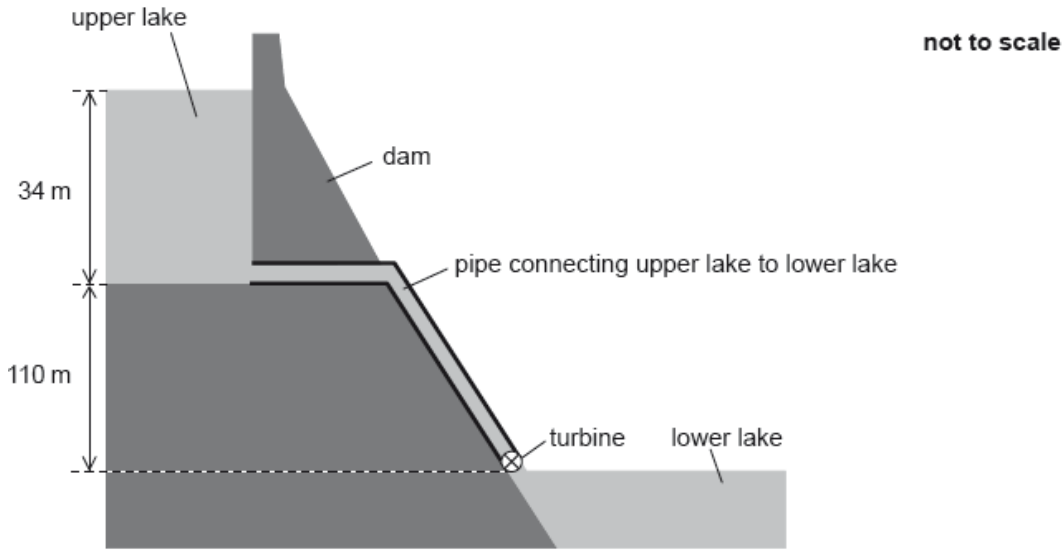
SL Paper 2

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]

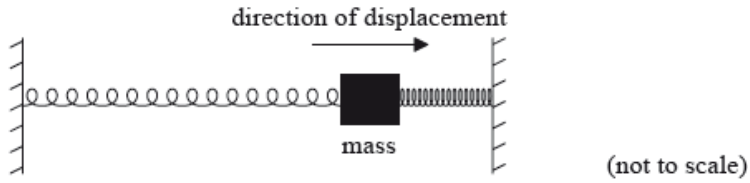
b. After the upper lake is emptied it must be refilled with water from the lower lake and this requires energy. Suggest how the operators of this storage system can still make a profit. [1]

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

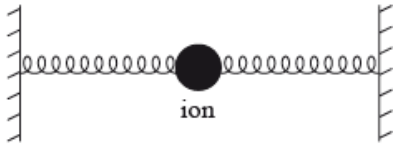
Part 1 Oscillation of a mass

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]

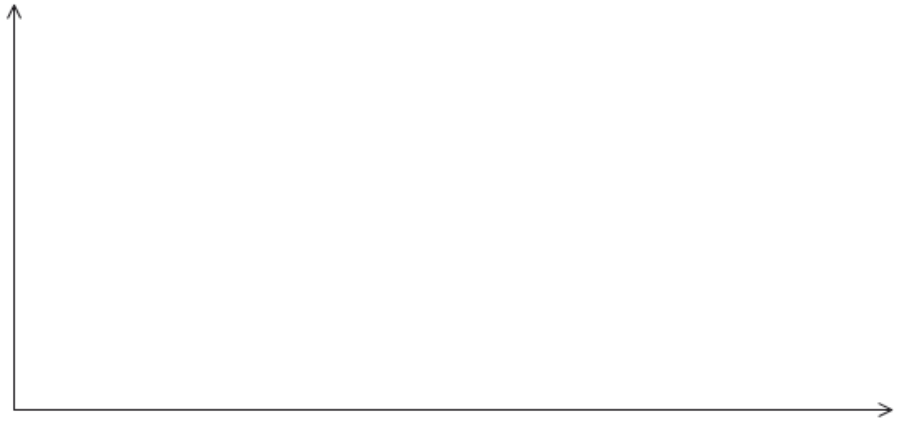
a.ii. Outline why the mass subsequently performs simple harmonic motion (SHM). [2]

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]

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.

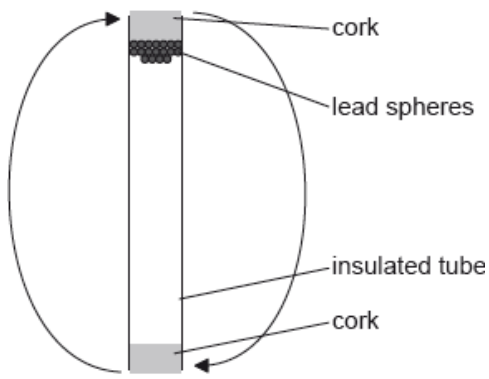
In a nuclear reactor, outline the purpose of the

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]

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

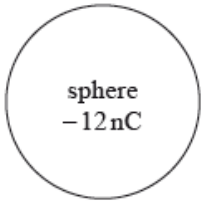
Part 1 Energy resources

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.

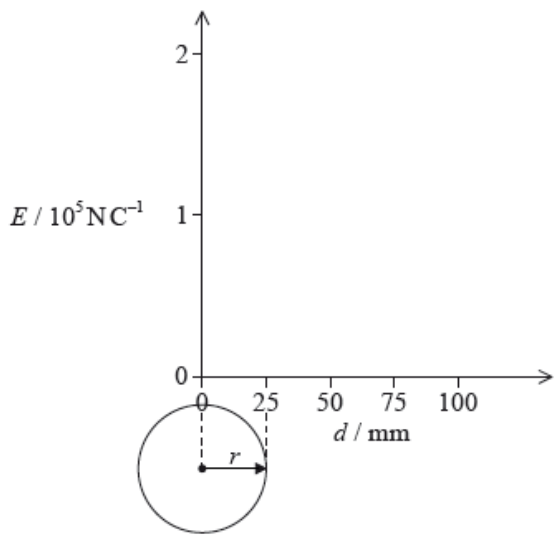
d.i. Calculate the minimum area of solar heating panel required to provide this power. [2]

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 $2 \times 10^5\ \mathrm{N\,C^{-1}}$. [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]

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

Part 1 Nuclear reactor

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]

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

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

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

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

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

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]

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 1400 Wm^{-2}. [2]

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

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

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]

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

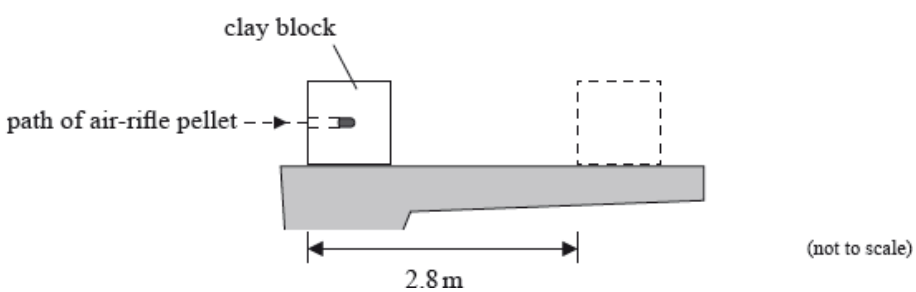
Part 1 Production of energy in nuclear fission

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	$= 140\ \mathrm{m\,s^{-1}}$
Stopping distance of clay block	$= 2.8$ m

Part 1 (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.

$$\begin{aligned} \text{Mass of neutron} &= 1.00867 \text{ u} \\ \text{Mass of U - 235 nucleus} &= 234.99333 \text{ u} \\ \text{Mass of Kr - 92 nucleus} &= 91.90645 \text{ u} \\ \text{Mass of Ba - 141 nucleus} &= 140.88354 \text{ u} \end{aligned}$$

(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 b. Outline the role of the moderator. [2]

Part 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]

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 $= 1000 \text{ kg m}^{-3}$

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 $9.8 \times 10^6 \text{ m s}^{-1}$ collides head-on with a stationary carbon-12 nucleus. Immediately after the collision the carbon-12 nucleus has a speed of $1.5 \times 10^6 \text{ m s}^{-1}$.

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 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 $5.4 \times 10^8\ \mathrm{kW\,h}$ 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 $8.0 \times 10^6\ \mathrm{m\,s^{-1}}$.

(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.

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 [3]

atmosphere is 0.300 and it may be assumed that no energy is absorbed by the atmosphere.

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

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

that the average temperature of the Earth's surface is predicted to be 256 K.

---

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 $\mathrm{kg^{-1}}$. Determine the maximum time [2]

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.

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]

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 = 1.1×10^{3} kgm^{-3}
Surface area of basin = 1.4×10^{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.

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 increase by 1.0 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.

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 $1.2 \times 10^7\ \mathrm{m}^2$.

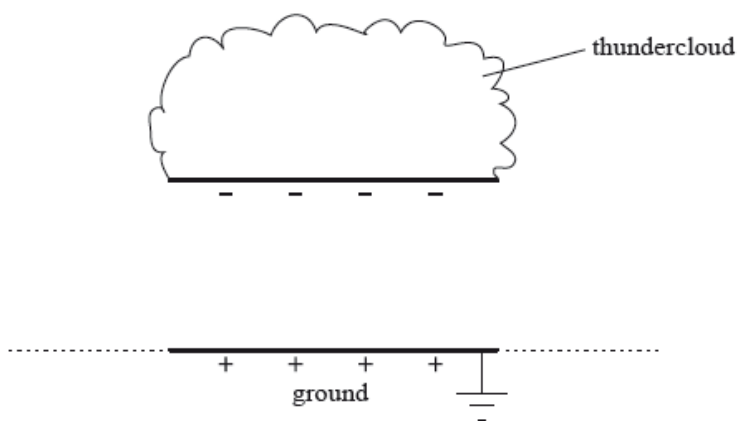
Part 2 Fuel for heating

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

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

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.

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]

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.

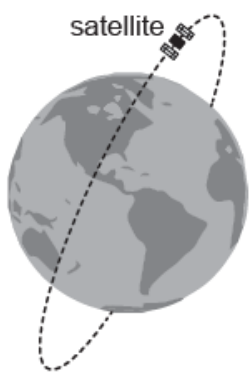
(ii) Discuss, with reference to the mechanism of infrared absorption, why the temperature of the Earth's surface would be lower if there were no greenhouse gases present in the atmosphere.

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]

This question is about nuclear power production.

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

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 = 6.0×10^{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.

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]

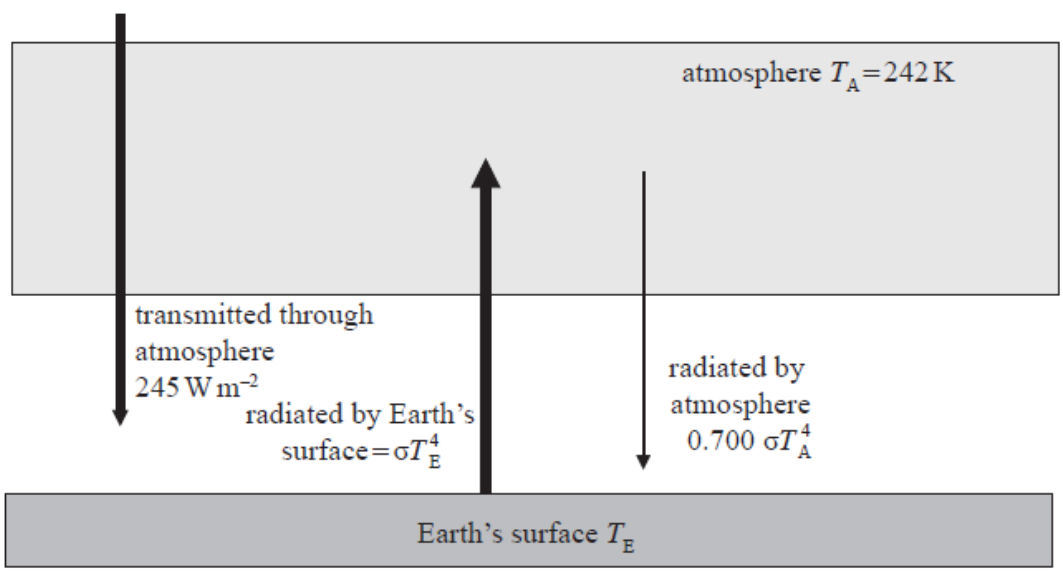
d. Describe, in terms of energy transfers, how thermal energy of the burning gas becomes electrical energy. [2]

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 $T_A = 242$ K.

(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.

---

a. A nuclide of deuterium $\left({}^{2}_{1}\mathrm{H}\right)$ and a nuclide of tritium $\left({}^{3}_{1}\mathrm{H}\right)$ 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.

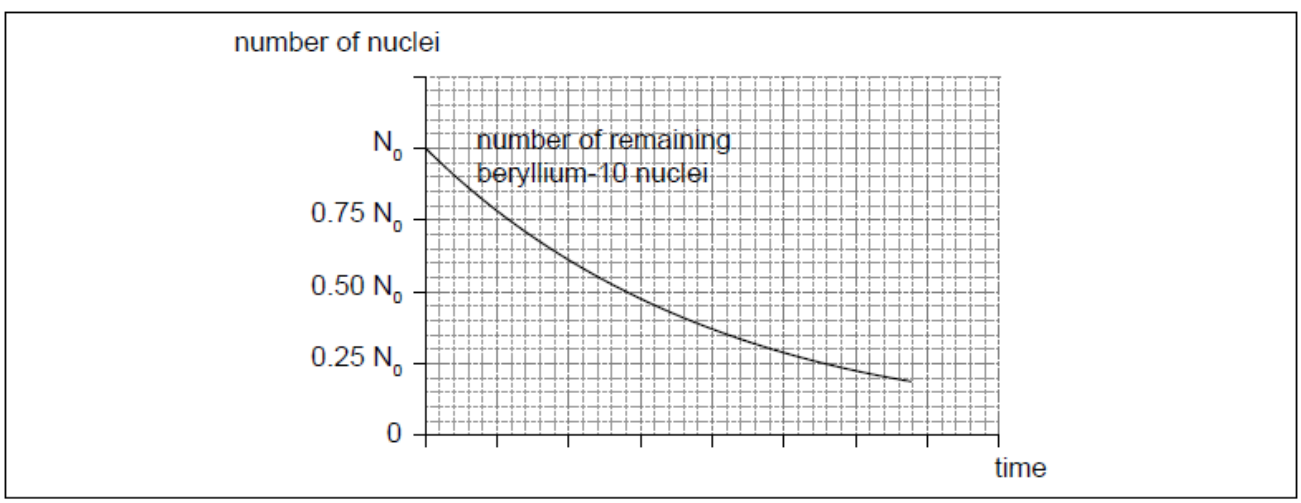
(ii) State **two** problems associated with sustaining this fusion reaction in order to produce energy on a commercial scale.

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.

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]

$$\square^{10}\text{Be} \rightarrow \square_{5}\text{B} + \beta + \bar{\upsilon}$$

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]

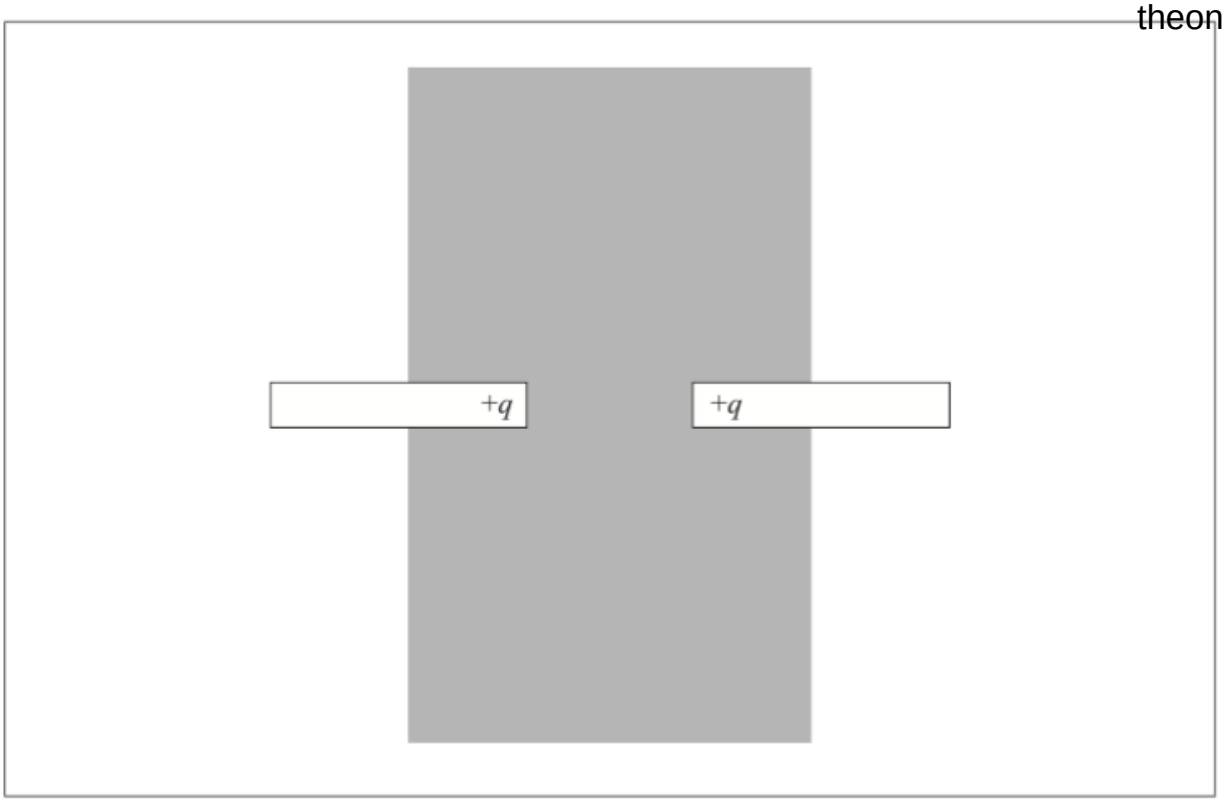
c.ii. Discuss how the frequency of the radiation emitted by a black body can be used to estimate the temperature of the body. [2]

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]

Part 2 Electric charge

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



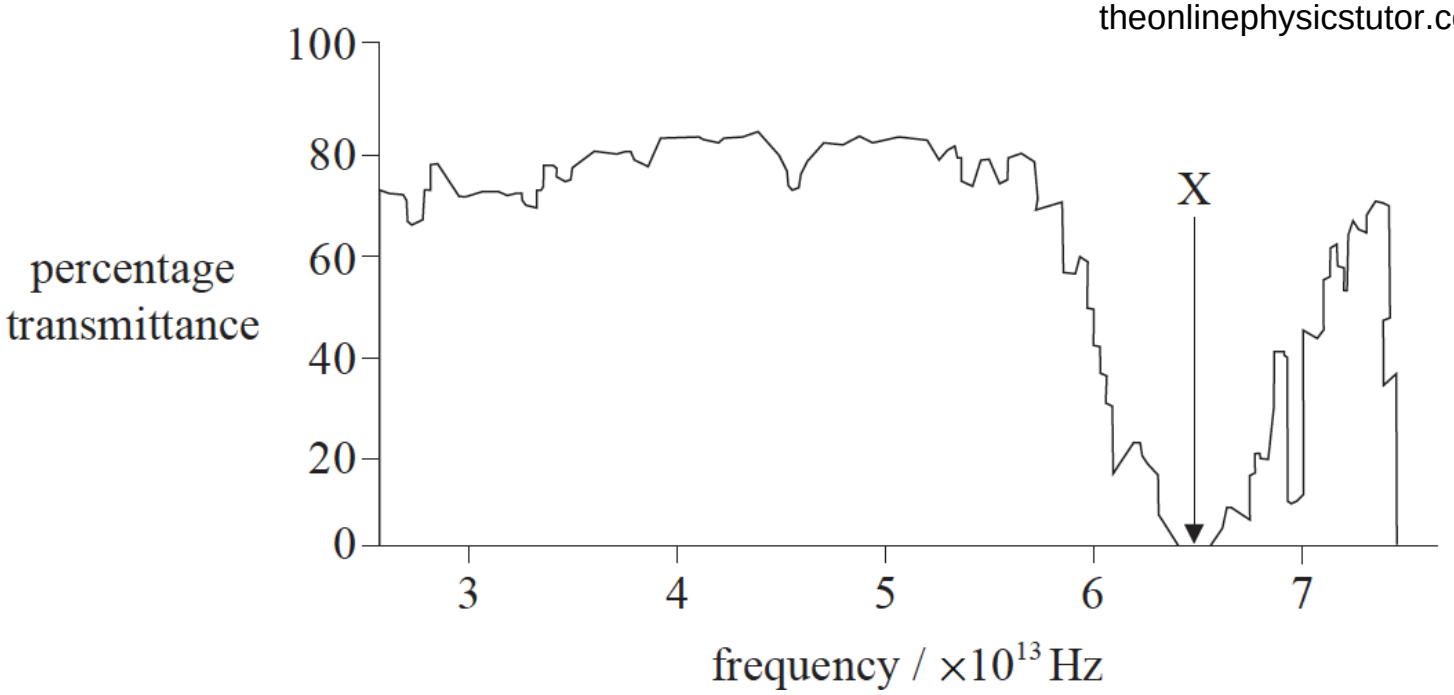
Assume that the charge at the end of each rod behaves as a point charge. Draw, in the shaded area on the diagram, the electric field pattern due to the two charges.

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.

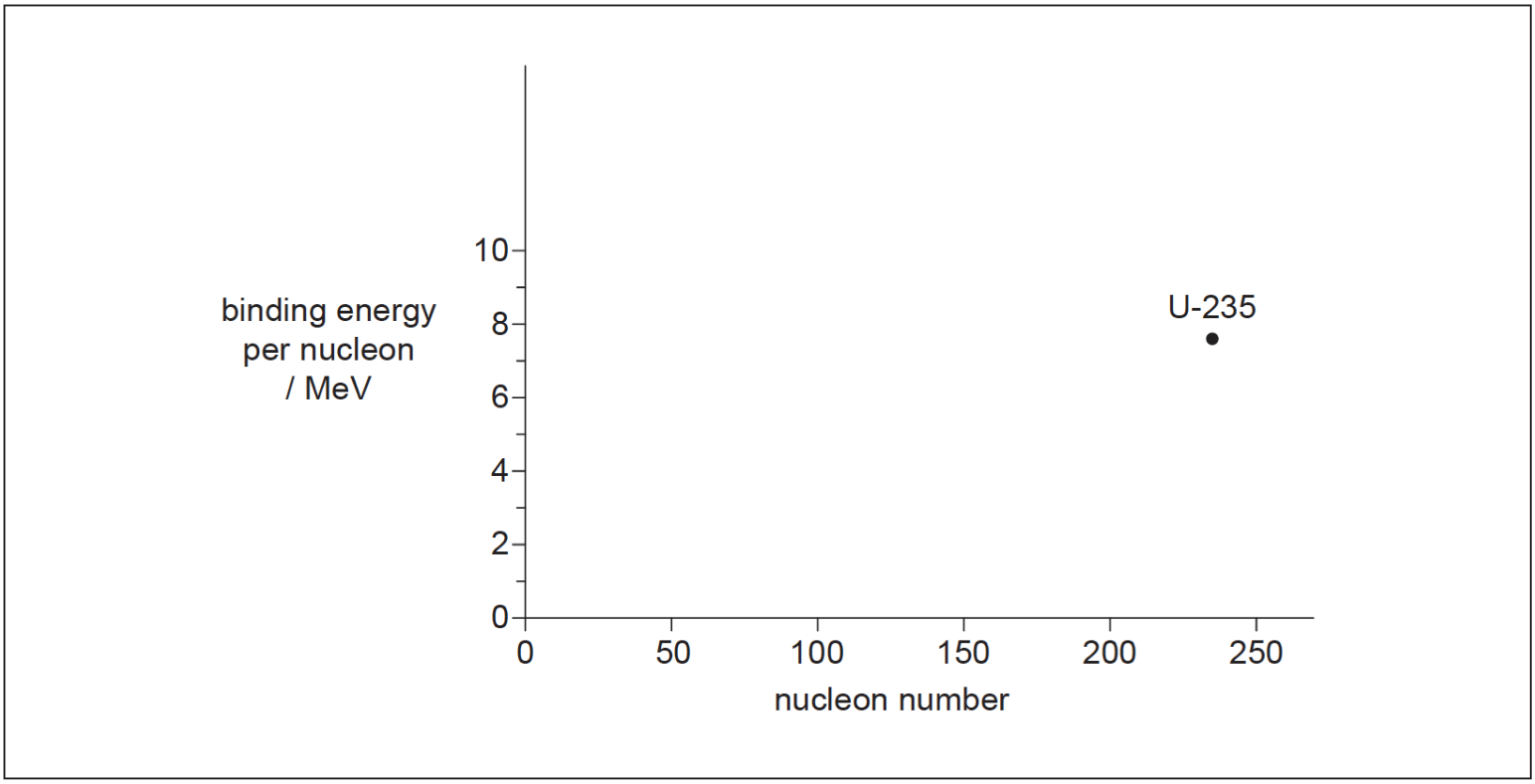
This question is in two parts. **Part 1** is about renewable energy. **Part 2** is about nuclear energy and radioactivity.

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 $8.5 ms^{-1}$ and the density of air is $1.3 kgm^{-3}$. 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 7.0×10^8 years. Calculate the initial mass of the U-235 if the rock sample was formed 2.1×10^9 years ago.

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} Wm^{-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).

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.

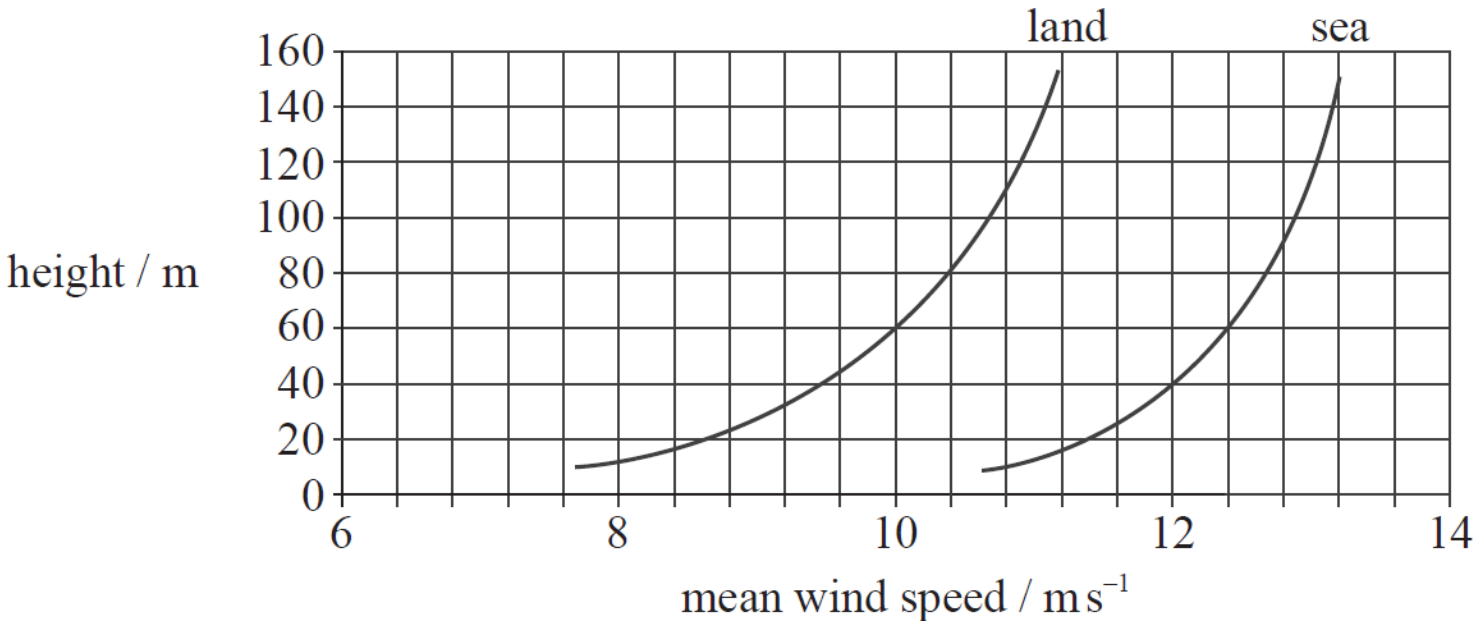
a. (i) Outline, with reference to the energy conversions in the machine, the main features of a conventional horizontal-axis wind generator. [7]

(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.

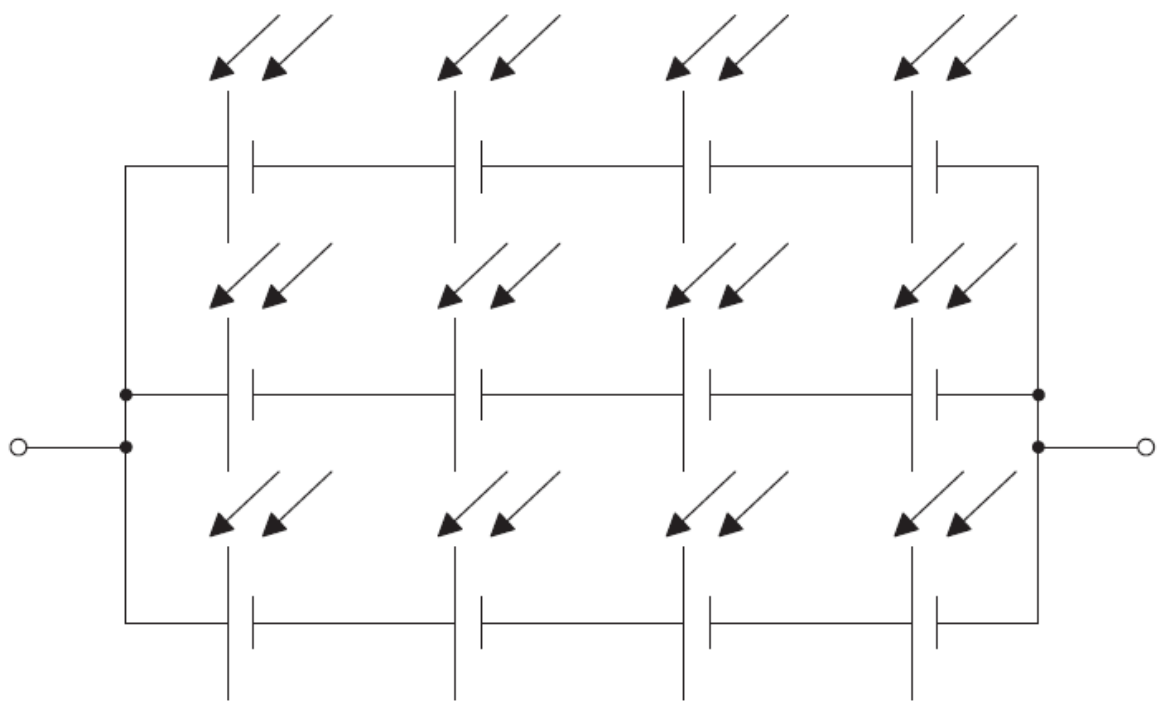
Calculate the ratio

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

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]

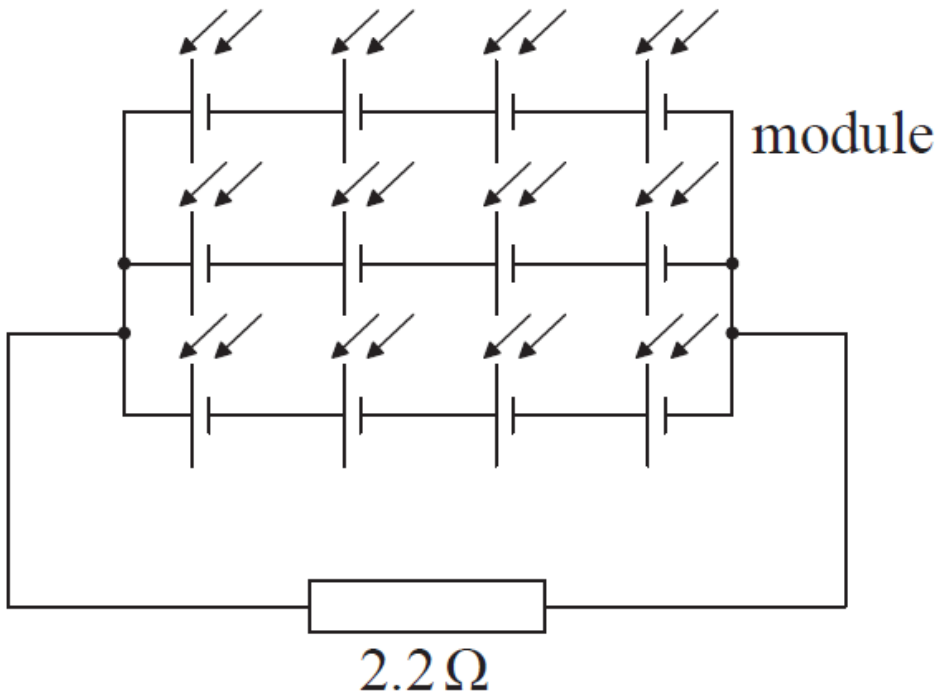


Each cell in the module has an emf of 0.75V and an internal resistance of 1.8Ω.

(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 $1.4\times10^{3}\,\mathrm{Wm^{-2}}$. [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.

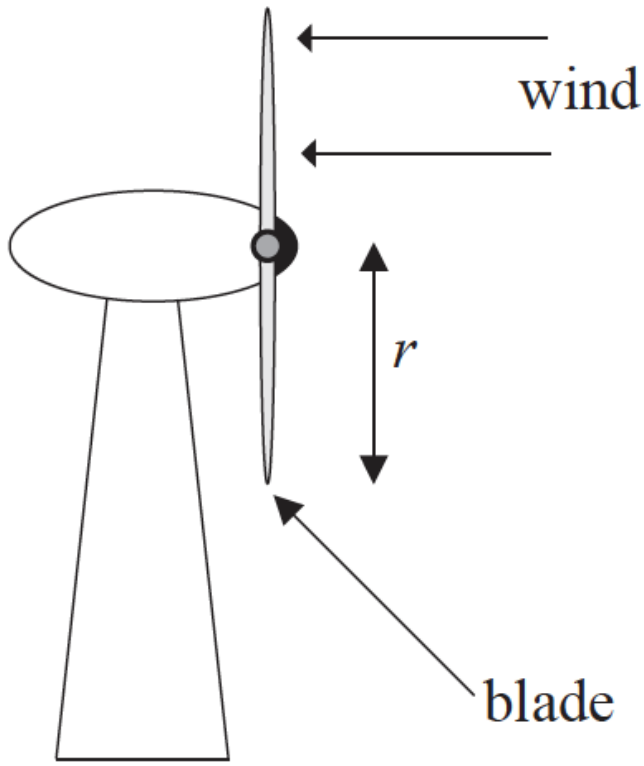
(iii) Photovoltaic cells are approximately 20% efficient. Estimate the minimum area needed to supply an average power of 850kW over a 24 hour period.

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:

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.

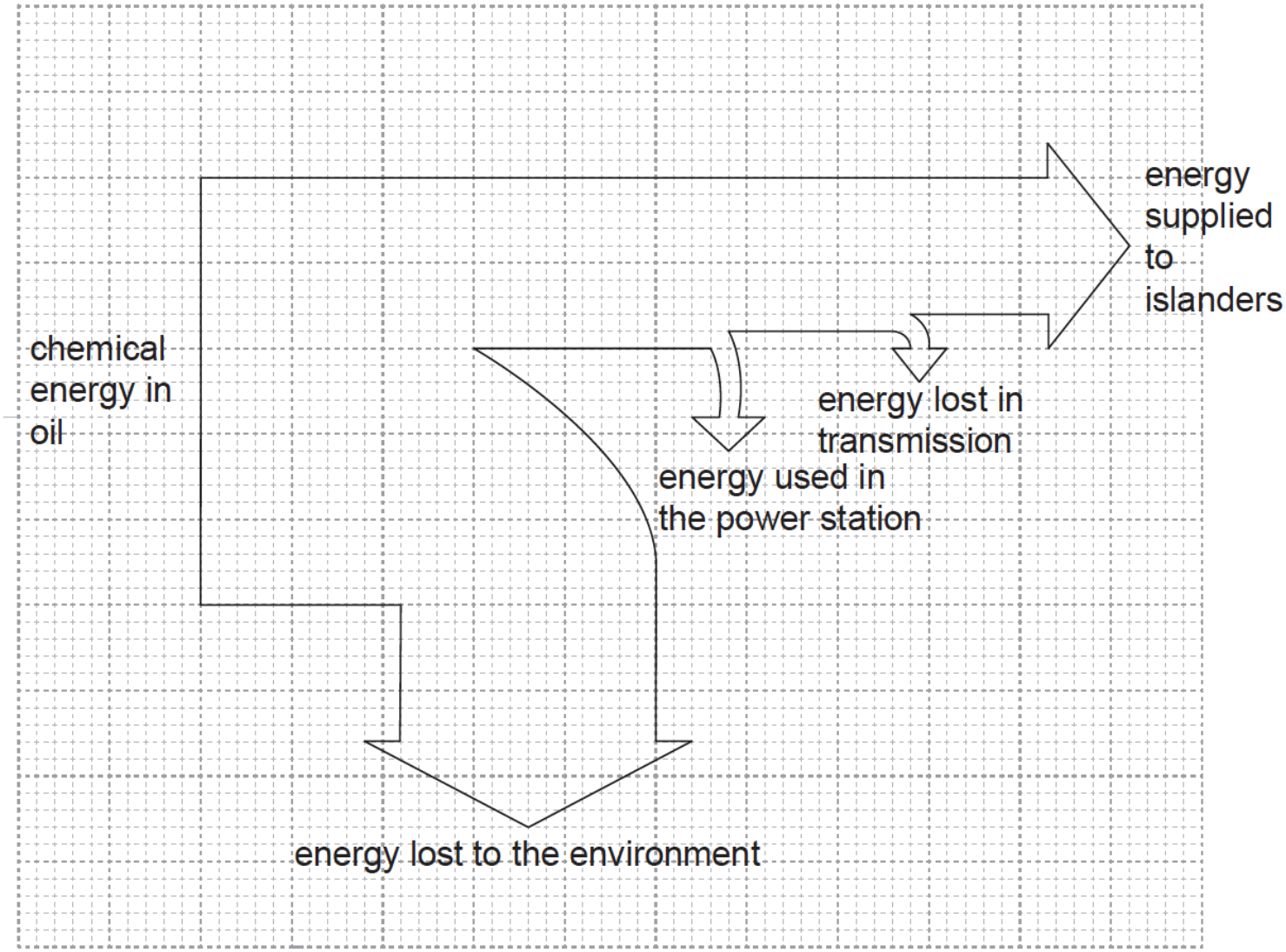
a. Suggest the conditions that would make use of wind generators in combination with either oil or nuclear fuel suitable for the islanders. [3]

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]

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

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]

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.

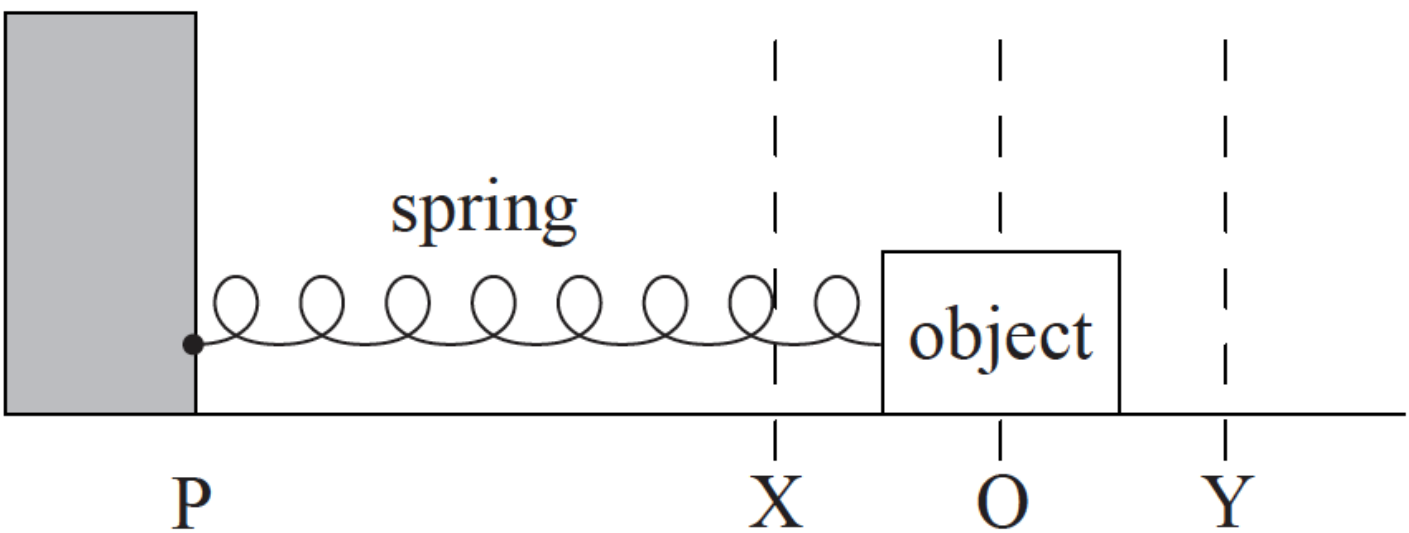
Part 1 Solar radiation and the greenhouse effect

The following data are available.

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

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]

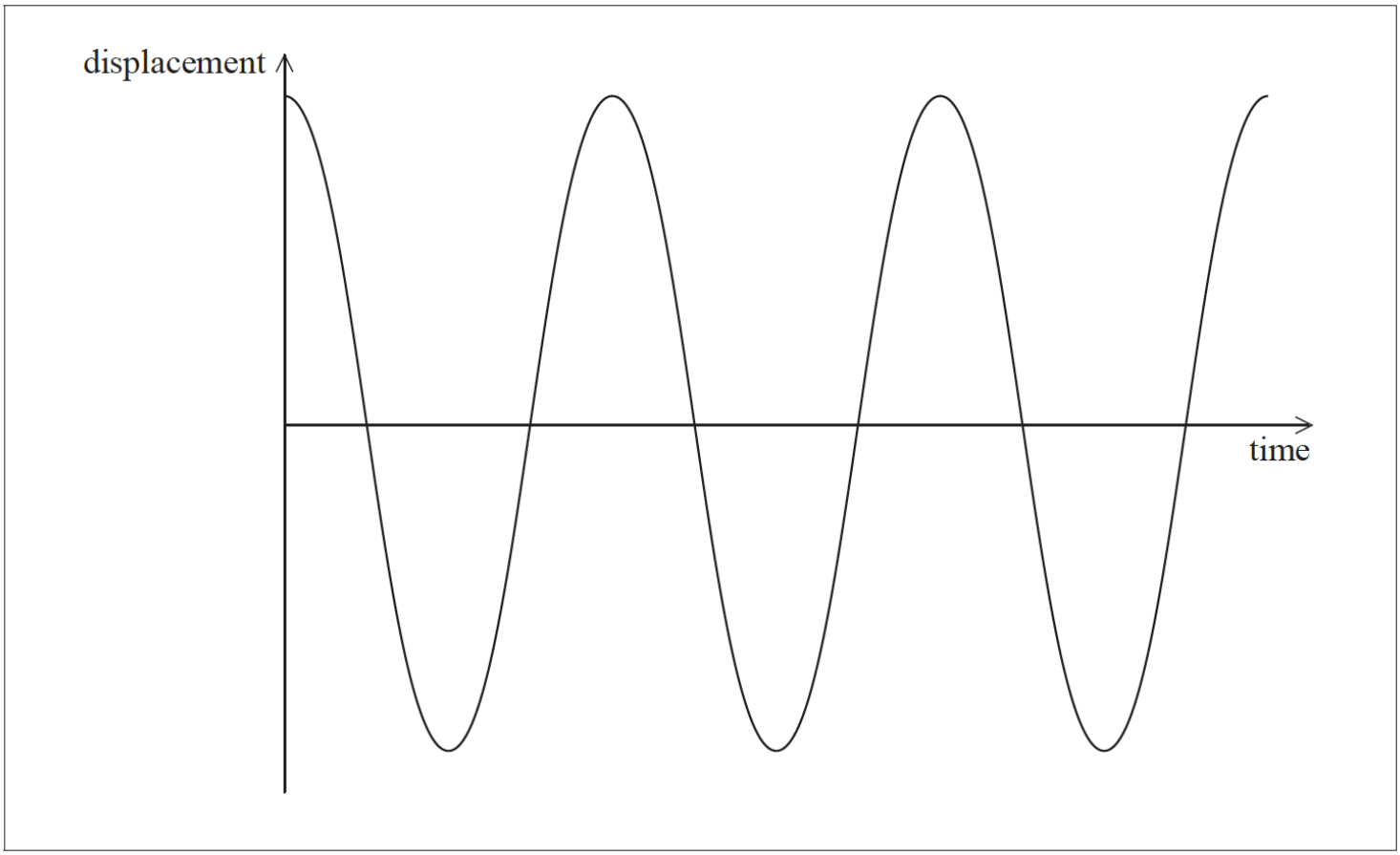
d. State **two** reasons why the solar power incident per unit area at a point on the surface of the Earth is likely to be different from your answer in (c). [2]

e. The average power absorbed per unit area at the Earth's surface is $240 Wm^{-2}$. 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.

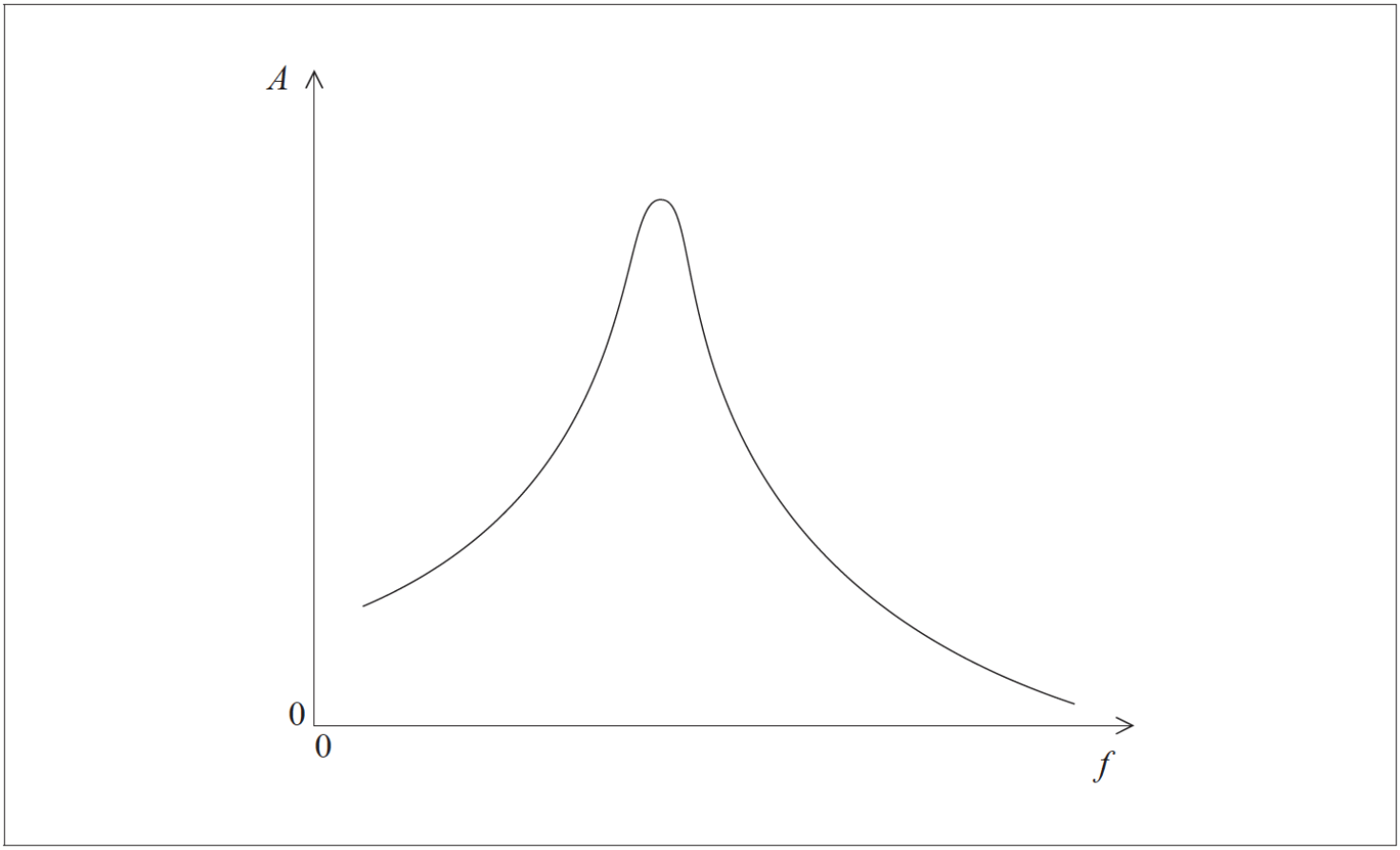
(ii) Label with the letter V a point at which the speed of the object is a maximum.

(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.