HL Paper 2

This question is about nuclear reactions.

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

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

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%.

a.i. State the nature of X. [1]

a.ii. State **one** form of energy that is instantaneously released in the reaction. [1]

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

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

c. In addition to the U-235, the nuclear reactor contains graphite that acts as a moderator. Explain the function of the moderator. [3]

d. Outline how energy released in the nuclear reactor is transformed to electrical energy. [3]

Markscheme

a.i. neutron / $^{1}_{0}\mathrm{n}$;

a.ii. kinetic energy / gamma radiation / binding energy;

b.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 $(= 8.2 \times 10^{24} \times 3.9 \times 10^{-25}) = 3.2\ \mathrm{kg}$;

b.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* $6.1 \times 10^{27}\ \mathrm{eVs}^{-1}$*.*

c. 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);

d. kinetic energy of neutrons/thermal energy of core is transferred into thermal energy of the coolant (and elsewhere);

(thermal energy) is converted into kinetic energy in moving steam;

(kinetic energy of steam) is transferred into (rotational) kinetic energy of turbine;

(kinetic energy of turbine) is transferred into electrical energy by dynamo/generator;

Examiners report

a.i. X is a neutron and almost all answers were correct. G2 comments suggested that the term “State the nature of X” was rather vague. This is a helpful comment, but on this occasion candidates did not seem to be affected by it.

a.ii. Instantaneous energy release: Binding energy, (particle) kinetic energy, gamma radiation were all accepted. Heat energy was not accepted.

b.i. Quite a few candidates found the mass defect rather than the mass of U-235 fissioned. The mass of a Uranium atom was often incorrect – candidates were expected to determine it from the mass number. A few stated the mass as 235g. Another common error was to find mass per second, rather than per day. However many correct answers were seen.

b.ii. Working was often unclear. The power station efficiency of 0.32 was often overlooked. Whilst many candidates were eventually able to determine the power output of the power station in W, there were also answers giving the energy output per day. Quite a few candidates used eV/s and this was accepted for 1 mark.

c. There was some confusion between a moderator and control rods. However, most candidates knew that the graphite moderator slowed neutrons (due to inelastic collisions) to thermal energies to maximise the probability of further fission.

d. Outlining the energy transfers occurring in a nuclear power plant is a frequent question, but answers were often poorly organised. A simple flow diagram would suffice. Thermal energy of core > thermal energy of coolant > KE of steam > KE of turbine > Electrical energy from generator, or similar. Far too many candidates barely mentioned energy; “…heat up water to make steam which turns a turbine…” gained no marks.

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 4.7 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]

(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

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.

Examiners report

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

This question is about 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	$= 0.13\ \text{g s}^{-1}$
Temperature at which air enters heater	$= 12\ ^\circ\text{C}$
Temperature at which air leaves heater	$= 32\ ^\circ\text{C}$
Specific heat capacity of air	$= 990\ \text{J kg}^{-1}\text{K}^{-1}$

All the energy output of the room heater raises the temperature of the air moving through it. Use the data to calculate the mass of air that moves through the room heater in **one** second.

Markscheme

$\text{temperature change} = 20\ (\text{K})$;

$\text{mass of air} = \frac{4400}{20 \times 990}$;

$= 0.22$ kg;

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

Examiners report

Almost all could recognize that the temperature change was 20 K and could use their earlier value of power output. However the numerical manipulations were sometimes weak (often leading to ludicrously large air masses moving through the heater in 1 second.

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.

The average surface temperature of the Earth is actually 288 K.

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.

Examiners report

[N/A]

This question is about electrical generation using nuclear power.

Exposure to radiation is a safety risk both to miners of uranium ore and to workers in nuclear power plants.

b. Outline why uranium ore needs to be enriched before it can be used successfully in a nuclear reactor. [3]

c. (i) One possible waste product of a nuclear reactor is the nuclide caesium-137 $\left({}^{137}_{55}\mathrm{Cs}\right)$ which decays by the emission of a beta-minus (β–) particle to form a nuclide of barium (Ba). [6]

State the nuclear reaction for this decay.

$$^{137}_{55}\mathrm{Cs} \rightarrow \,^{\cdots\cdots}_{\cdots\cdots}\mathrm{Ba} + \,^{\cdots\cdots}_{\cdots\cdots}\beta^{-} + \cdots\cdots$$

(ii) The half-life of caesium-137 is 30 years. Determine the fraction of caesium-137 remaining in the waste after 100 years.

d. Some waste products in nuclear reactors are good absorbers of neutrons. Suggest why the formation of such waste products requires the removal of the uranium fuel rods well before the uranium is completely used up. [2]

Markscheme

b. U-238 is much more common than U-235 in ore;

U-235 is more likely to undergo fission / critical amount of U-235 required to ensure fission / *OWTTE*;

U-238 absorbs neutrons;

U-238 reduces reaction rate in reactor;

c. (i) ${}^{137}_{56}\mathrm{Ba}$;

${}^{0}_{-1}\beta^{-}$;

anti-neutrino / $\bar{v}$;

(ii) $\lambda = \left(\frac{\ln 2}{30} =\right) 0.0231\mathrm{year}^{-1}$;
$(N = N_0)\,\mathrm{e}^{-0.0231\times 100}$;
0.099 ***or*** 9.9%;

d. proportion of waste builds up in fuel rod as uranium is consumed;

increasing numbers of neutrons will be absorbed;

this reduces the number available to sustain the chain reaction;

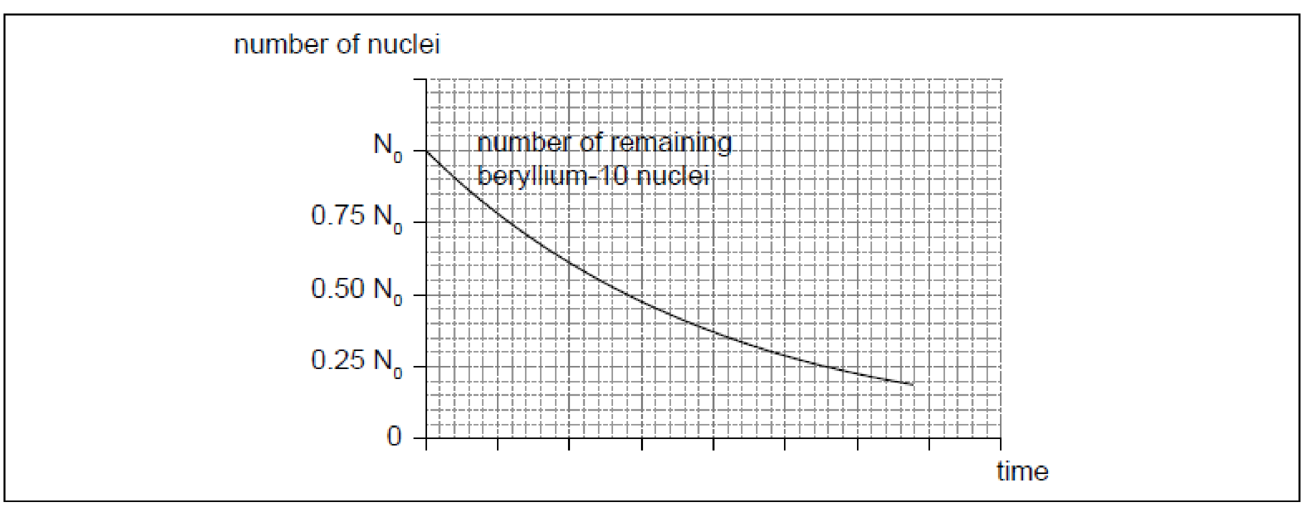
build up of waste deforms fuel rod (which can then be difficult to remove);

Examiners report

b. [N/A]
c. [N/A]
d. [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. [2]

$$^{10}_{\square}\text{Be} \rightarrow ^{\square}_{5}\text{B} + ^{\square}_{\square}\text{e} + ^{0}_{0}\square$$

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. The present activity of the sample is 8.0×10^{-3} Bq. [3]

Determine, in years, the age of the sample.

c.iv. The temperature in the laboratory is higher than the temperature of the ice sample. Describe **one** other energy transfer that occurs between the ice sample and the laboratory. [2]

Markscheme

a. $^{10}_{4}\text{Be} \rightarrow ^{10}_{5}\text{B} + ^{0}_{-1}\text{e} + \overline{\text{V}}_{\text{e}}$

antineutrino ***AND*** charge ***AND*** mass number of electron $^{0}_{-1}\text{e}, \overline{\text{V}}$

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

Do not accept V.

Accept $\bar{V}$ without subscript e.

[2 marks]

b.iii. λ «$= \frac{\ln 2}{1.4 \times 10^{6}}$» $= 4.95 \times 10^{-7}$ «y^{-1}»

rearranging of $A = \lambda N_0 e^{-\lambda t}$ to give $-\lambda t = \ln \frac{8.0 \times 10^{-3} \times 365 \times 24 \times 60 \times 60}{4.95 \times 10^{-7} \times 7.6 \times 10^{11}}$ «= –0.400»

$t = \frac{-0.400}{-4.95 \times 10^{-7}} = 8.1 \times 10^{5}$ «y»

Allow ECF from MP1

[3 marks]

c.iv. from the laboratory to the sample

conduction – contact between ice and lab surface.

OR

convection – movement of air currents

Must clearly see direction of energy transfer for MP1.

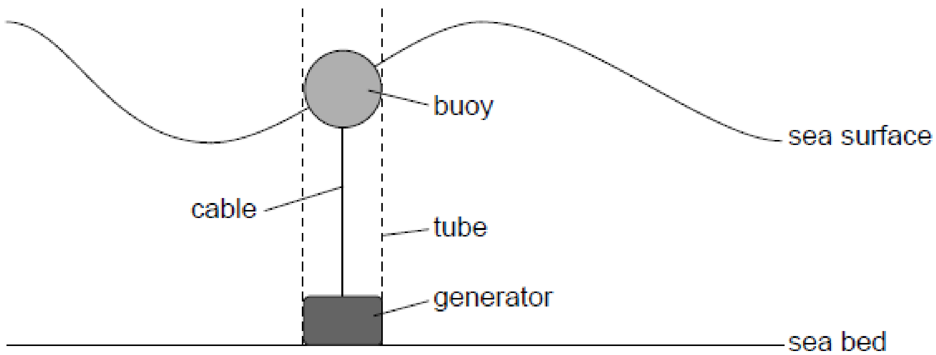
Must see more than just words "conduction" or "convection" for MP2.

[2 marks]

Examiners report

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

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.



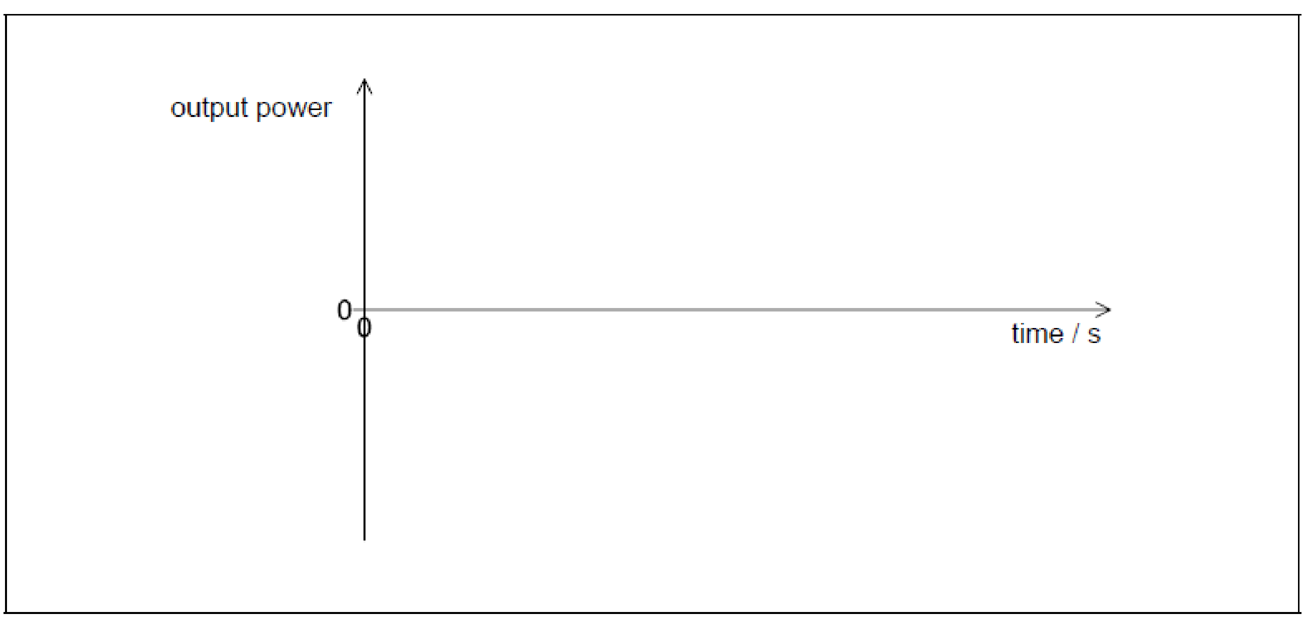
The motion of the buoy can be assumed to be simple harmonic.

Water can be used in other ways to generate energy.

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

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

b.ii. Sketch a graph to show the variation with time of the generator output power. Label the time axis with a suitable scale. [2]



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

c.ii. 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]

c.iii. 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 1.5×10^{10} kg of water passes through the turbines. [2]

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

1. ....

....

....

2. ....

....

....

Markscheme

a. 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.*

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

OR

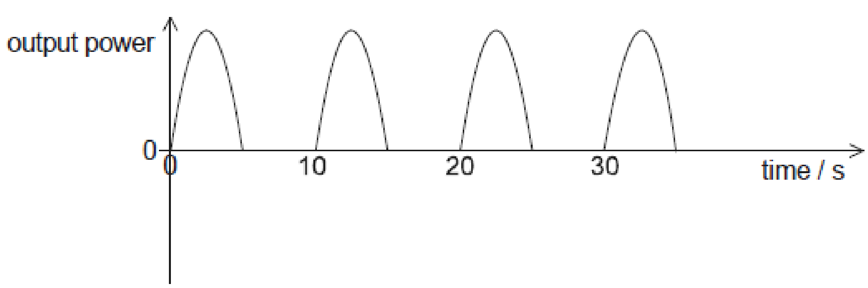
time period of buoy $= \frac{35}{3.4}$ ***or*** 10.3 «s» ***or*** 10 «s»

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}»

b.ii. 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.

c.i. 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

c.ii. 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

c.iii 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 = «$\frac{4.0\times10^{13}}{4\times2.5\times10^{8}}$» 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.*

c.iv 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.

Examiners report

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

This question is in **two** parts. **Part 1** is about solar radiation and the greenhouse effect. **Part 2** is about orbital motion.

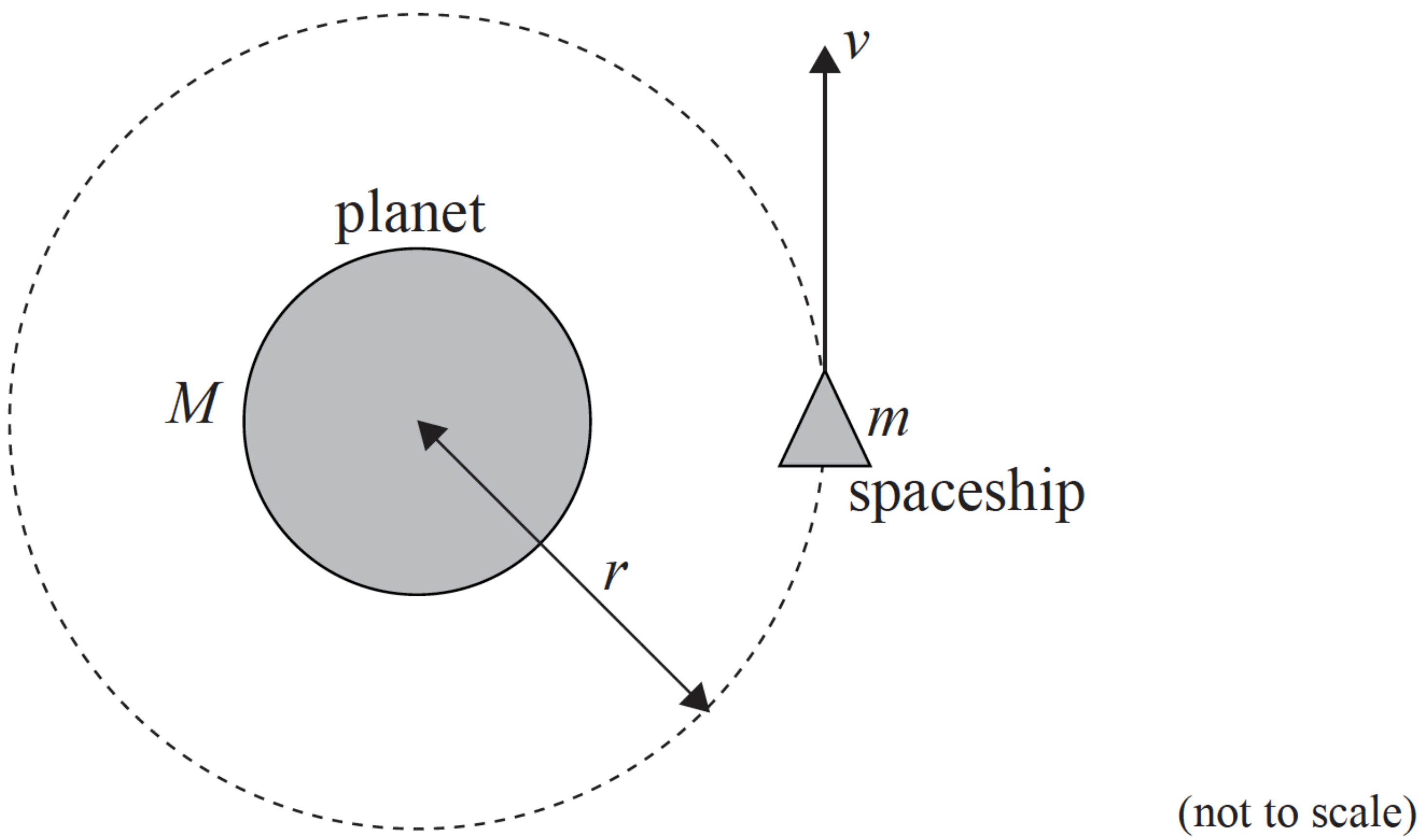
Part 1 Solar radiation and the greenhouse effect

The following data are available.

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

Part 2 Orbital motion

A spaceship of mass *m* is moving at speed *v* in a circular orbit of radius *r* around a planet of mass *M*.



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. (i) Identify the force that causes the centripetal acceleration of the spaceship. [4]

(ii) Explain why astronauts inside the spaceship would feel "weightless", even though there is a force acting on them.

i. Deduce that the speed of the spaceship is $v = \sqrt{\frac{GM}{r}}$. [2]

j. The table gives equations for the forms of energy of the orbiting spaceship. [4]

Form of Energy	Equation
Kinetic	$E_K = \frac{GMm}{2r}$
Gravitational potential	$E_P = -\frac{GMm}{r}$
Total (kinetic + potential)	$E = -\frac{GMm}{2r}$

The spaceship passes through a cloud of gas, so that a small frictional force acts on the spaceship.

(i) State and explain the effect that this force has on the total energy of the spaceship.

(ii) Outline the effect that this force has on the speed of the spaceship.

Markscheme

a. power/energy per second emitted is 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. $\left(\frac{\sigma R^2T^4}{d^2}=\right)\frac{5.7\times10^{-8}\times[7.0\times10^8]^2\times[5.8\times10^3]^4}{[1.5\times10^{11}]^2}$;

$=1.4\times10^3(\mathrm{Wm^{-2}})$;

*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. (i) gravitational force / gravitational attraction / weight; *(do not accept gravity)*

(ii) astronauts and spaceship have the same acceleration;
acceleration is towards (centre of) planet;
so no reaction force between astronauts and spaceship;

or

astronauts and spaceships are both falling towards the (centre of the) planet;
at the same rate;
so no reaction force between astronauts and spaceship;

i. gravitational force equated with centripetal force / $\frac{GmM}{r^2}=\frac{mv^2}{r}$;

$\Rightarrow v^2=\frac{GM}{r}\Rightarrow\left(v=\sqrt{\frac{GM}{r}}\right)$;

j. (i) thermal energy is lost;

total energy decreases;

(ii) since E decreases, r also decreases;
as r decreases v increases / E_k increases so v increases;

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. (i) Most were able to state gravitational force, however a significant number stated gravity and consequently did not get the mark.

(ii) Many answers only discussed the astronauts and not the spaceship, missing points such as 'falling at the same rate' or 'with the same acceleration'.

i. This was well answered with candidates able to adequately show in their explanation where the expression comes from.

j. ji) Most appreciated that the effect of the force would be to decrease the total energy.

jii) Very few appreciated that they should use the equations above to answer this part of the question. As a consequence, the most common answer discussed a decrease in kinetic energy and a decrease in speed.