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]

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).

This question is about fuel for heating.

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

Density of liquid fuel	$= 8.0 \times 10^2\ \mathrm{kg\,m^{-3}}$
Energy produced by 1 $\mathrm{m^3}$ of liquid fuel	$= 2.7 \times 10^{10}\ \mathrm{J}$
Rate at which fuel is consumed	$= 0.13\ \mathrm{g\,s^{-1}}$
Temperature at which air enters heater	$= 12\ ^\circ\mathrm{C}$
Temperature at which air leaves heater	$= 32\ ^\circ\mathrm{C}$
Specific heat capacity of air	$= 990\ \mathrm{J\,kg^{-1}K^{-1}}$

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.

The Sun has a radius of 7.0×10^8m 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.

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.

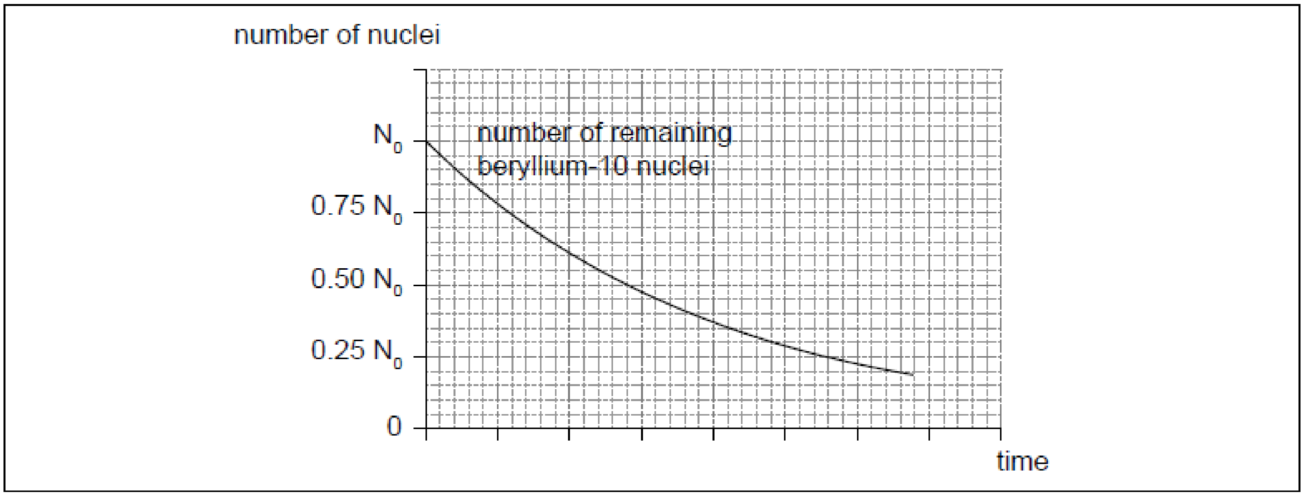
$$^{137}_{55}\mathrm{Cs} \rightarrow {}^{\cdots\cdots}_{\cdots\cdots}\mathrm{Ba} + {}^{\cdots\cdots}_{\cdots\cdots}\beta^{-} + \cdots\cdots$$

(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]

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]

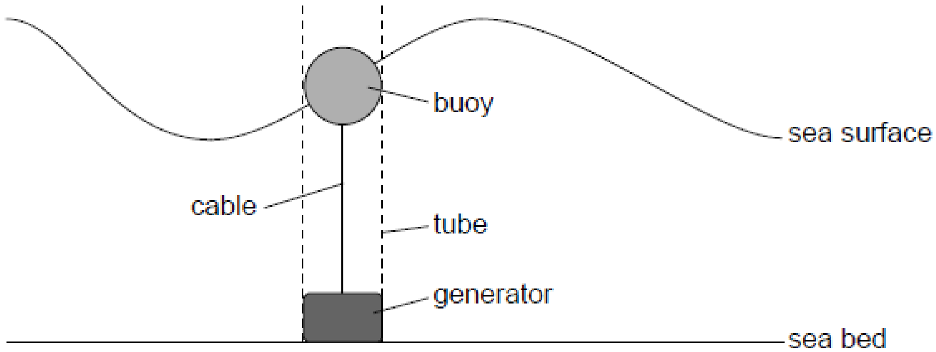
$$^{10}_{\square}Be \rightarrow {}^{\square}_{5}B + {}^{\square}_{\square}e + {}^{0}_{0}\square$$

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]

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.



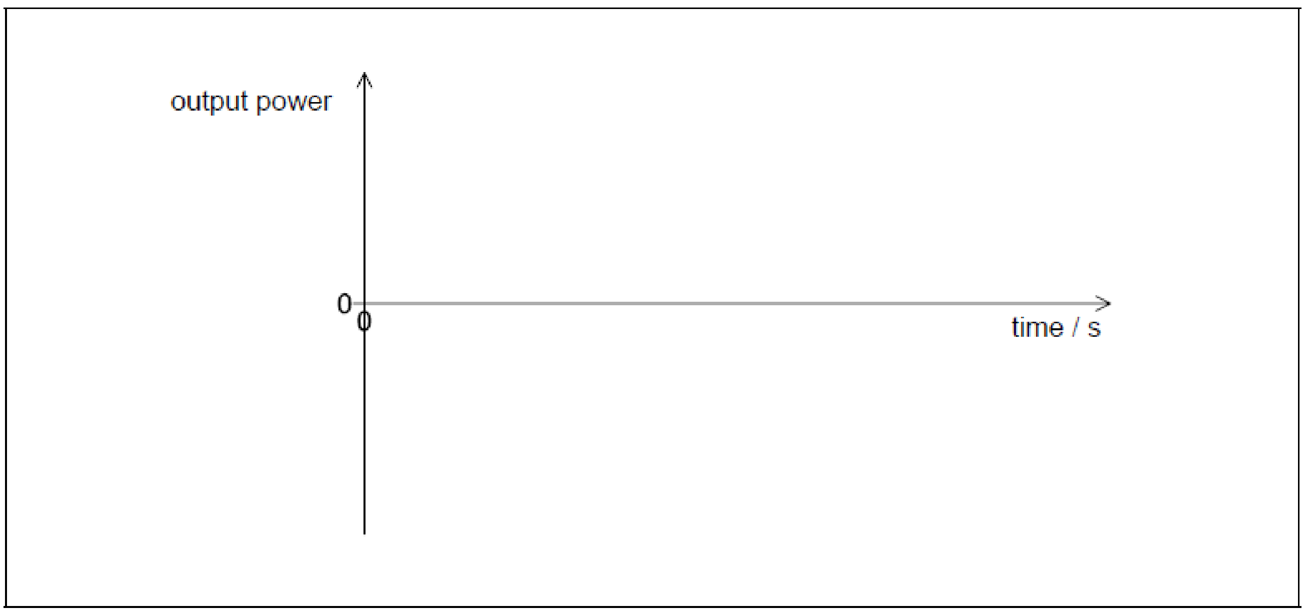
The motion of the buoy can be assumed to be simple harmonic.

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 x 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. ....

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2. ....

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

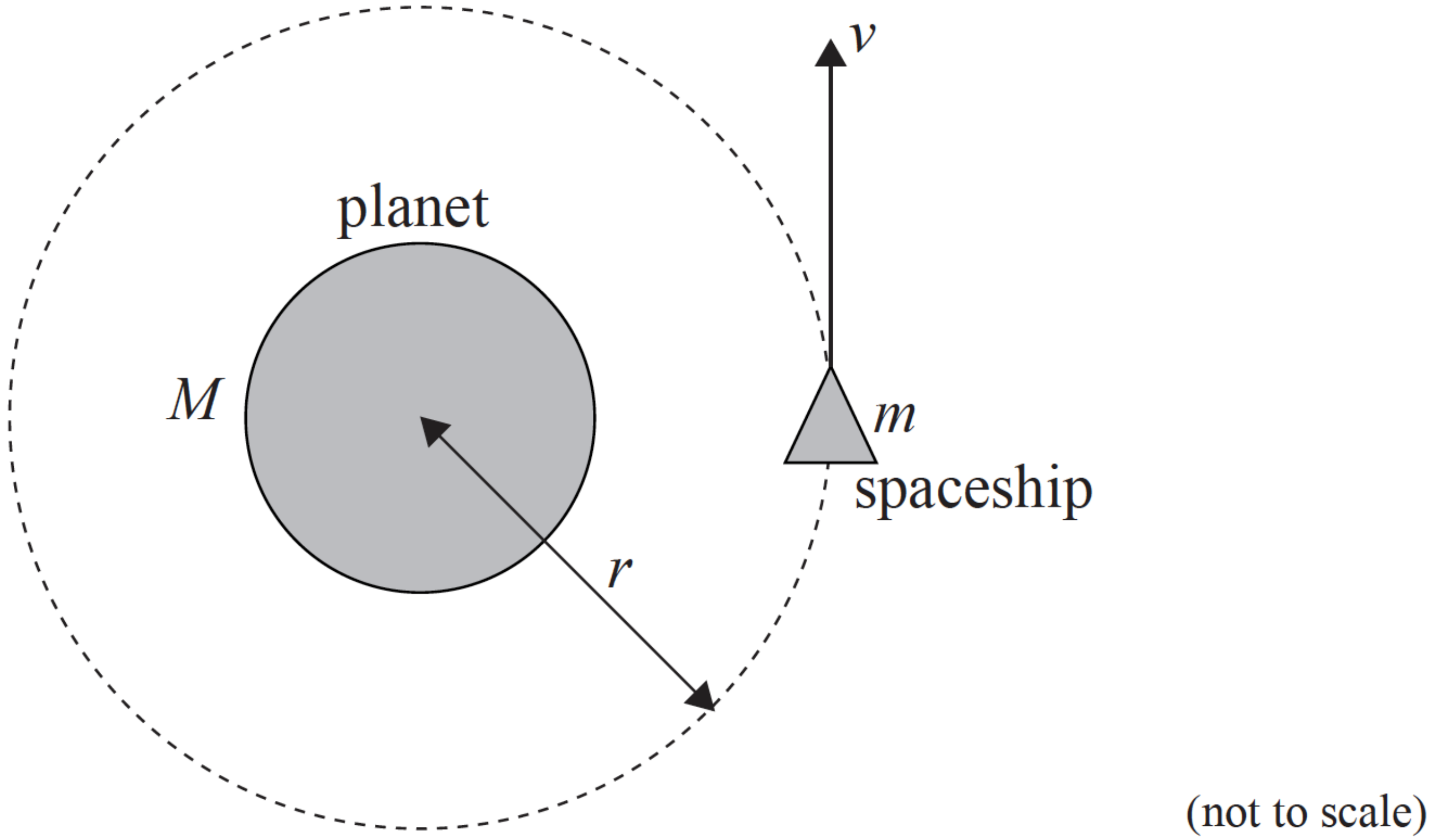
Part 1 Solar radiation and the greenhouse effect

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.