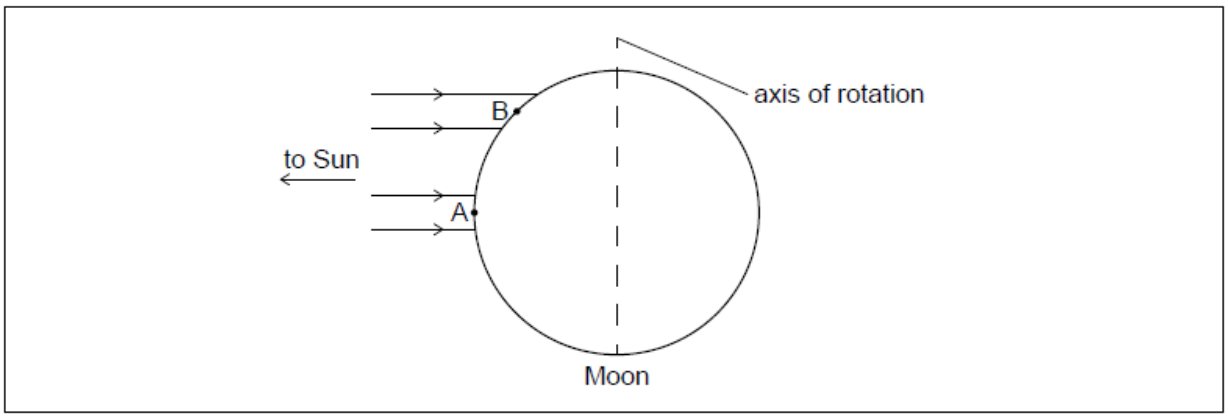
EnergyPro-practice-1-ShortA

[164 marks]

The Moon has no atmosphere and orbits the Earth. The diagram shows the Moon with rays of light from the Sun that are incident at 90° to the axis of rotation of the Moon.



1a. A black body is on the Moon's surface at point A. Show that the maximum temperature that this body can reach is 400 K. Assume that the Earth and the Moon are the same distance from the Sun. *[2 marks]*

1b. Another black body is on the Moon's surface at point B. *[2 marks]*

Outline, without calculation, why the aximum temperature of the black body at point B is less than at point A.

1c. The albedo of the Earth's atmosphere is 0.28. Outline why the maximum temperature of a black body on the Earth when the Sun is overhead is less than that at point A on the Moon. *[1 mark]*

1d. Outline why a force acts on the Moon. *[1 mark]*

1e. Outline why this force does no work on the Moon. *[1 mark]*

The average temperature of ocean surface water is 289 K. Oceans behave as black bodies.

2a. Show that the intensity radiated by the oceans is about 400 W m^{-2}. *[1 mark]*

2b. Explain why some of this radiation is returned to the oceans from the atmosphere. *[3 marks]*

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

3a. Show that the intensity of solar radiation at the orbit of Mars is about 600 W m^{-2}. *[2 marks]*

3b. Determine, in K, the mean surface temperature of Mars. Assume that Mars acts as a black body. *[2 marks]*

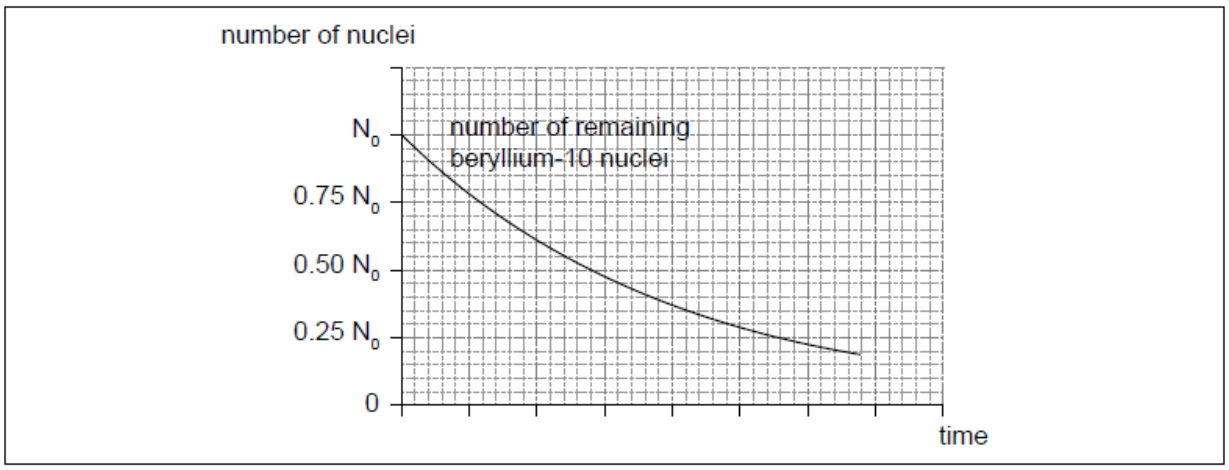
3c. The atmosphere of Mars is composed mainly of carbon dioxide and has a pressure less than 1 % of that on the Earth. Outline why the greenhouse effect is not significant on Mars. *[2 marks]*

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

4a. Identify the missing information for this decay. *[1 mark]*

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

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.



4b. On the graph, sketch how the number of **boron** nuclei in the sample varies with time. *[2 marks]*

4c. 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.

4d. 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]*

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

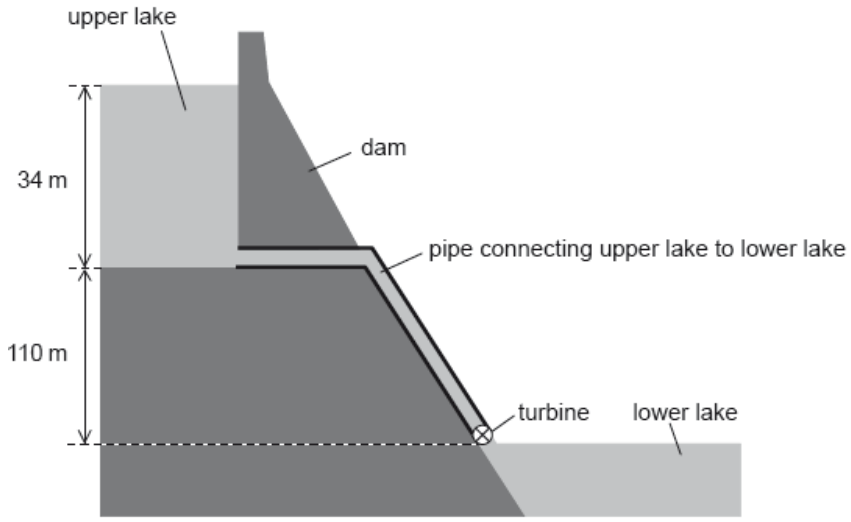
4e. State what is meant by thermal radiation. *[1 mark]*

4f. Discuss how the frequency of the radiation emitted by a black body can be used to estimate the temperature of the body. *[2 marks]*

4g. Calculate the peak wavelength in the intensity of the radiation emitted by the ice sample. *[2 marks]*

4h. Derive the units of intensity in terms of fundamental SI 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}.

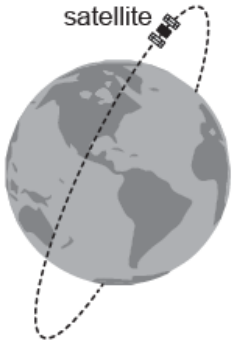
5a. Estimate the specific energy of water in this storage system, giving an appropriate unit for your answer. *[2 marks]*

5b. Show that the average rate at which the gravitational potential energy of the water decreases is 2.5 GW. *[3 marks]*

5c. The storage system produces 1.8 GW of electrical power. Determine the overall efficiency of the storage system. *[1 mark]*

5d. 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]*

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.

6a. Determine the orbital period for the satellite. *[3 marks]*

Mass of Earth = 6.0×10^{24} kg

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.

6b. Determine the mean temperature of the Earth. *[2 marks]*

6c. Suggest how the difference between λ_S and λ_E helps to account for the greenhouse effect. *[3 marks]*

6d. Not all scientists agree that global warming is caused by the activities of man. *[1 mark]*

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

Two renewable energy sources are solar and wind.

7a. Describe the difference between photovoltaic cells and solar heating panels. *[1 mark]*

7b. 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]*

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}

7c. Determine the minimum number of turbines needed to generate the same power as the solar farm. *[3 marks]*

7d. Explain **two** reasons why the number of turbines required is likely to be greater than your answer to (c)(i). *[2 marks]*

8a. Outline, with reference to energy changes, the operation of a pumped storage hydroelectric system. *[2 marks]*

8b. The hydroelectric system has four 250 MW generators. The specific energy available from the water is 2.7 kJ kg^{-1}. Determine the maximum time for which the hydroelectric system can maintain full output when a mass of 1.5×10^{10} kg of water passes through the turbines. *[2 marks]*

8c. Not all the stored energy can be retrieved because of energy losses in the system. Explain **one** such loss. *[1 mark]*

8d. 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 marks]*

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

9a. Calculate, with a suitable unit, the electrical power output of the power station. *[1 mark]*

9b. Calculate the mass of CO_2 generated in a year assuming the power station operates continuously. *[1 mark]*

9c. Explain, using your answer to (b), why countries are being asked to decrease their dependence on fossil fuels. *[2 marks]*

9d. Describe, in terms of energy transfers, how thermal energy of the burning gas becomes electrical energy. *[2 marks]*

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.

10a. Show that the intensity of the solar radiation incident on the upper atmosphere of the Earth is approximately 1400Wm^{-2}. *[2 marks]*

10b. 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]*

10c. Estimate the average surface temperature of the Earth. *[2 marks]*

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.

11a. Outline which of the three generation methods above is renewable. *[2 marks]*

In a nuclear reactor, outline the purpose of the

11b. heat exchanger. *[1 mark]*

11c. moderator. *[2 marks]*

Fission of one uranium-235 nucleus releases 203 MeV.

11d. Determine the maximum amount of energy, in joule, released by 1.0 g of uranium-235 as a result of fission. *[3 marks]*

11e. Describe the main principles of the operation of a pump storage hydroelectric scheme. *[3 marks]*

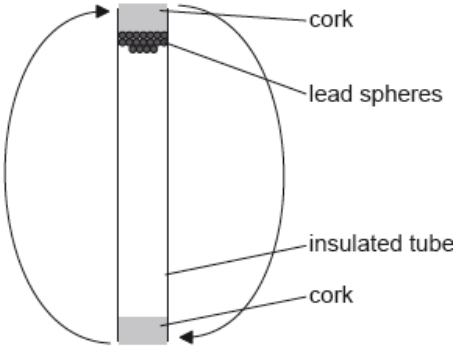
11f. A hydroelectric scheme has an efficiency of 92%. Water stored in the dam falls through an average height of 57 m. Determine the rate of flow of water, in $\mathrm{kg\,s^{-1}}$, required to generate an electrical output power of 4.5 MW. *[3 marks]*

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

Part 2 Thermal physics

11g. Distinguish between specific heat capacity and specific latent heat. *[2 marks]*

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.



11h. Discuss the changes to the energy of the lead spheres. *[2 marks]*

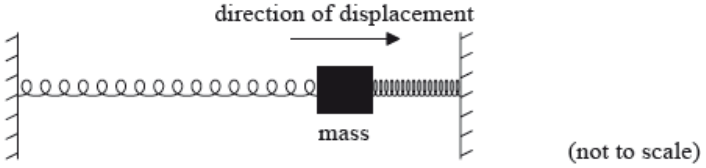
11i. The specific heat capacity of lead is $1.3 \times 10^2\ \mathrm{J\,kg^{-1}K^{-1}}$. Deduce the number of times that the tube is turned upside down. *[4 marks]*

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.

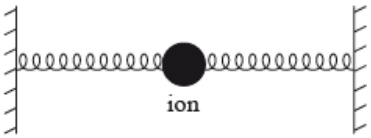


12a. Determine the acceleration of the mass at the moment of release. *[3 marks]*

12b. Outline why the mass subsequently performs simple harmonic motion (SHM). *[2 marks]*

12c. Calculate the period of oscillation of the mass. *[2 marks]*

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 $7 \times 10^{12}\ \mathrm{Hz}$ and the mass of the ion is $5 \times 10^{-26}\ \mathrm{kg}$. The amplitude of vibration of the ion is $1 \times 10^{-11}\ \mathrm{m}$.

12d. Estimate the maximum kinetic energy of the ion. *[2 marks]*

12e. 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 marks]*
You should add appropriate values to the axes, showing the variation over one period.

12f. Calculate the wavelength of an infrared wave with a frequency equal to that of the model in (b). *[1 mark]*

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%.

12g. Determine the mass of U-235 that undergoes fission in the reactor every day. *[3 marks]*

12h. Calculate the power output of the nuclear power station. *[2 marks]*

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

12i. moderator. *[3 marks]*

12j. control rods. *[2 marks]*

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

Part 1 Energy resources

13a. 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 marks]*

13b. With reference to the energy transformations and the operation of the devices, distinguish between a photovoltaic cell and a solar heating panel. *[2 marks]*

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.

13c. Determine the efficiency of the photovoltaic panel. *[2 marks]*

13d. State **two** reasons why the intensity of solar radiation at the location of the panel is not constant. *[2 marks]*

1.

2.

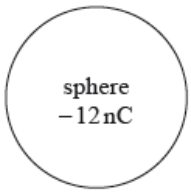
The owner of the house chooses between photovoltaic panels and solar heating panels to provide 4.2 kW of power to heat water. The solar heating panels have an efficiency of 70%. The maximum intensity of solar radiation at the location remains at $750\ \mathrm{W\,m^{-2}}$.

13e. Calculate the minimum area of solar heating panel required to provide this power. *[2 marks]*

13f. 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 marks]*

Part 2 Electric fields

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

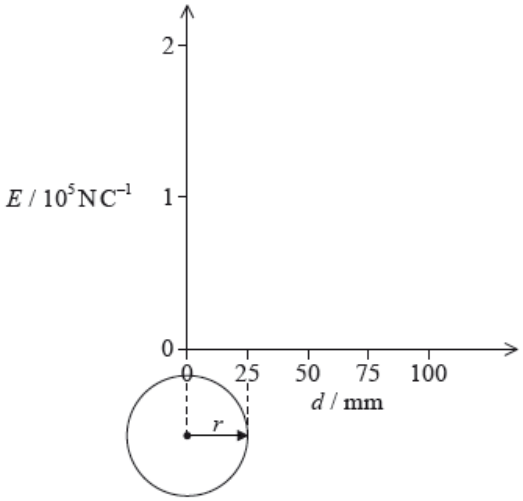


13g. Using the diagram, draw the electric field pattern due to the charged sphere. *[2 marks]*

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.

13h. 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 marks]*

13i. 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 marks]*



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

13j. Calculate the initial acceleration of the electron. *[2 marks]*

13k. Discuss the subsequent motion of the electron. *[2 marks]*

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	$7.0\times10^{8}\,\text{m}$
Surface temperature of Sun	T	$5.8\times10^{3}\,\text{K}$
Distance from Sun to Earth	d	$1.5\times10^{11}\,\text{m}$
Stefan-Boltzmann constant	σ	$5.7\times10^{-8}\,\text{W m}^{-2}\,\text{K}^{-4}$

14a. State the Stefan-Boltzmann law for a black body. *[2 marks]*

14b. Deduce that the solar power incident per unit area at distance d from the Sun is given by *[2 marks]*

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

14c. Calculate, using the data given, the solar power incident per unit area at distance d from the Sun. *[2 marks]*

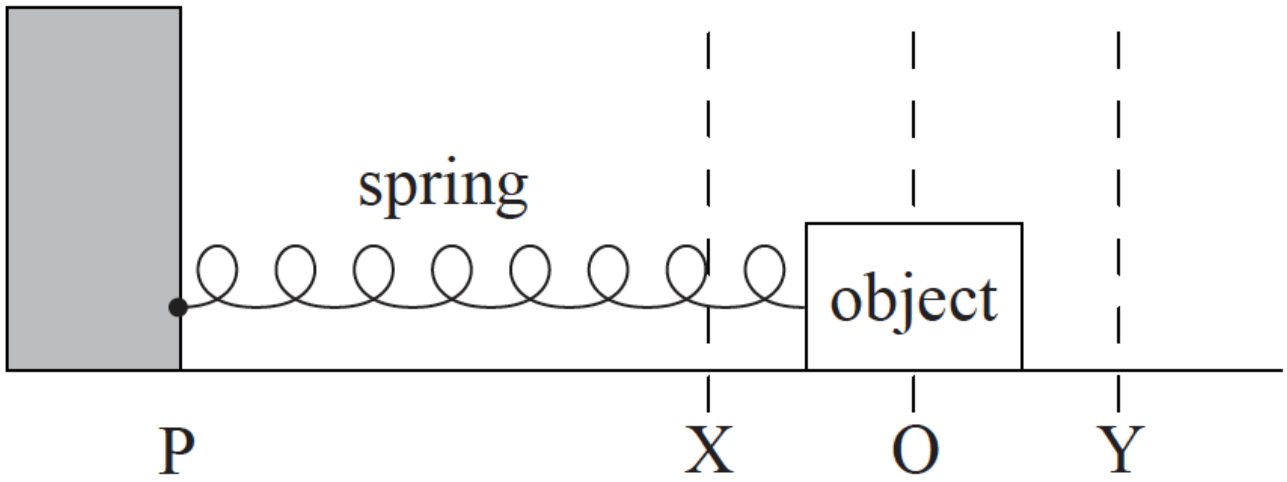
14d. State **two** reasons why the solar power incident per unit area at a point on the surface of the Earth is likely to be different from your answer in (c). *[2 marks]*

14e. 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 marks]*

14f. Explain why the actual surface temperature of the Earth is greater than the value in (e). *[3 marks]*

Part 2 A mass on a spring

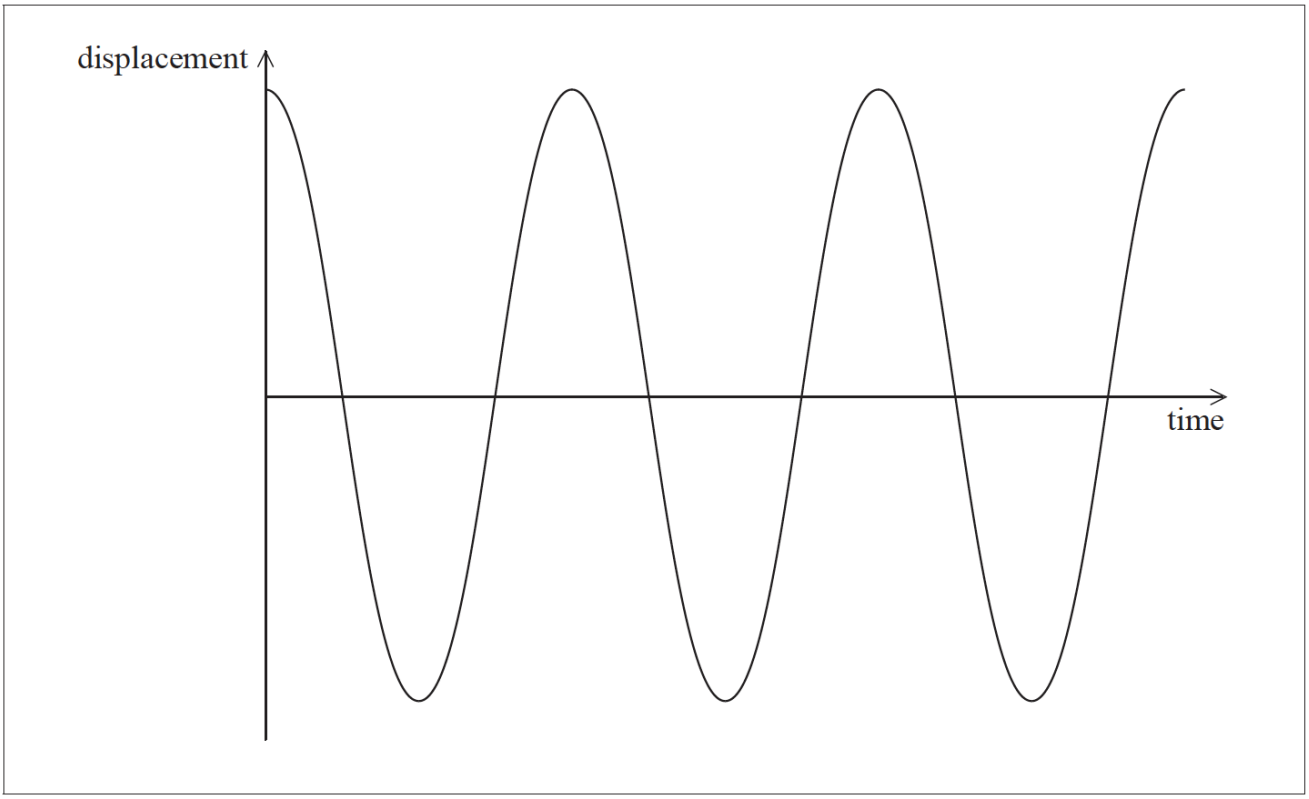
An object is placed on a frictionless surface and attached to a light horizontal spring.



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.

14g. Outline the conditions necessary for the object to execute simple harmonic motion. *[2 marks]*

14h. The sketch graph below shows how the displacement of the object from point O varies with time over three time periods. *[4 marks]*



(i) Label with the letter A a point at which the magnitude of the acceleration of the object is a maximum.

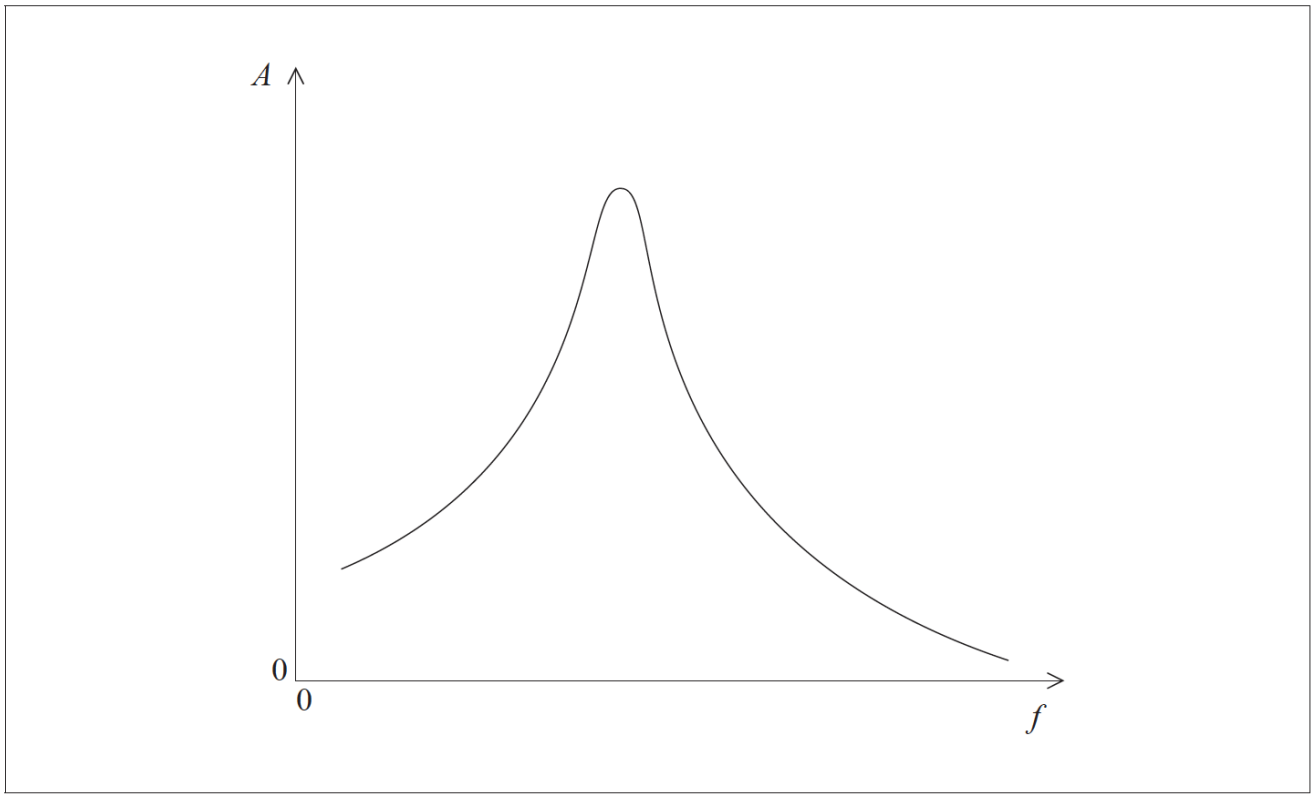
(ii) Label with the letter V a point at which the speed of the object is a maximum.

(iii) Sketch on the same axes a graph of how the displacement varies with time if a **small** frictional force acts on the object.

14i. 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 marks]*

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.