R2019_810P2 *[217 marks]*

The ratio $\frac{\text{distance of Mars from the Sun}}{\text{distance of Earth from the Sun}}$ = 1.5.

1a. Show that the intensity of solar radiation at the orbit of Mars is about 600 W m $^{-2}$. *[2 marks]*

Markscheme

use of $I \propto \frac{1}{r^2}$ «1.36 × 10^3 × $\frac{1}{1.5^2}$» ✔

604 «W m^{-2}» ✔

1b. Determine, in K, the mean surface temperature of Mars. Assume that Mars acts as a black body. *[2 marks]*

Markscheme

use of $\frac{600}{4}$ for mean intensity ✔

temperature/K = « $\sqrt[4]{\frac{600}{4 \times 5.67 \times 10^{-8}}}$ =» 230 ✔

1c. The atmosphere of Mars is composed mainly of carbon dioxide and has a pressure less than 1 % of that on the Earth. Outline why the greenhouse effect is not significant on Mars. *[2 marks]*

Markscheme

recognize the link between molecular density/concentration and pressure ✔

low pressure means too few molecules to produce a significant heating effect

OR

low pressure means too little radiation re-radiated back to Mars ✔

2a. State how the density of a nucleus varies with the number of nucleons in the nucleus. *[1 mark]*

Markscheme

it is constant ✔

2b. Show that the nuclear radius of phosphorus-31 ($^{31}_{15}\mathrm{P}$) is about 4 fm. *[1 mark]*

Markscheme

R = $1.20 \times 10^{-15} \times 31^{\frac{1}{3}} = 3.8 \times 10^{-15}$ «m» ✔

Must see working and answer to at least 2SF

$^{32}_{15}\mathrm{P}$ is formed when a nucleus of deuterium ($^{2}_{1}\mathrm{H}$) collides with a nucleus of $^{31}_{15}\mathrm{P}$. The radius of a deuterium nucleus is 1.5 fm.

2c. State the maximum distance between the centres of the nuclei for which the production of $^{32}_{15}\mathrm{P}$ is likely to occur. *[1 mark]*

Markscheme

separation for interaction = 5.3 ***or*** 5.5 «fm» ✔

2d. Determine, in J, the minimum initial kinetic energy that the deuterium nucleus must have in order to produce $^{32}_{15}\mathrm{P}$. Assume that the phosphorus nucleus is stationary throughout the interaction and that only electrostatic forces act. *[2 marks]*

Markscheme

energy required = $\frac{15e^2}{4\pi\varepsilon_0 \times 5.3 \times 10^{-15}}$ ✔

= 6.5 / 6.6 $\times 10^{-13}$ ***OR*** 6.3 $\times 10^{-13}$ «J» ✔

Allow ecf from (b)(i)

2e. $^{32}_{15}\mathrm{P}$ undergoes beta-minus (β^-) decay. Explain why the energy gained by the emitted beta particles in this decay is not the same for every beta particle. *[2 marks]*

Markscheme

«electron» <u>antineutrino</u> also emitted ✔

energy split between electron and «anti»neutrino ✔

2f. State what is meant by decay constant. *[2 marks]*

Markscheme

probability of decay of a nucleus ✔

OR

the fraction of the number of nuclei that decay

in one/the next second

OR

per unit time ✔

2g. In a fresh pure sample of ${}^{32}_{15}\text{P}$ the activity of the sample is 24 Bq. After one week the activity has become 17 Bq. Calculate, in s^{-1}, the decay constant of ${}^{32}_{15}\text{P}$. *[3 marks]*

Markscheme

1 week = 6.05 × 10^5 «s»

17 = $24\text{e}^{-\lambda \times 6.1 \times 10^5}$ ✔

5.7 × 10^{-7} «s^{-1}» ✔

*Award **[2 max]** if answer is not in seconds*

*If answer **not** in seconds and **no** unit quoted award **[1 max]** for correct substitution into equation (MP2)*

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

3a. Identify the missing information for this decay. *[1 mark]*

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

Markscheme

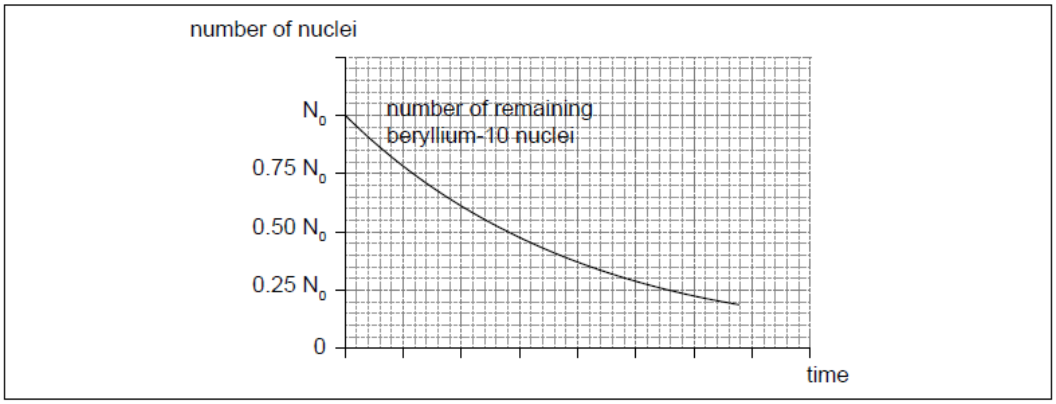
${}^{10}_{4}\text{Be} \rightarrow {}^{10}_{5}\text{B} + \beta + \overline{\text{V}}_{\text{e}}$

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]

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.

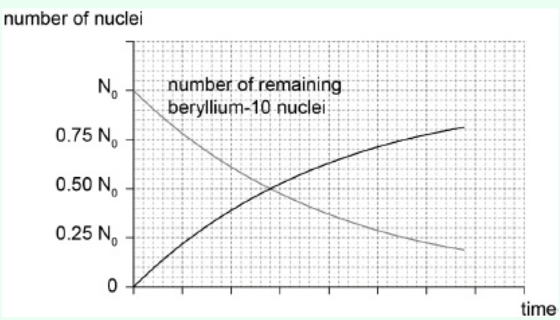


3b. On the graph, sketch how the number of **boron** nuclei in the sample varies with time. *[2 marks]*

Markscheme

correct shape *ie* increasing from 0 to about 0.80 N_0

crosses given line at 0.50 N_0



[2 marks]

3c. After 4.3 × 10^6 years, *[3 marks]*

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

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

Markscheme

ALTERNATIVE 1

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

therefore 3 half lives have elapsed

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

ALTERNATIVE 2

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

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

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

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

[3 marks]

3d. 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 mark]*

Markscheme

1.9 × 10^{11}

[1 mark]

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

3e. State what is meant by thermal radiation. *[1 mark]*

Markscheme

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

[1 mark]

3f. Discuss how the frequency of the radiation emitted by a black body can be used to estimate the temperature of the body. *[2 marks]*

Markscheme

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]

3g. Calculate the peak wavelength in the intensity of the radiation emitted by the ice sample. *[2 marks]*

Markscheme

$\lambda = \frac{2.90 \times 10^{-3}}{253}$

= 1.1×10^{-5} «m»

Allow ECF from MP1 (incorrect temperature).

[2 marks]

3h. Derive the units of intensity in terms of fundamental SI units. *[2 marks]*

Markscheme

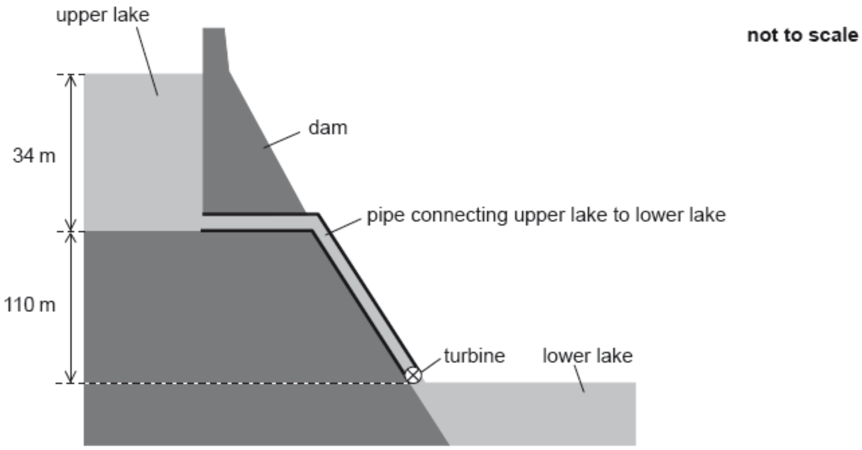
correct units for Intensity (allow *W, Nms^{-1} OR Js^{-1} in numerator)*

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

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

[2 marks]

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}.

4a. Estimate the specific energy of water in this storage system, giving an appropriate unit for your answer. *[2 marks]*

Markscheme

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]

4b. Show that the average rate at which the gravitational potential energy of the water decreases is 2.5 GW. *[3 marks]*

Markscheme

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 × 10^6 × 9.81 × 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]

4c. The storage system produces 1.8 GW of electrical power. Determine the overall efficiency of the storage system. *[1 mark]*

Markscheme

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

[1 mark]

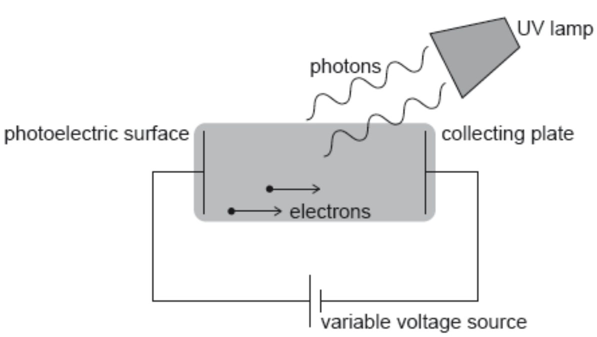
4d. After the upper lake is emptied it must be refilled with water from the lower lake and this requires energy. Suggest how the operators of this storage system can still make a profit. *[1 mark]*

Markscheme

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

[1 mark]

Hydrogen atoms in an ultraviolet (UV) lamp make transitions from the first excited state to the ground state. Photons are emitted and are incident on a photoelectric surface as shown.



5a. Show that the energy of photons from the UV lamp is about 10 eV. *[2 marks]*

Markscheme

E_1 = –13.6 «eV» $E_2 = -\frac{13.6}{4}$ = –3.4 «eV»

energy of photon is difference $E_2 - E_1$ = 10.2 «≈ 10 eV»

Must see at least 10.2 eV.

[2 marks]

The photons cause the emission of electrons from the photoelectric surface. The work function of the photoelectric surface is 5.1 eV.

5b. Calculate, in J, the maximum kinetic energy of the emitted electrons. *[2 marks]*

Markscheme

10 – 5.1 = 4.9 «eV»

$4.9 \times 1.6 \times 10^{-19} = 7.8 \times 10^{-19}$ «J»

Allow 5.1 *if* 10.2 *is used to give* 8.2×10^{-19} «J».

5c. Suggest, with reference to conservation of energy, how the variable voltage source can be used to stop all emitted electrons from reaching the collecting plate. *[2 marks]*

Markscheme

EPE produced by battery

exceeds maximum KE of electrons / electrons don't have enough KE

For first mark, accept explanation in terms of electric potential energy difference of electrons between surface and plate.

[2 marks]

5d. The variable voltage can be adjusted so that no electrons reach the collecting plate. Write down the minimum value of the voltage for which no electrons reach the collecting plate. *[1 mark]*

Markscheme

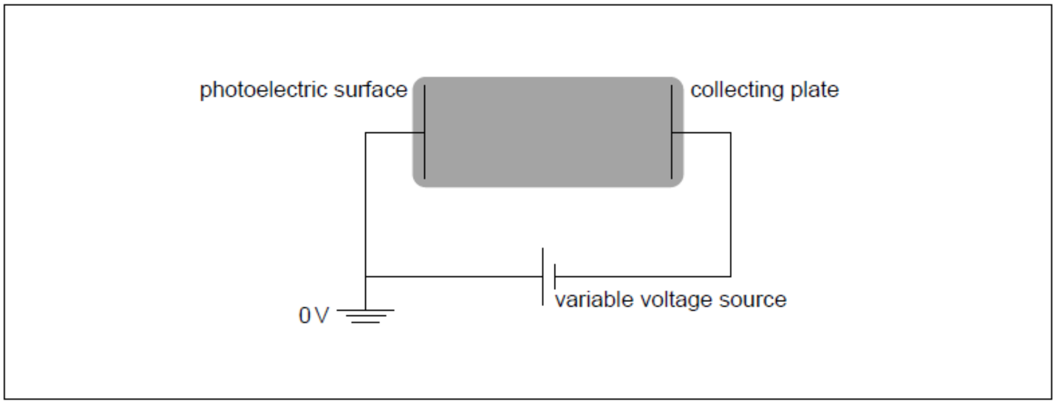
4.9 «V»

Allow 5.1 if 10.2 is used in (b)(i).

Ignore sign on answer.

[1 mark]

The electric potential of the photoelectric surface is 0 V. The variable voltage is adjusted so that the collecting plate is at –1.2 V.

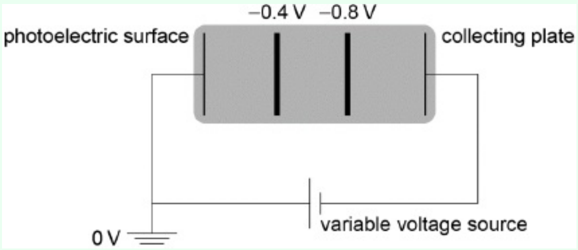


5e. On the diagram, draw and label the equipotential lines at –0.4 V and –0.8 V. *[2 marks]*

Markscheme

two equally spaced vertical lines (judge by eye) at approximately 1/3 and 2/3

labelled correctly



[2 marks]

5f. An electron is emitted from the photoelectric surface with kinetic energy 2.1 eV. Calculate the speed of the electron at the collecting plate. *[2 marks]*

Markscheme

kinetic energy at collecting plate = 0.9 «eV»

speed = «$\sqrt{\frac{2\times0.9\times1.6\times10^{-19}}{9.11\times10^{-31}}}$» = 5.6 × 10^5 «ms^{-1}»

Allow ECF from MP1

[2 marks]

A planet has radius *R*. At a distance *h* above the surface of the planet the gravitational field strength is *g* and the gravitational potential is *V*.

6a. State what is meant by gravitational field strength. *[1 mark]*

Markscheme

the «gravitational» force per unit mass exerted on a point/small/test mass

[1 mark]

6b. Show that $V = -g(R + h)$. *[2 marks]*

Markscheme

at height *h* potential is $V = -\frac{GM}{(R+h)}$

field is $g = \frac{GM}{(R+h)^2}$

«dividing gives answer»

Do not allow an answer that starts with $g = -\frac{\Delta V}{\Delta r}$ *and then cancels the deltas and substitutes R + h*

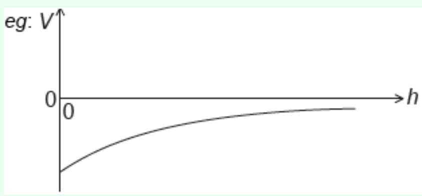
[2 marks]

6c. Draw a graph, on the axes, to show the variation of the gravitational potential *V* of the planet with height *h* above the surface of the planet. *[2 marks]*

Markscheme

correct shape and sign

non-zero negative vertical intercept



[2 marks]

6d. A planet has a radius of 3.1×10^6 m. At a point P a distance 2.4×10^7 m above the surface of the planet the gravitational field strength is 2.2 N kg^{-1}. Calculate the gravitational potential at point P, include an appropriate unit for your answer. *[1 mark]*

Markscheme

$V =$ «$-2.2 \times (3.1 \times 10^6 + 2.4 \times 10^7) =$» «$-$» 6.0×10^7 J kg^{-1}

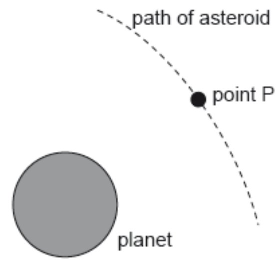
Unit is essential

Allow eg MJ kg^{-1} if power of 10 is correct

Allow other correct SI units eg m^{2}s^{-2}, N m kg^{-1}

[1 mark]

6e. The diagram shows the path of an asteroid as it moves past the planet. *[3 marks]*



When the asteroid was far away from the planet it had negligible speed. Estimate the speed of the asteroid at point P as defined in (b).

Markscheme

total energy at P = 0 / KE gained = GPE lost

« $\frac{1}{2}mv^2 + mV = 0 \Rightarrow$» $v = \sqrt{-2V}$

v = « $\sqrt{2 \times 6.0 \times 10^7}$ =» 1.1×10^4 «ms^{-1}»

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

Ignore negative sign errors in the workings

Allow ECF from 6(b)

[3 marks]

6f. The mass of the asteroid is 6.2×10^{12} kg. Calculate the gravitational force experienced by the **planet** when the asteroid is at point P. *[2 marks]*

Markscheme

ALTERNATIVE 1

force on asteroid is «$6.2 \times 10^{12} \times 2.2$ =» 1.4×10^{13} «N»

«by Newton's third law» this is also the force on the planet

ALTERNATIVE 2

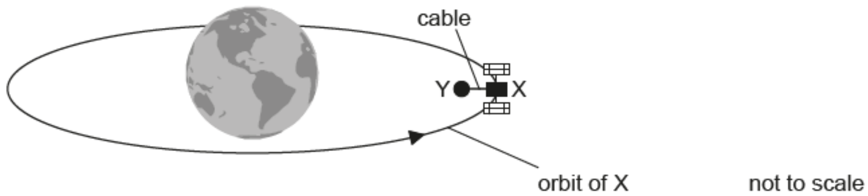
mass of planet = 2.4×10^{25} «kg» «from $V = -\frac{GM}{(R+h)}$»

force on planet «$\frac{GMm}{(R+h)^2}$» = 1.4×10^{13} «N»

MP2 must be explicit

[2 marks]

There is a proposal to power a space satellite X as it orbits the Earth. In this model, X is connected by an electronically-conducting cable to another smaller satellite Y.



7a. Satellite X orbits 6600 km from the centre of the Earth. *[2 marks]*

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

Show that the orbital speed of satellite X is about 8 km s^{-1}.

Markscheme

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

7800 «m s^{-1}»

Full substitution required

Must see 2+ significant figures.

Satellite Y orbits closer to the centre of Earth than satellite X. Outline why

7b. the orbital times for X and Y are different. *[1 mark]*

Markscheme

Y has smaller orbit/orbital speed is greater so time period is less

Allow answer from appropriate equation

Allow converse argument for X

7c. satellite Y requires a propulsion system. *[2 marks]*

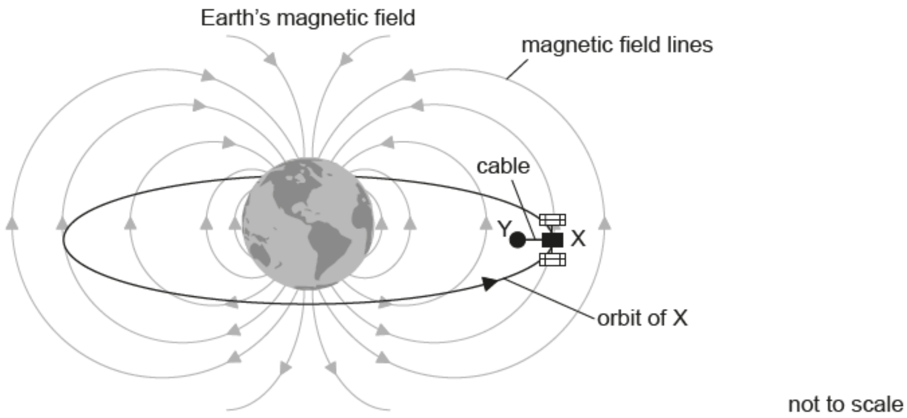
Markscheme

to stop Y from getting ahead

to remain stationary with respect to X

otherwise will add tension to cable/damage satellite/pull X out of its orbit

7d. The cable between the satellites cuts the magnetic field lines of the Earth at right angles. *[3 marks]*



Explain why satellite X becomes positively charged.

Markscheme

cable is a conductor and contains electrons

electrons/charges experience a force when moving in a magnetic field

use of a suitable hand rule to show that satellite Y becomes negative «so X becomes positive»

Alternative 2

cable is a conductor

so current will flow by induction flow when it moves through a B field

use of a suitable hand rule to show current to right so «X becomes positive»

Marks should be awarded from either one alternative or the other.

Do not allow discussion of positive charges moving towards X

7e. Satellite X must release ions into the space between the satellites. Explain why the current in the cable will become zero unless there is a method for transferring charge from X to Y. *[3 marks]*

Markscheme

electrons would build up at satellite Y/positive charge at X

preventing further charge flow

by electrostatic repulsion

unless a complete circuit exists

7f. The magnetic field strength of the Earth is 31 μT at the orbital radius of the satellites. The cable is 15 km in length. Calculate the emf induced in the cable. *[2 marks]*

Markscheme

«$\varepsilon = Blv$ =» 31 x 10^{-6} x 7990 x 15000

3600 «V»

Allow 3700 «V» from v = 8000 m s^{-1}.

The cable acts as a spring. Satellite Y has a mass *m* of 3.5 x 10^2 kg. Under certain circumstances, satellite Y will perform simple harmonic motion (SHM) with a period *T* of 5.2 s.

7g. Estimate the value of *k* in the following expression. *[3 marks]*

$T = 2\pi\sqrt{\frac{m}{k}}$

Give an appropriate unit for your answer. Ignore the mass of the cable and any oscillation of satellite X.

Markscheme

use of k = «$\frac{4\pi^2 m}{T^2}$ =» $\frac{4\times\pi^2\times350}{5.2^2}$

510

N m^{-1} ***or*** kg s^{-2}

Allow MP1 and MP2 for a bald correct answer

Allow 500

Allow N/m etc.

7h. Describe the energy changes in the satellite Y-cable system during one cycle of the oscillation. *[2 marks]*

Markscheme

E_p in the cable/system transfers to E_k of Y

and back again twice in each cycle

Exclusive use of gravitational potential energy negates MP1

Two renewable energy sources are solar and wind.

8a. Describe the difference between photovoltaic cells and solar heating panels. *[1 mark]*

Markscheme

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.

8b. A solar farm is made up of photovoltaic cells of area 25 000 m^2. The average solar intensity falling on the farm is 240 W m^{-2} and the average power output of the farm is 1.6 MW. Calculate the efficiency of the photovoltaic cells. *[2 marks]*

Markscheme

power received = 240 × 25000 = «6.0 MW»

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

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}

8c. Determine the minimum number of turbines needed to generate the same power as the solar farm. *[3 marks]*

Markscheme

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)*

8d. Explain **two** reasons why the number of turbines required is likely to be greater than your answer to (c)(i). *[2 marks]*

Markscheme

«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.

9a. Outline the conditions necessary for simple harmonic motion (SHM) to occur. *[2 marks]*

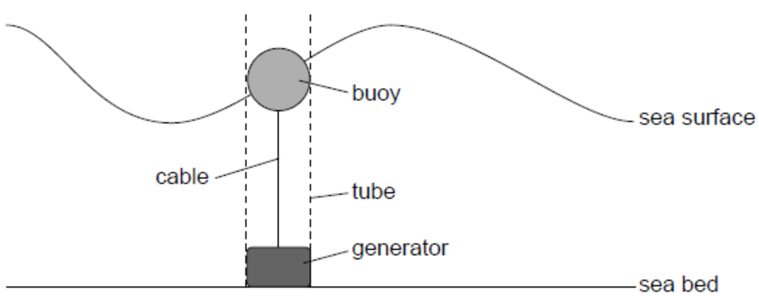
Markscheme

force/acceleration proportional to displacement «from equilibrium position»

and directed towards equilibrium position/point
OR
and directed in opposite direction to the displacement from equilibrium position/point

Do not award marks for stating the defining equation for SHM.
*Award **[1 max]** for a ω–=^{2}x with a and x defined.*

A buoy, floating in a vertical tube, generates energy from the movement of water waves on the surface of the sea. When the buoy moves up, a cable turns a generator on the sea bed producing power. When the buoy moves down, the cable is wound in by a mechanism in the generator and no power is produced.



The motion of the buoy can be assumed to be simple harmonic.

9b. A wave of amplitude 4.3 m and wavelength 35 m, moves with a speed of 3.4 m s $^{-1}$. *[3 marks]*
Calculate the maximum vertical speed of the buoy.

Markscheme

frequency of buoy movement $= \frac{3.4}{35}$ ***or*** 0.097 «Hz»

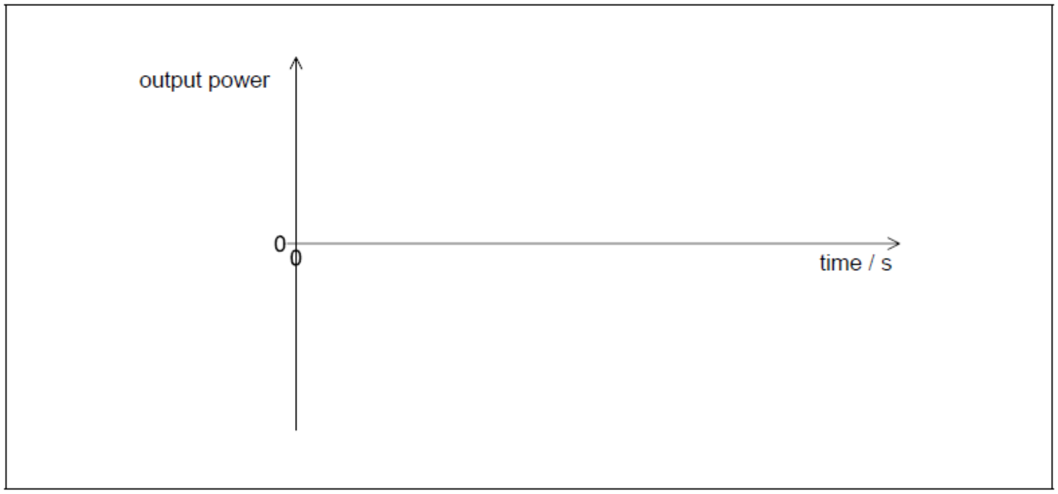
OR

time period of buoy $= \frac{35}{3.4}$ ***or*** 10.3 «s» ***or*** 10 «s»

v = «$\frac{2\pi x_0}{T}$ ***or*** $2\pi f x_0$» $= \frac{2\times\pi\times4.3}{10.3}$ ***or*** $2 \times \pi \times 0.097 \times 4.3$

2.6 «m s^{-1}»

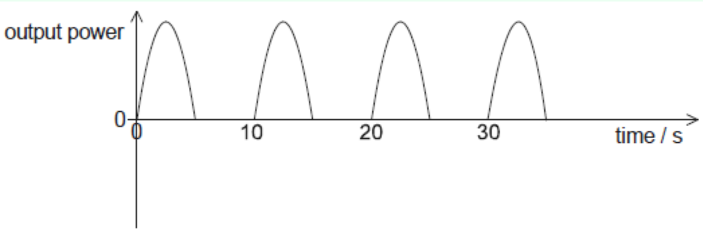
9c. Sketch a graph to show the variation with time of the generator output power. Label the time axis with a suitable scale. *[2 marks]*



Markscheme

peaks separated by gaps equal to width of each pulse «shape of peak roughly as shown»

one cycle taking 10 s shown on graph



Judge by eye.
Do not accept $\cos_2$ or $\sin_2$ graph
At least two peaks needed.
Do not allow square waves or asymmetrical shapes.
Allow ECF from (b)(i) value of period if calculated.

Water can be used in other ways to generate energy.

9d. Outline, with reference to energy changes, the operation of a pumped storage hydroelectric system. *[2 marks]*

Markscheme

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

---

9e. The water in a particular pumped storage hydroelectric system falls a vertical distance of 270 m to the turbines. Calculate the speed at which water arrives at the turbines. Assume that there is no energy loss in the system. *[2 marks]*

Markscheme

specific energy available = «*gh* =» 9.81 x 270 «= 2650J kg^{-1}»

OR

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

OR

v^2 = 2gh

v = 73 «ms^{-1}»

Do not allow 72 as round from 72.8

9f. The hydroelectric system has four 250 MW generators. 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 marks]*

Markscheme

total energy = «*mgh* = 1.5 x 10^{10} x 9.81 x 270=» 4.0 x 10^{13} «J»

OR

total energy = «$\frac{1}{2}mv^2 = \frac{1}{2} \times 1.5 \times 10^{10} \times$ (answer (c)(ii))^2 =» 4.0 x 10^{13} «J»

time = «$\frac{4.0 \times 10^{13}}{4 \times 2.5 \times 10^{8}}$» 11.1h ***or*** 4.0 x 10^4 s

Use of 3.97 x 10^{13} «J» gives 11 h.

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

9g. Not all the stored energy can be retrieved because of energy losses in the system. Explain **two** such losses. *[2 marks]*

1. ....

....

....

2. ....

....

....

Markscheme

friction/resistive losses in pipe/fluid resistance/turbulence/turbine or generator «bearings»
OR
sound energy losses from turbine/water in pipe

thermal energy/heat losses in wires/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.

The gravitational potential due to the Sun at its surface is -1.9×10^{11} J kg^{-1}. The following data are available.

Mass of Earth	$= 6.0 \times 10^{24}$ kg
Distance from Earth to Sun	$= 1.5 \times 10^{11}$ m
Radius of Sun	$= 7.0 \times 10^{8}$ m

10a. Outline why the gravitational potential is negative. *[2 marks]*

Markscheme

potential is defined to be zero at infinity

so a positive amount of work needs to be supplied for a mass to reach infinity

---

10b. The gravitational potential due to the Sun at a distance r from its centre is V_S. Show that *[1 mark]*

rV_S = constant.

Markscheme

$V_S = -\frac{GM}{r}$ so r x V_S «= $-GM$» = constant because G and M are constants

10c. Calculate the gravitational potential energy of the Earth in its orbit around the Sun. Give your answer to an appropriate number of significant figures. *[2 marks]*

Markscheme

GM = 1.33 x 10^{20} «J m kg^{-1}»

GPE at Earth orbit «= $-\frac{1.33\times10^{20}\times6.0\times10^{24}}{1.5\times10^{11}}$» = «–» 5.3 x 10^{33} «J»

*Award **[1 max]** unless answer is to 2 sf.*

Ignore addition of Sun radius to radius of Earth orbit.

10d. Calculate the total energy of the Earth in its orbit. *[2 marks]*

Markscheme

ALTERNATIVE 1

work leading to statement that kinetic energy $\frac{GMm}{2r}$, ***AND*** kinetic energy evaluated to be «+» 2.7 x 10^{33} «J»

energy «= PE + KE = answer to (b)(ii) + 2.7 x 10^{33}» = «–» 2.7 x 10^{33} «J»

ALTERNATIVE 2

statement that kinetic energy is $= -\frac{1}{2}$ gravitational potential energy in orbit

so energy «$= \frac{\text{answer to (b)(ii)}}{2}$» = «–» 2.7 x 10^{33} «J»

Various approaches possible.

10e. An asteroid strikes the Earth and causes the orbital speed of the Earth to suddenly decrease. Suggest the ways in which the orbit of the Earth will change. *[2 marks]*

Markscheme

«KE will initially decrease so» total energy decreases
OR
«KE will initially decrease so» total energy becomes more negative

Earth moves closer to Sun

new orbit with greater speed «but lower total energy»

changes ellipticity of orbit

10f. Outline, in terms of the force acting on it, why the Earth remains in a circular orbit around the Sun. *[2 marks]*

Markscheme

centripetal force is required

and is provided by gravitational force between Earth and Sun

*Award **[1 max]** for statement that there is a "centripetal force of gravity" without further qualification.*

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

11a. Calculate, with a suitable unit, the electrical power output of the power station. *[1 mark]*

Markscheme

«55.5 × 14.6 × 0.59» = 4.78 × 108 W

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

No sf penalty.

11b. Calculate the mass of CO_2 generated in a year assuming the power station operates continuously. *[1 mark]*

Markscheme

«14.6 × 2.75 × 3.16 × 10^7 =» 1.27 × 10^9 «kg»

If no unit assume kg

11c. Explain, using your answer to (b), why countries are being asked to decrease their dependence on fossil fuels. *[2 marks]*

Markscheme

CO_2 linked to greenhouse gas OR greenhouse effect

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

11d. Describe, in terms of energy transfers, how thermal energy of the burning gas becomes electrical energy. *[2 marks]*

Markscheme

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

12a. Explain what is meant by the gravitational potential at the surface of a planet. *[2 marks]*

Markscheme

the «gravitational» work done «by an external agent» per/on unit mass/kg

Allow definition in terms of reverse process of moving mass to infinity eg "work done on external agent by…".
Allow "energy" as equivalent to "work done"

in moving a «small» mass from infinity to the «surface of» planet / to a point

***N.B.**: on SL paper Q5(a)(i) and (ii) is about "gravitational field".*

12b. An unpowered projectile is fired vertically upwards into deep space from the surface of planet Venus. Assume that the gravitational effects of the Sun and the other planets are negligible. *[5 marks]*

The following data are available.

Mass of Venus = 4.87×10^{24} kg Radius of Venus = 6.05×10^{6} m Mass of projectile = 3.50×10^{3} kg Initial speed of projectile = 1.10×escape speed

(i) Determine the initial kinetic energy of the projectile.

(ii) Describe the subsequent motion of the projectile until it is effectively beyond the gravitational field of Venus.

Markscheme

i
escape speed
Care with ECF from MP1.

v = « $\sqrt{\left(\frac{2\,\mathrm{GM}}{R}\right)}$ =»

$\sqrt{\left(\frac{2\times6.67\times10^{-11}\times4.87\times10^{24}}{6.05\times10^{6}}\right)}$ ***or*** 1.04×10^{4} «$m\ s^{-1}$»

or «$1.1\times1.04\times10^{4}$ m s^{-1}»= 1.14×10^{4} «m s^{-1}»

KE = «$0.5\times3500\times(1.1\times1.04\times10^{4}\ \mathrm{m\ s^{-1}})^2$ =» 2.27×10^{11} «J»

*Award **[1 max]** for omission of 1.1 – leads to 1.88×10^{11} m s^{-1}.*
*Award **[2]** for a bald correct answer.*

ii
Velocity/speed decreases / projectile slows down «at decreasing rate»

«magnitude of» deceleration decreases «at decreasing rate»
Mention of deceleration scores MP1 automatically.

velocity becomes constant/non-zero
OR
deceleration tends to zero

Accept "negative acceleration" for "deceleration".

Must see "velocity" not "speed" for MP3.

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.

13a. Show that the intensity of the solar radiation incident on the upper atmosphere of the Earth is approximately 1400Wm^{-2}. *[2 marks]*

Markscheme

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

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

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 $^{-2.}$

13b. The albedo of the atmosphere is 0.30. Deduce that the average intensity over the entire surface of the Earth is 245Wm^{-2}. *[2 marks]*

Markscheme

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

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

245Wm^{-2}

13c. Estimate the average surface temperature of the Earth. *[2 marks]*

Markscheme

5.67 × 10^{-8} × T^4 = 245

T = 256K

14. The average surface temperature of the Earth is actually 288 K. *[2 marks]*

Suggest how the greenhouse effect helps explain the difference between the temperature estimated in (c) and the actual temperature of the Earth.

Markscheme

the emitted radiation is in the infrared/IR/long wavelength/low frequency region

«greenhouse» gases in the atmosphere absorb «infrared» radiation

radiated in all directions «including back down to Earth» warming the Earth

Do not allow "traps the heat".

Must see clear implication somewhere in response that gases are in the atmosphere for MP2.

Must see sense that Earth temperature is raised for MP3.

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.

15a. Outline which of the three generation methods above is renewable. *[2 marks]*

Markscheme

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")*

In a nuclear reactor, outline the purpose of the

15b. heat exchanger. *[1 mark]*

Markscheme

(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.

15c. moderator. *[2 marks]*

Markscheme

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

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

Fission of one uranium-235 nucleus releases 203 MeV.

15d. Determine the maximum amount of energy, in joule, released by 1.0 g of uranium-235 as a result of fission. *[3 marks]*

Markscheme

(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;

$(2.56 \times 10^{21}$ 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.*

15e. Describe the main principles of the operation of a pump storage hydroelectric scheme. *[3 marks]*

Markscheme

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;

15f. 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 marks]*

Markscheme

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.*

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

Part 2 Thermal physics

15g. Distinguish between specific heat capacity and specific latent heat. *[2 marks]*

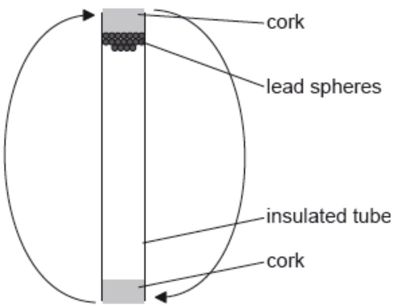
Markscheme

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.

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.



15h. Discuss the changes to the energy of the lead spheres. *[2 marks]*

Markscheme

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.

15i. 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 marks]*

Markscheme

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.*

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.

16a. Suggest the conditions that would make use of wind generators in combination with either oil or nuclear fuel suitable for the islanders. *[3 marks]*

Markscheme

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;

16b. Conventional horizontal-axis wind generators have blades of length 4.7m. The average wind speed on the island is 7.0ms^{-1} and the average air density is 1.29kgm^{-3}. *[5 marks]*

(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).

Markscheme

(i) π4.72 or 69.4 m2;

power = 15300 to 15400 W;

470 to 490 GJ;

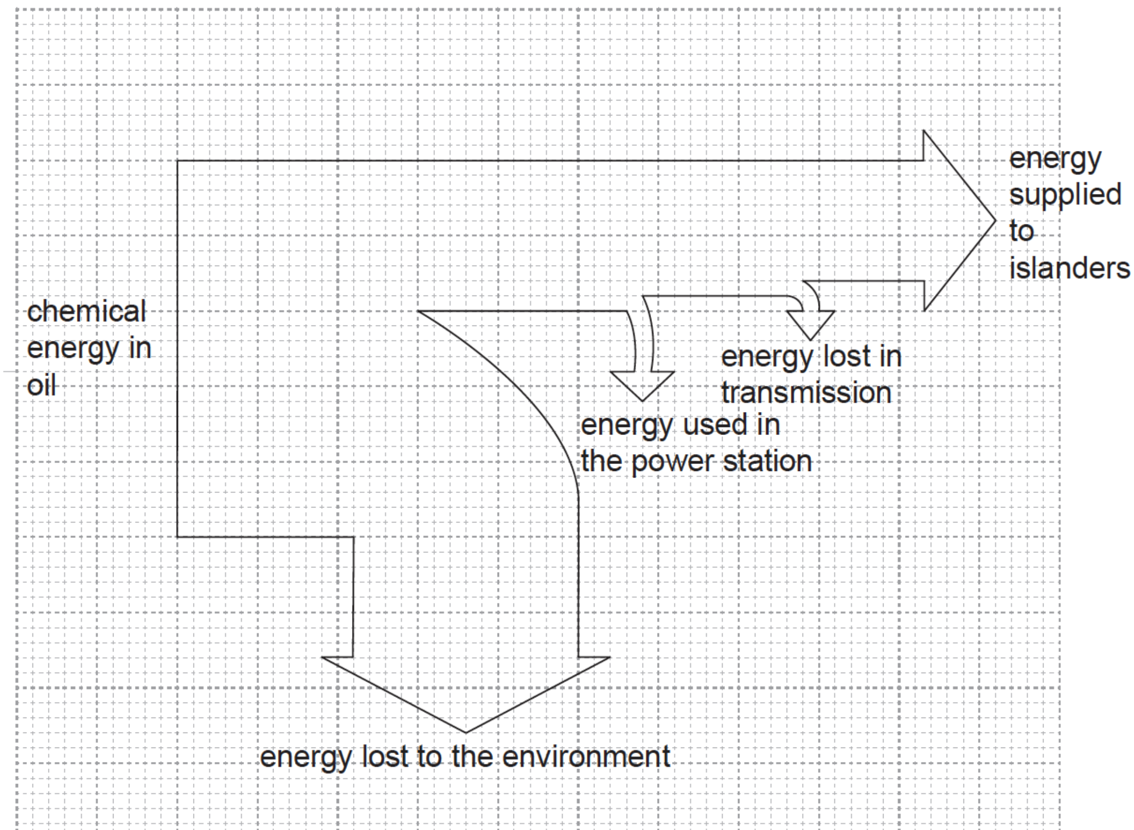
(ii) wind must retain kinetic energy to escape or not all KE of wind can be converted to KE of blades;

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.

16c. The energy flow diagram (Sankey diagram) below is for an oil-fired power station that the islanders might use. *[4 marks]*



(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.

Markscheme

(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;

16d. The emissions from the oil-fired power station in (c) are likely to increase global warming by the enhanced greenhouse effect. *[3 marks]*

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

Markscheme

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;

16e. Nuclear fuel must be enriched before it can be used. Outline why fuel enrichment is needed. *[2 marks]*

Markscheme

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;

16f. The nuclear equation below shows one of the possible fission reactions in a nuclear reactor. *[3 marks]*

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

Identify the missing numbers in the equation.

Markscheme

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

235;
36;
3;
The number of neutrons must be consistent with chosen isotope of uranium.

16g. 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 marks]*

Markscheme

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.

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%.

17a. (i) Determine the diameter that will be required for the turbine blades to achieve the maximum power of 0.75 MW. *[8 marks]*

(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.

Markscheme

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

maximum wind power required per turbine, $P = \frac{750000}{5 \times 0.3} (= 500\mathrm{kW})$;

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

*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]**.*

17b. 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 marks]*

(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.

Markscheme

(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 $= \left(\frac{2700}{35} =\right) 77.1(\text{kg});$

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

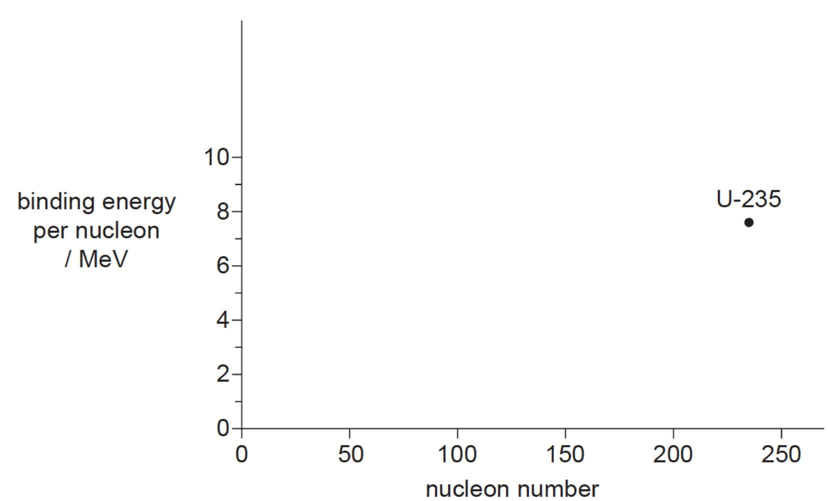
(ii) *advantage:*
energy is free (apart from maintenance and start-up costs) / energy is renewable / sufficient for small community with predominance of wind / supplies energy to remote community / independent of national grid / any other reasonable advantage;
Answer must focus on wind farm not coal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

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.



17c. State what is meant by the binding energy of a nucleus. *[1 mark]*

Markscheme

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.

17d. (i) On the axes, sketch a graph showing the variation of nucleon number with the binding energy per nucleon. *[5 marks]*

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

Markscheme

(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.*

17e. U-235 $\left({}^{235}_{92}\mathrm{U}\right)$ can undergo alpha decay to form an isotope of thorium (Th). *[4 marks]*

(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 7.0×10^{8} years. Calculate the initial mass of the U-235 if the rock sample was formed 2.1×10^{9} years ago.

Markscheme

(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.*

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.

18a. Suggest the conditions that would make use of wind generators in combination with either oil or nuclear fuel suitable for the islanders. *[3 marks]*

Markscheme

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;

18b. Conventional horizontal-axis wind generators have blades of length 4.7 m. The average wind speed on the island is 7.0 ms^{-1} and the average air density is 1.29 kg m^{-3}. *[5 marks]*

(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).

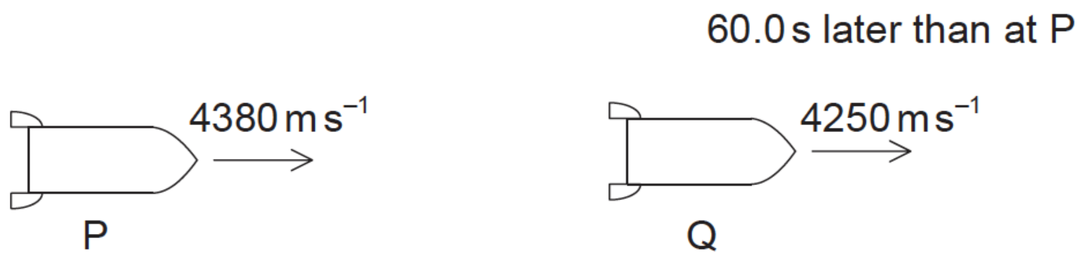
Markscheme

(i) π4.72 or 69.4 m2;
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.

Part 2 Motion of a rocket

A rocket is moving away from a planet within the gravitational field of the planet. When the rocket is at position P a distance of 1.30×10^7m from the centre of the planet, the engine is switched off. At P, the speed of the rocket is $4.38 \times 10^3 ms^{-1}$.



At a time of 60.0 s later, the rocket has reached position Q. The speed of the rocket at Q is $4.25 \times 10^3 ms^{-1}$. Air resistance is negligible.

19a. Outline, with reference to the energy of the rocket, why the speed of the rocket is changing between P and Q. *[2 marks]*

Markscheme

gravitational potential energy is being gained;
this is at the expense of kinetic energy (and speed falls);

19b. Estimate the average gravitational field strength of the planet between P and Q. *[2 marks]*

Markscheme

$\left(\text{acceleration} = \frac{(v-u)}{t} = \frac{4.25 \times 10^3 - 4.38 \times 10^3}{60} = \right) (-)\, 2.17 \left(\text{ms}^{-2}\right);$

gravitational field strength = acceleration of rocket (=2.17 N kg–1); } *(allow g = a in symbols)*

or

computes potential difference from KE per unit mass change (5.61 $\times$105),
computes distance travelled (0.259 Mm), uses $g = \frac{(-)\Delta V}{\Delta r}$;
g=(−)2.17(ms^{-2});

19c. A space station is in orbit at a distance *r* from the centre of the planet in (e)(i). A satellite is launched from the space station so as just to escape from the gravitational field of the planet. The launch takes place in the same direction as the velocity of the space station. Outline why the launch velocity relative to the space station can be less than your answer to (e)(i). *[1 mark]*

Markscheme

the satellite has velocity/kinetic energy as it is orbiting with the space station;