Radius of Sun	R	7.0×10^{8} m
Surface temperature of Sun	T	5.8×10^{3} K
Distance from Sun to Earth	d	1.5×10^{11} m
Stefan-Boltzmann constant	σ	5.7×10^{-8} W m^{-2} K^{-4}

Part 2 A mass on a spring

An object is placed on a frictionless surface and attached to a light horizontal spring.



The other end of the spring is attached to a stationary point P. Air resistance is negligible. The equilibrium position is at O. The object is moved to position Y and released.

a. State the Stefan-Boltzmann law for a black body. [2]

b. Deduce that the solar power incident per unit area at distance *d* from the Sun is given by [2]

$$\frac{\sigma R^2 T^4}{d^2}$$

c. Calculate, using the data given, the solar power incident per unit area at distance *d* from the Sun. [2]

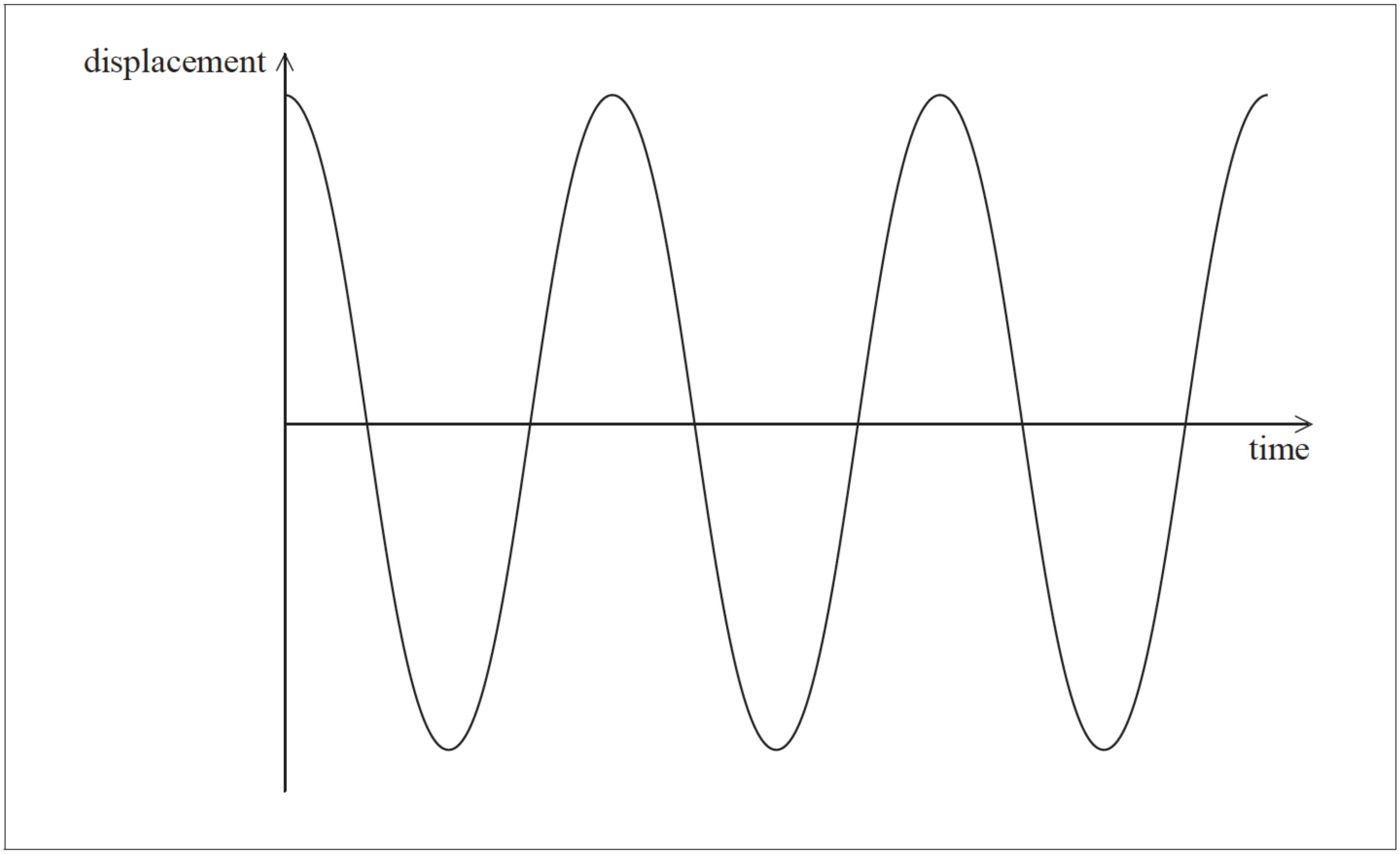
d. State **two** reasons why the solar power incident per unit area at a point on the surface of the Earth is likely to be different from your answer in (c). [2]

e. The average power absorbed per unit area at the Earth's surface is 240Wm^{-2}. By treating the Earth's surface as a black body, show that the average surface temperature of the Earth is approximately 250K. [2]

f. Explain why the actual surface temperature of the Earth is greater than the value in (e). [3]

h. Outline the conditions necessary for the object to execute simple harmonic motion. [2]

i. The sketch graph below shows how the displacement of the object from point O varies with time over three time periods. [4]



(i) Label with the letter A a point at which the magnitude of the acceleration of the object is a maximum.

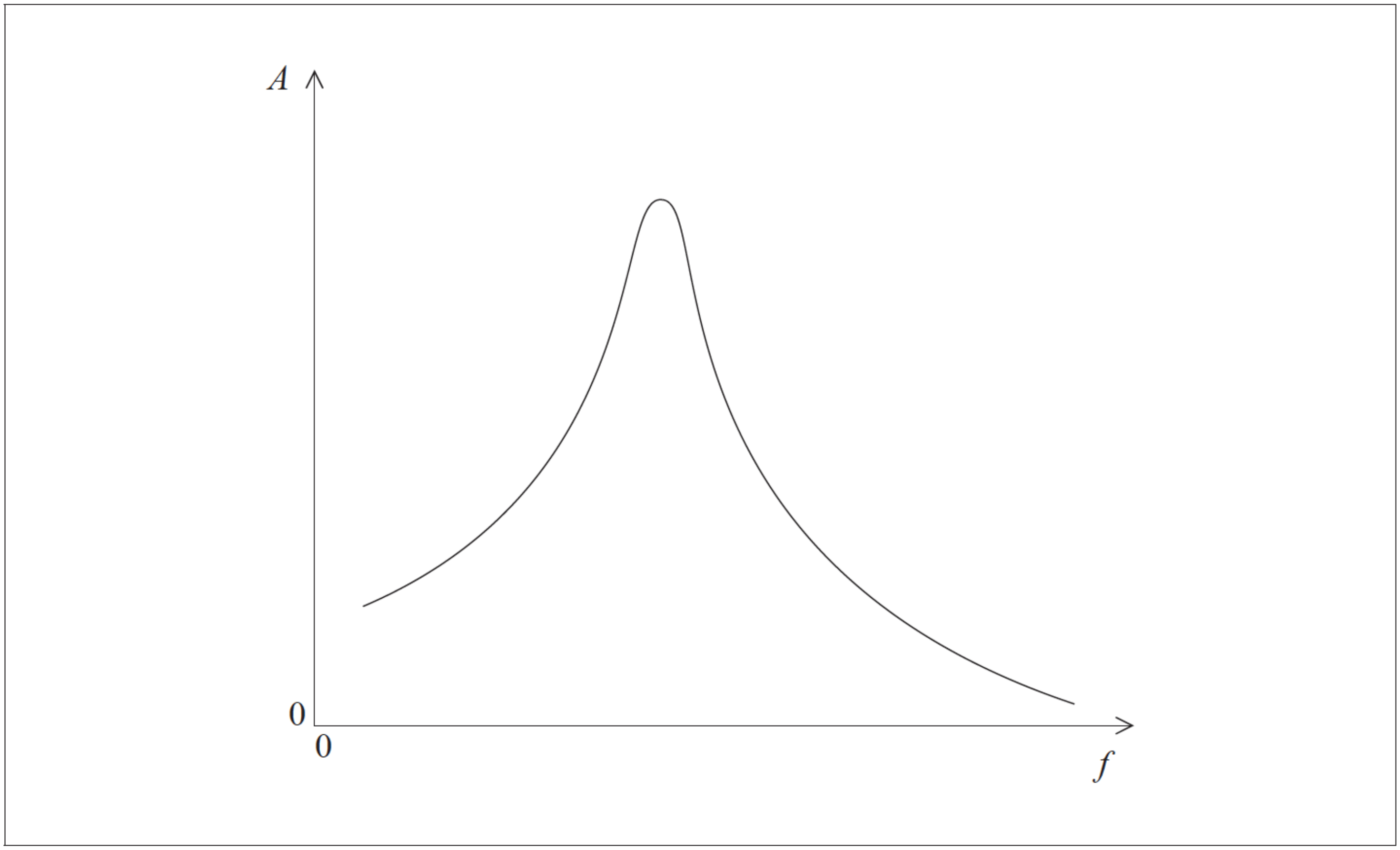
(ii) Label with the letter V a point at which the speed of the object is a maximum.

(iii) Sketch on the same axes a graph of how the displacement varies with time if a **small** frictional force acts on the object.

j. Point P now begins to move from side to side with a small amplitude and at a variable driving frequency *f*. The frictional force is still small. [4]

At each value of *f*, the object eventually reaches a constant amplitude *A*.

The graph shows the variation with *f* of *A*.



(i) With reference to resonance and resonant frequency, comment on the shape of the graph.

(ii) On the same axes, draw a graph to show the variation with *f* of *A* when the frictional force acting on the object is increased.

Markscheme

a. power/energy per second emitted proportional to surface area;

and proportional to fourth power of absolute temperature / temperature in K;

Accept equation with symbols defined.

b. solar power given by $4\pi R^2\sigma T^4$;

spreads out over sphere of surface area $4\pi d^2$;

Hence equation given.

c. $\left(\frac{\sigma R^2 T^4}{d^2}=\right)\frac{5.7\times10^{-8}\times[7.0\times10^8]^2\times[5.8\times10^3]^4}{[1.5\times10^{11}]^2}$;

$=1.4\times10^3(\text{Wm}^{-2})$;

*Award **[2]** for a bald correct answer.*

d. some energy reflected;

some energy absorbed/scattered by atmosphere; depends on latitude;

depends on time of day;

depends on time of year;

depends on weather (*eg* cloud cover) at location; power output of Sun varies;

Earth-Sun distance varies;

e. power radiated = power absorbed;

$T = \sqrt[4]{\frac{240}{5.7\times10^{-8}}} = (250\mathrm{K});$

Accept answers given as 260 (K).

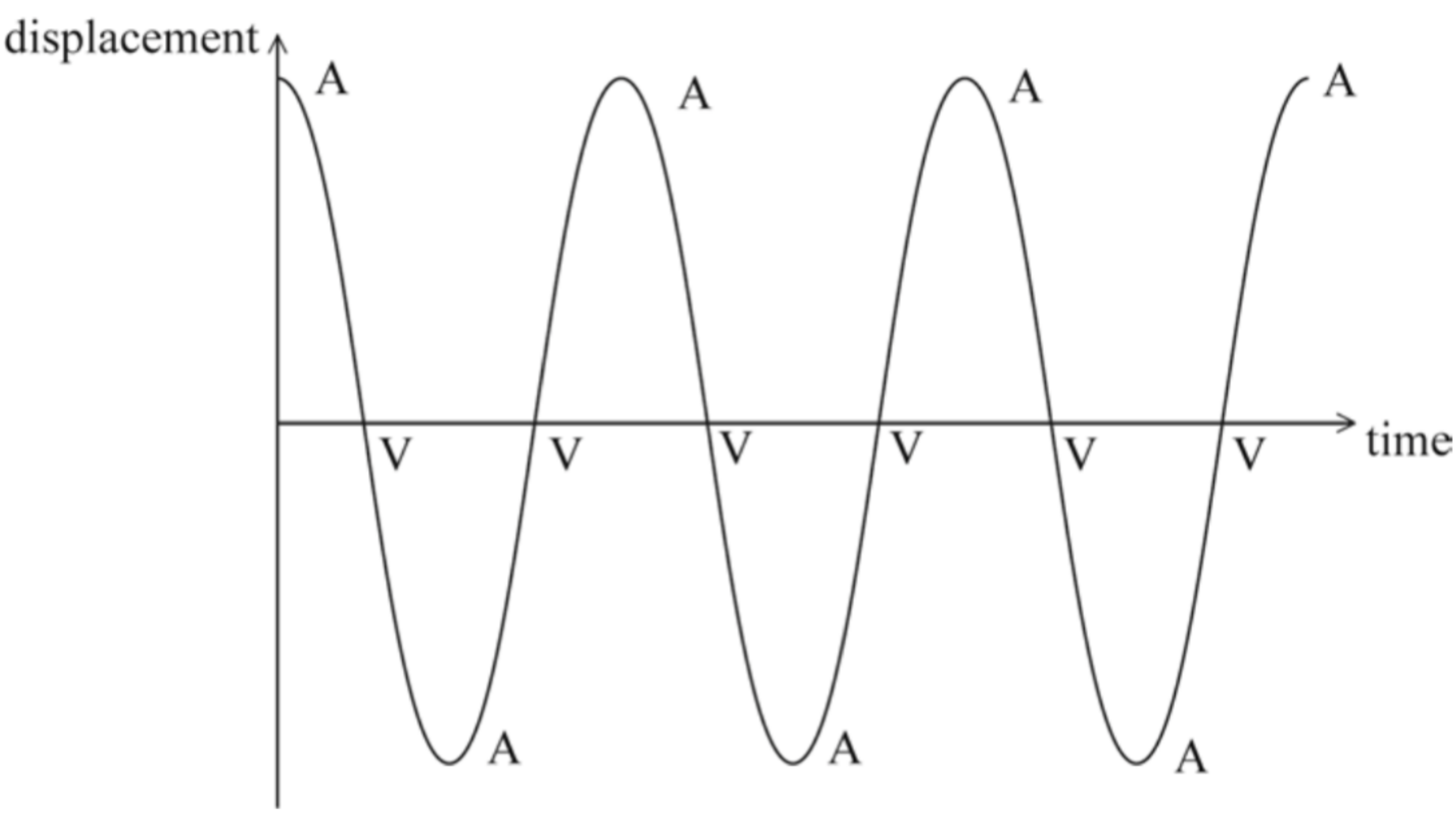
f. radiation from Sun is re-emitted from Earth at longer wavelengths; greenhouse gases in the atmosphere absorb some of this energy; and radiate some of it back to the surface of the Earth;

h. the force (of the spring on the object)/acceleration (of the object/point O) must be proportional to the displacement (from the equilibrium position/centre/point O);

and in the opposite direction to the displacement / always directed towards the equilibrium position/centre/point O;

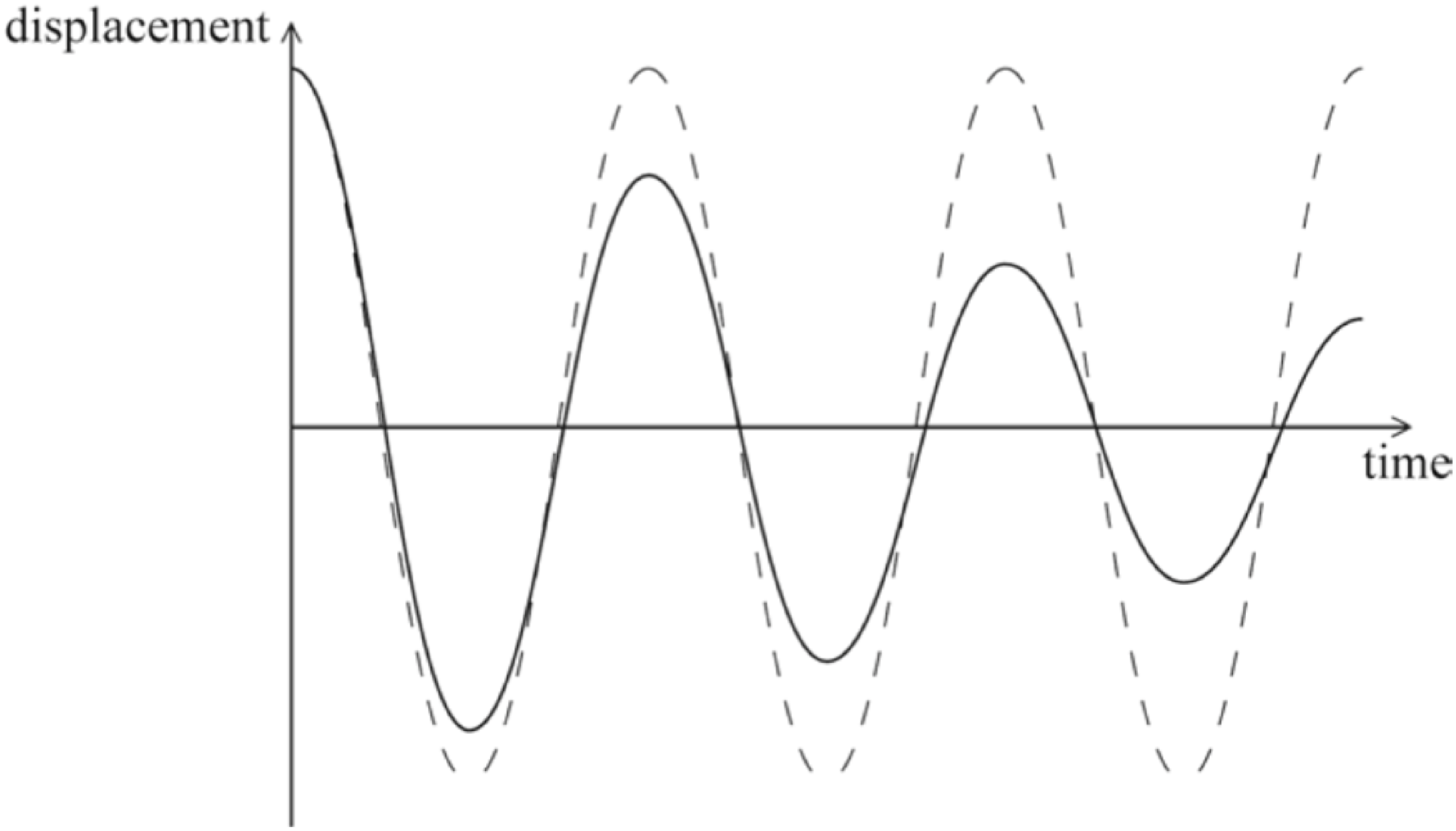
i. (i) one A correctly shown;

(ii) one V correctly shown;



(iii) same period; *(judge by eye)*

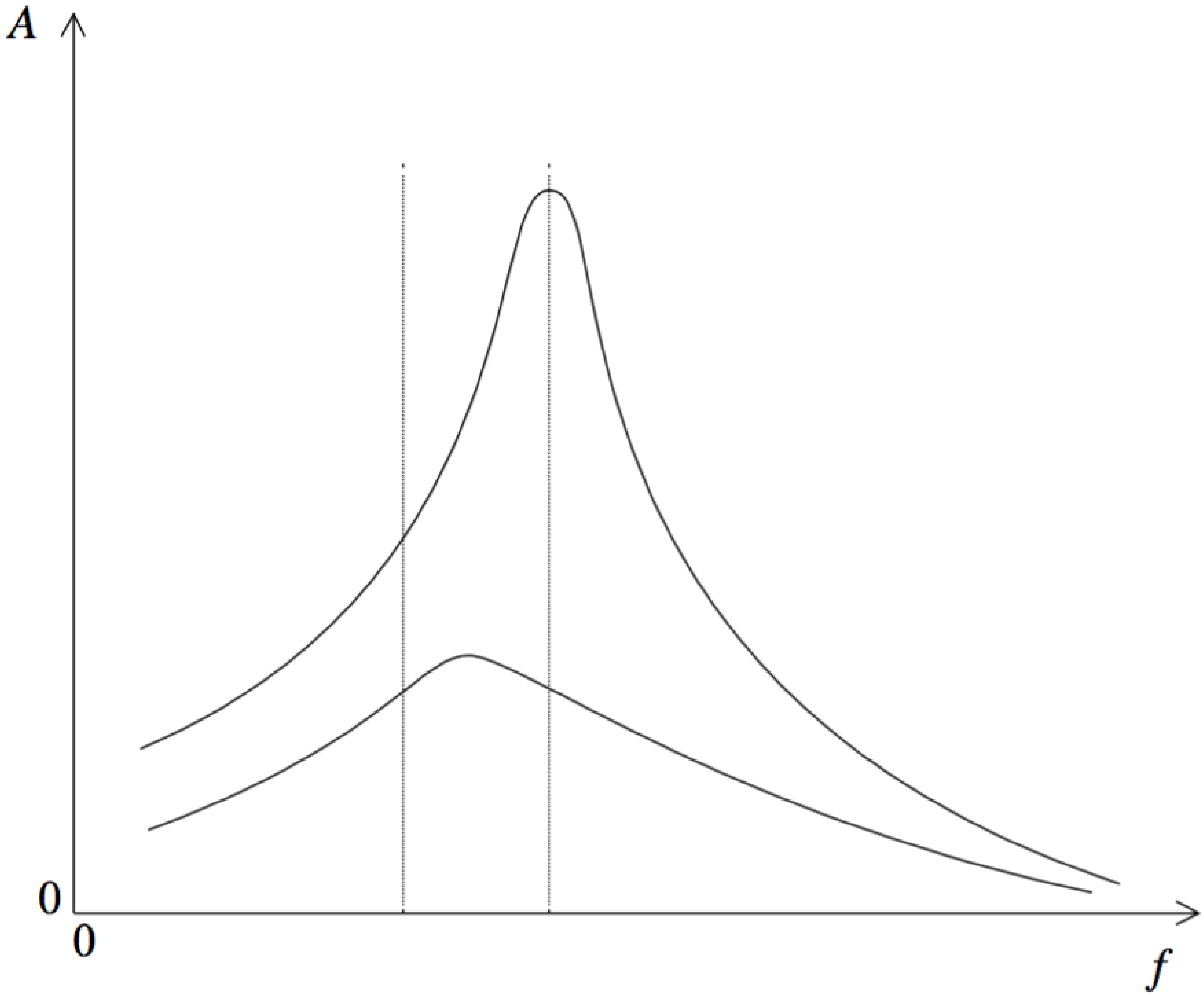
amplitude decreasing with time;



j. (i) resonance is where driving frequency equals/is close to natural/resonant frequency;

the natural/resonant frequency is at/near the maximum amplitude of the graph;

(ii) lower amplitude everywhere on graph, bit still positive;
maximum in same place/moved slightly *(that is, between the lines)* to left on graph;



Examiners report

a. The Stefan-Boltzmann law was poorly understood with few candidates stating that the absolute temperature is raised to the fourth power.

b. This question was poorly done with few candidates substituting the surface area of the sun or the surface area of a sphere at the Earth's radius of orbit.

c. Despite not being able to state or manipulate the Stefan-Boltzmann law most candidates could substitute values into the expression and calculate a result.

d. This question was well answered at higher level.

e. To show the given value there is the requirement for an explanation of why the incident power absorbed by the Earth's surface is equal to the power radiated by the Earth, few candidates were successful in this aspect. Although most could substitute into the Stefan-Boltzmann equation they needed to either show that the fourth root was used or to find the temperature to more significant figures than the value given.

f. A surprising number of candidates could not explain the greenhouse effect. A common misunderstanding was that the Earth reflected radiation into the atmosphere and that the atmosphere reflected the radiation back to the Earth.

h. The conditions for simple harmonic motion were poorly outlined by most candidates. Few identified a relationship between force/acceleration and displacement, with most talking about it going backwards and forwards without slowing down.

i. This question was well answered by many. The only notable mistake was with reducing the time period of the damped oscillation.

j. i) Identifying the peak of the graph with the resonant frequency was broadly successfully done but not many candidates stated that this occurs when the driving frequency is equal to the natural frequency.

   ii) This sketch was generally well done.