Diploma Programme
Programme du diplôme
Programa del Diploma

Physics
Higher level
Paper 2

Specimen paper

Candidate session number

2 hours 30 minutes

Instructions to candidates

- Write your session number in the boxes above.
- Do not open this examination paper until instructed to do so.
- Answer all questions.
- Answers must be written within the answer boxes provided.
- A calculator is required for this paper.
- A clean copy of the **physics data booklet** is required for this paper.
- The maximum mark for this examination paper is **[90 marks]**.

0000 – 6503

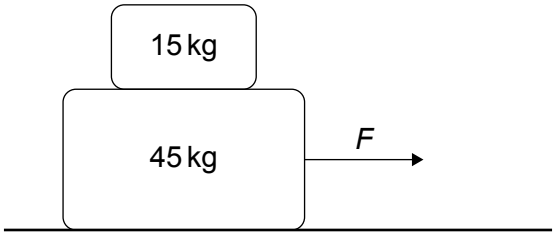
28 pages

Answer **all** questions. Answers must be written within the answer boxes provided.

1. A block of mass 45 kg is placed on a horizontal table. There is no friction between the block and the table.

An object of mass 15 kg is placed on top of the block.

A force *F* acts on the block so that it accelerates. The acceleration of the object and the acceleration of the block are the same so that they do not move relative to each other.



The coefficient of static friction between the block and the object is 0.60.

(a) State the nature and direction of the force that accelerates the 15 kg object. [1]

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(b) Determine the largest magnitude of *F* for which the block and the object do not move relative to each other. [3]

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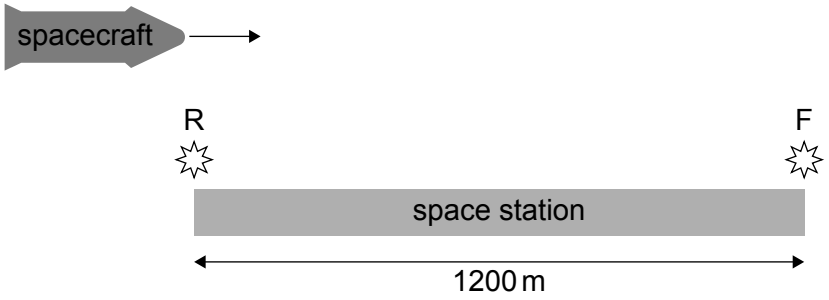
2. A spacecraft is flying past a space station at a relative speed of 0.80*c*. Beacons, R and F, at each end of the space station emit light pulses at the same time according to observers on the space station. The pulses are emitted 1200 m apart as measured by space station observers.



(a) Calculate γ for a speed of 0.80*c*. [1]

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(b) Calculate, for the reference frame of the spacecraft,

(i) the distance between the light pulses. [1]

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(ii) the time between the light pulses. [2]

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(c) Determine which light pulse happened first. [2]

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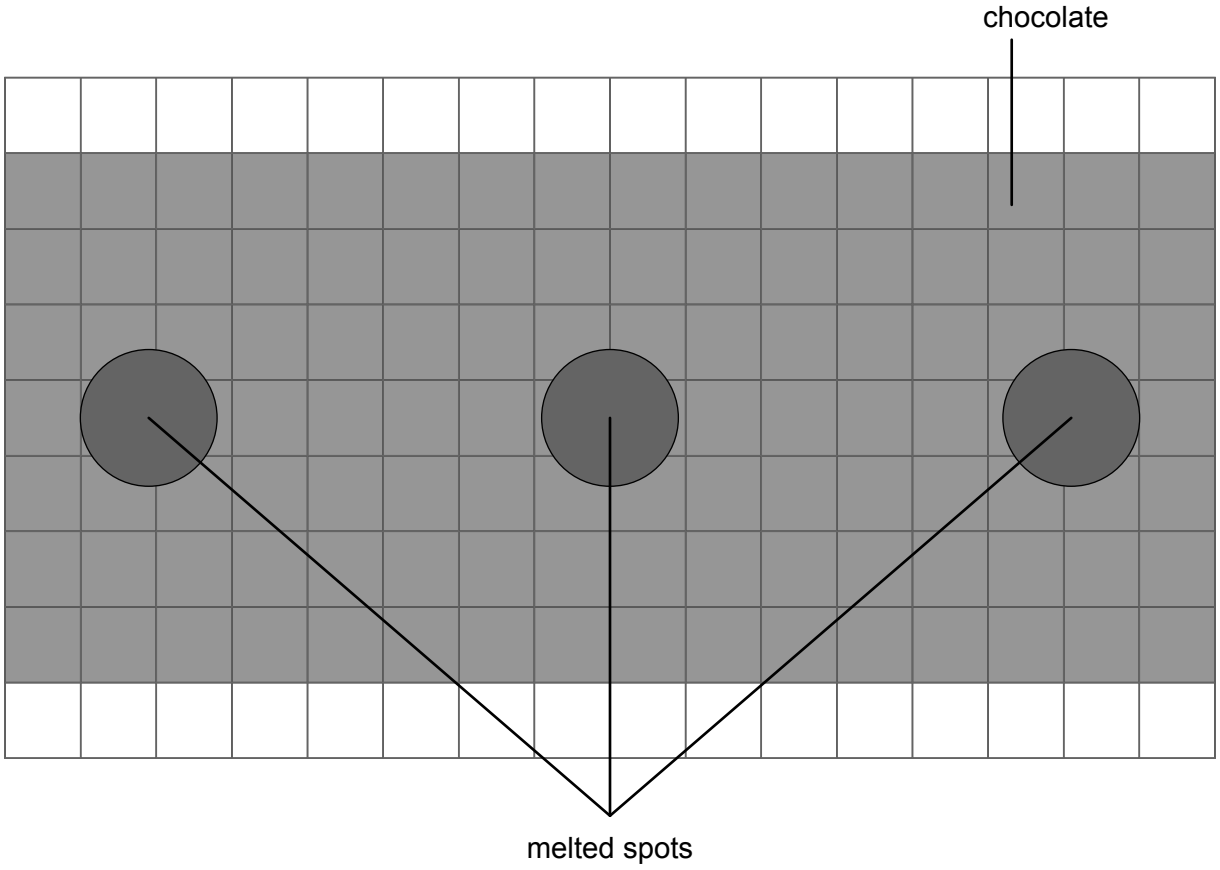
3. In a microwave oven electromagnetic waves are emitted so that a standing wave pattern is established inside the oven.

A flat piece of chocolate is placed inside the oven and the microwaves are switched on. The chocolate is stationary.

Melted spots form on the surface of the chocolate. The diagram shows the pattern of melting on the chocolate. Each square has a length of 1 cm.



(a) Outline how this standing wave pattern of melted spots is formed. [2]

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(Question 3 continued)

(b) Determine, taking appropriate measurements from the diagram, the frequency of the electromagnetic waves in the oven. [3]

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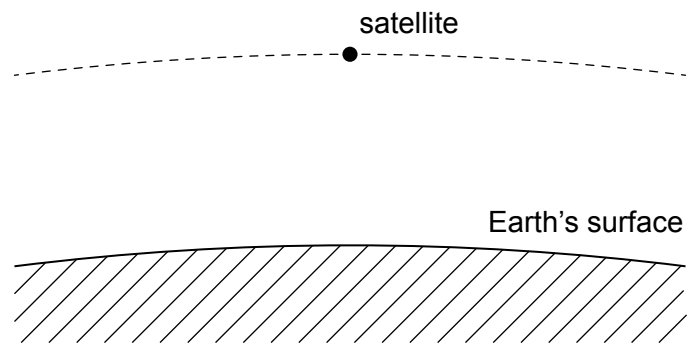
4. A satellite moves around Earth in a circular orbit.



(a) Draw an arrow on the diagram to represent the direction of the acceleration of the satellite. [1]

(b) The following data are given:

Mass of Earth, $M = 5.97 \times 10^{24}\,\text{kg}$

Radius of Earth, $R = 6.37 \times 10^{6}\,\text{m}$

Orbital period of the satellite, $T = 5.62 \times 10^{3}\,\text{s}$

(i) Kepler's Third Law of orbital motion states that $T^2 = kr^3$ where k is a constant and r is the orbital radius of the satellite.

Show that $k = \dfrac{4\pi^2}{GM}$. [1]

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(ii) Determine the height of the satellite above the Earth's surface. [2]

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(Question 4 continued)

(c) The atmosphere exerts a small viscous drag force on the satellite.

Outline how the total energy, kinetic energy, and gravitational potential energy change for the satellite during one orbit around Earth. [3]

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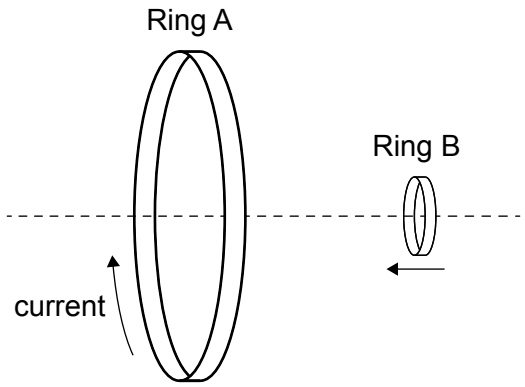
5. Two conducting rings, A and B, have their centres on the same line. The planes of A and B are parallel. There is a constant clockwise current in A. Ring A is stationary and ring B moves towards ring A at a constant speed.



(a) Outline why the magnetic flux in ring B increases. [1]

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(b) State the direction of the induced current in ring B. [1]

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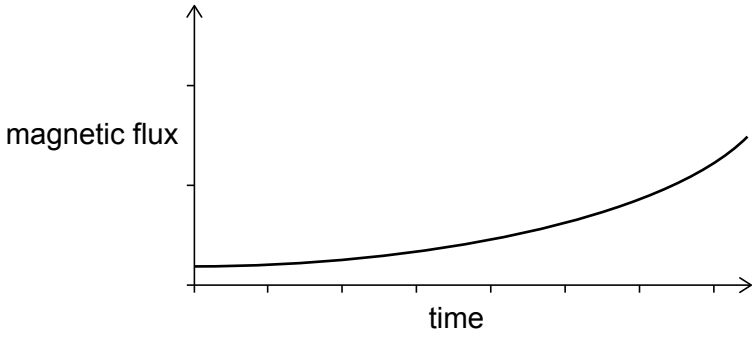
(Question 5 continued)

(c) The graph shows how the magnetic flux in ring B varies with time.



Discuss the variation with time of the induced current in ring B. [3]

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(d) Outline why work must be done on ring B as it moves towards ring A at a constant speed. [2]

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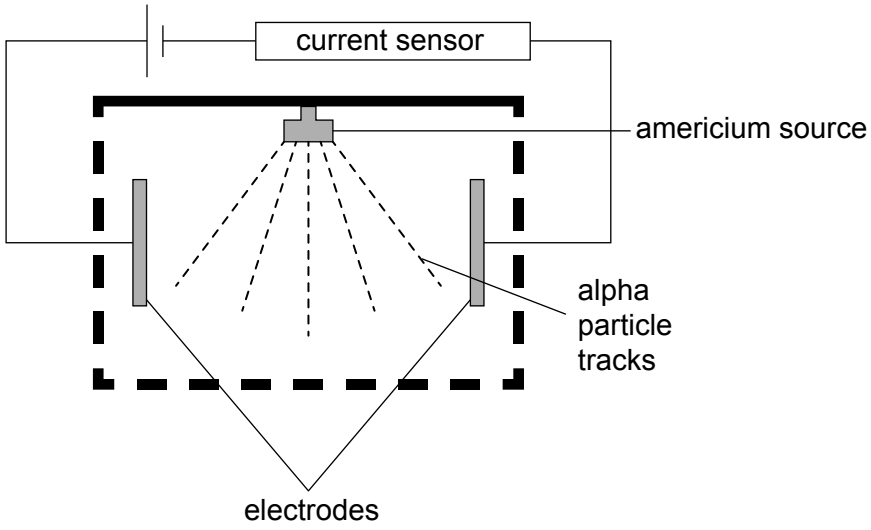
6. A smoke detector uses the radioactive nuclide americium-241.

The americium is contained in a chamber that is open to the air. There are two electrodes in the chamber that are connected to a power supply and a current sensor.



Americium-241 emits alpha particles that ionize the air in the chamber. Each ionization forms one positive ion and one electron; these are called an ion pair. The electrons and the positive ions move towards the electrodes and the sensor detects a current in the air.

When smoke enters the chamber, fewer ion pairs are formed and the current in the sensor decreases, sounding an alarm.

The decay constant of americium-241 is $5.08 \times 10^{-11}\,s^{-1}$.
The chamber is 0.10 m in each dimension.

(a) A nucleus of americium-241 has 146 neutrons. This nuclide decays to neptunium through alpha emission.

Complete the nuclear equation for this decay. [2]

$$\_\!\!^{\_}_{\_}\text{Am} \rightarrow \_\!\!^{\_}_{\_}\text{Np} + \_\!\!^{\_}_{\_}\alpha$$

(This question continues on the following page)

(Question 6 continued)

(b) Outline why the radioactive source is safe for use in a house. [1]

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(c) Deduce whether the radioactive source will need to be replaced during the life of the detector. [3]

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The initial activity of the source is 42 kBq. 33 % of the alpha particles emitted by this source enter the chamber and form an ion pair.
Each alpha particle has an initial kinetic energy of 5.5 MeV.
The energy required to form one ion pair is 15 eV.

(d) Calculate the maximum current in the chamber due to the electrons when there is no smoke in the chamber. [3]

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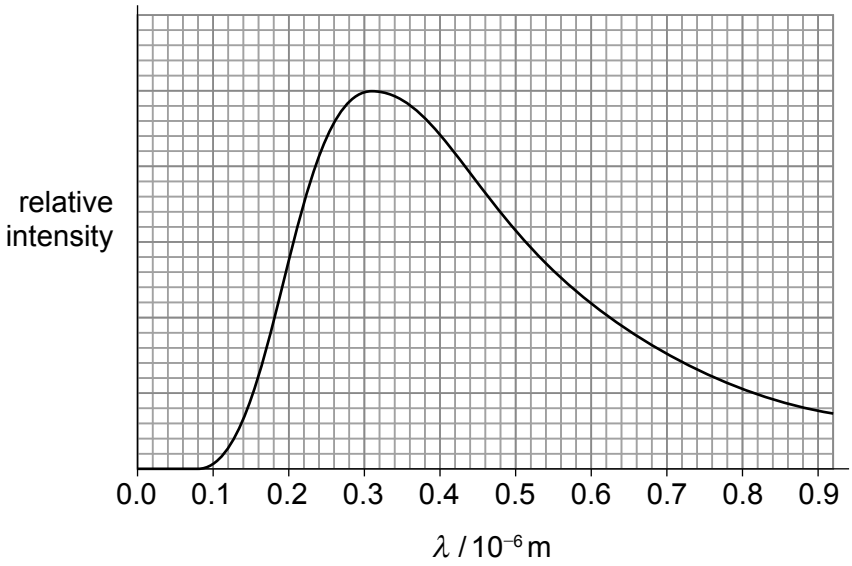
7. The star δ Vel A is a main sequence star that has a black-body spectrum as shown.



(a) Show that the surface temperature of δ Vel A is about 9000 K. [1]

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(b) The apparent brightness of δ Vel A is $2.2 \times 10^{-9}\,\text{W m}^{-2}$ and it is 6.2×10^{14} km from Earth.

Estimate the radius of δ Vel A. [3]

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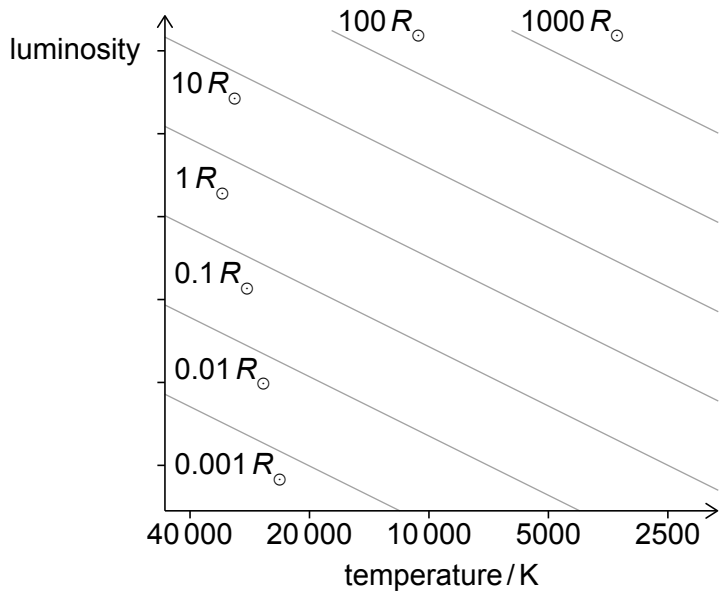
(Question 7 continued)

(c) The radius of the Sun, $R_\odot$, is 7.0×10^5 km.

Sketch, on the Hertzsprung-Russell diagram, the position of δ Vel A. [2]



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8. Small pieces of solid paraffin with a total mass of 30 g at a temperature of 42 °C are mixed with 150 g of liquid paraffin at a temperature of 240 °C. The mixture is stirred until an equilibrium temperature is reached.

The following data for paraffin are available:

Specific heat capacity of solid paraffin = $0.7\,kJ\,kg^{-1}\,K^{-1}$
Specific heat capacity of liquid paraffin = $2.13\,kJ\,kg^{-1}\,K^{-1}$
Specific latent heat of fusion of paraffin = $220\,kJ\,kg^{-1}$
Melting point of paraffin = 47 °C

(a) Calculate the theoretical equilibrium temperature of the mixture. [3]

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(b) (i) When the experiment was carried out, the equilibrium temperature of the mixture was found to be different from the theoretical value.

Suggest the reason for this difference. [2]

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(ii) The mixture was held in a large metal container during the mixing.

Explain **one** change to the procedure that will reduce the difference in (b)(i). [1]

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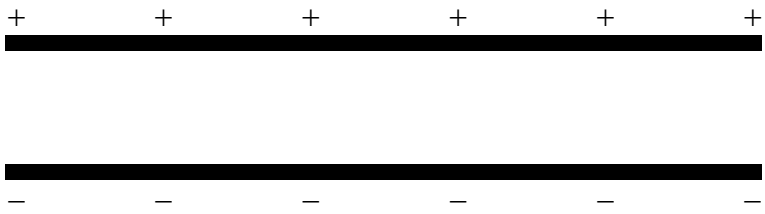
9. The diagram shows two parallel conducting plates that are oppositely charged.



(a) (i) Draw the electric field lines due to the charged plates. [2]

(ii) The potential difference between the plates is 960 V and the distance between them is 8.0 mm. Calculate the electric field strength *E* between the plates. [2]

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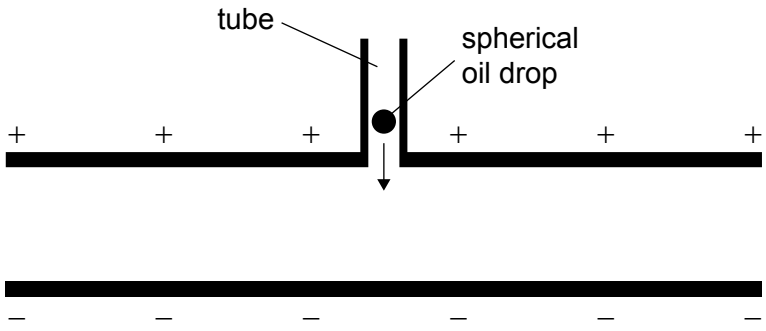
(Question 9 continued)

In an experiment, an oil drop is introduced into the space between the plates through a small hole in the upper plate. The oil drop moves through air in a tube before falling between the plates.



(b) Explain why the oil drop becomes charged as it falls through the tube. [1]

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(Question 9 continued)

(c) The oil drop is observed to be stationary in the space between the plates. Buoyancy is one of the forces acting on the drop.

The density of oil is 730 times greater than that of air.

(i) Show that the buoyancy force is much smaller than the weight. [3]

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(ii) Draw the forces acting on the oil drop, ignoring the buoyancy force. [2]

oil drop

(This question continues on the following page)

(Question 9 continued)

(iii) Show that the electric charge on the oil drop is given by

$$q = \frac{\rho_o g V}{E}$$

where ρ_o is the density of oil and V is the volume of the oil drop. [2]

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(iv) State the sign of the charge on the oil drop. [1]

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will not be marked.

(Question 9 continued)

(d) The electric field is turned off. The oil drop falls vertically reaching a constant speed v.

(i) Outline why, for this drop, $\rho_o gV = 6\pi\eta rv$ where η is the viscosity of air and r is the radius of the oil drop. [2]

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(ii) Show that the charge on the oil drop is about 4.8×10^{-19} C.

The following data for the oil drop are available:

$r = 1.36\,\mu m$
$\eta = 1.60 \times 10^{-5}\,Pa\,s$
$v = 0.140\,mm\,s^{-1}$ [3]

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(iii) The oil drop splits into two parts of equal mass. Both are charged. Deduce the net charge on each part. [2]

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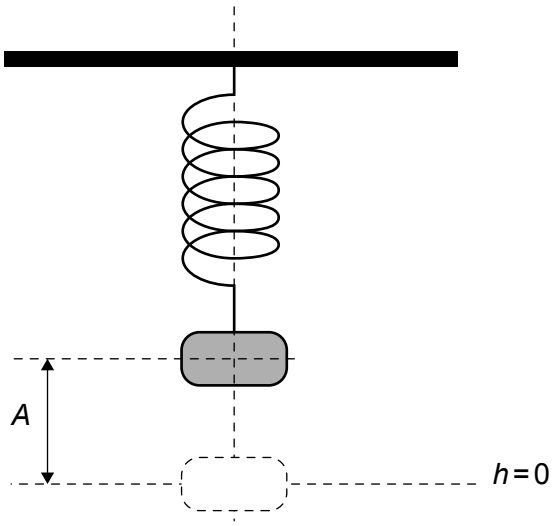
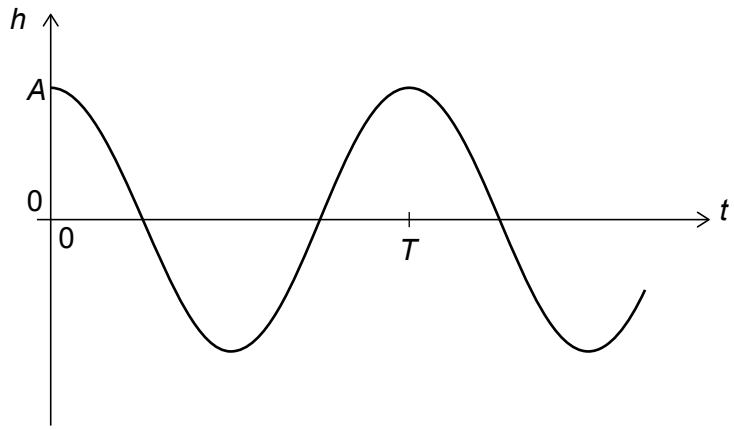
10. An object hangs in equilibrium from a spring of elastic constant k. The object is displaced through a vertical height $h = A$ and released at time $t = 0$ so that it oscillates with a simple harmonic motion of period T.



The graph shows the variation of h with t.



(a) State the equation of motion for this oscillation. [1]

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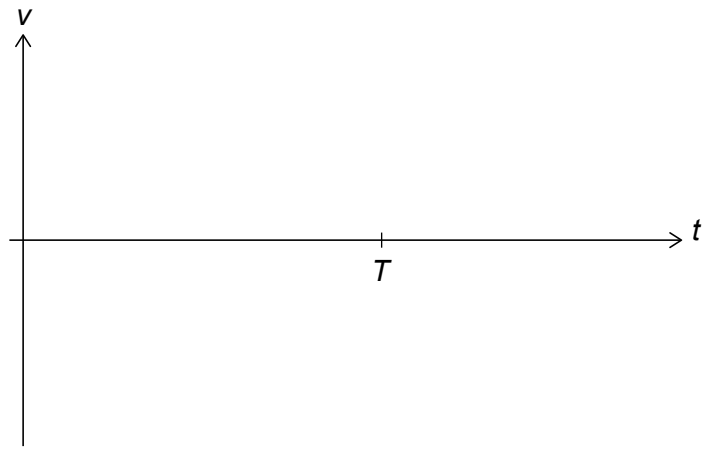
(Question 10 continued)

(b) Sketch, on the axes, the variation with t of the velocity v of the object. Label the peak value on the v-axis with an appropriate expression in terms of A and T. [2]



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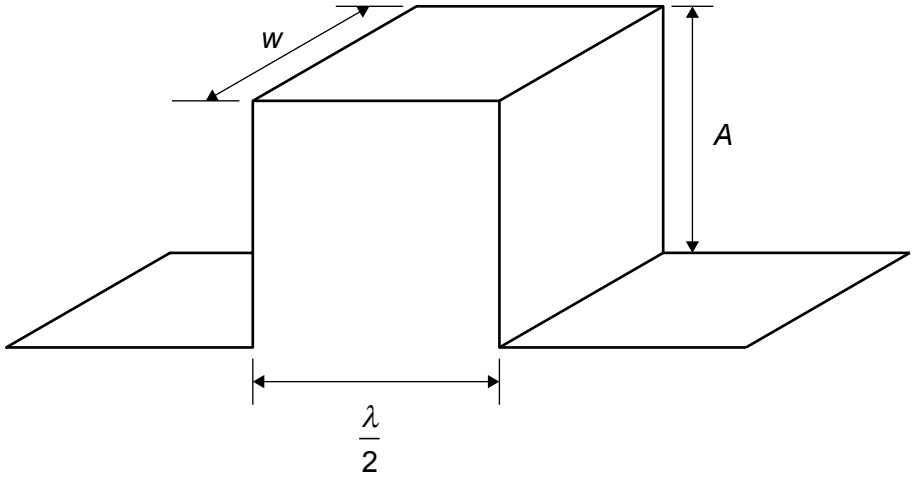
(Question 10 continued)

Sea waves are produced by wind and carry energy that can be transferred into electrical energy. A sea wave can be modelled as a square wave of wavelength λ, amplitude A, and width w.



(c) (i) Show that the gravitational potential energy of the sea wave shown in the diagram can be modelled as

$$E_p = \frac{1}{4}\rho g w \lambda A^2$$

where ρ is the density of sea water. [3]

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(This question continues on the following page)

(Question 10 continued)

(ii) The wave is moving at a speed v. The maximum power available from the sea wave is P.

Explain why the maximum power per unit length of the wavefront $\frac{P}{w}$ available from the sea wave is $\frac{1}{2}\rho g v A^2$. [2]

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(This question continues on the following page)

(Question 10 continued)

Thermal energy is also used in the production of electrical energy. The thermal energy is usually transferred from the chemical energy of a fuel or from the nuclear energy of a fissionable element.

(d) (i) A fuel is used to transfer thermal energy to water to produce steam at a pressure of 20 MPa and a temperature of 550 °C. The steam turns the blades of a turbine generator system and finally condenses at atmospheric pressure and a temperature of 30 °C.

Explain, with reference to the second law of thermodynamics, why a steam turbine operating between these temperatures must be less than about 60 % efficient. [2]

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In nuclear reactors, the water is vaporized in the transfer of nuclear energy from the fission of Uranium-235 ($^{235}_{92}U$). The fission is induced by the collision of a neutron with the nucleus.

The table gives some common nuclear fragments that are present in a fuel rod following the fission of $^{235}_{92}U$. The symbol of the element is followed by its proton number and some of the nucleon numbers that are observed in the fragments.

Element symbol	Proton number	Observed nucleon numbers						
Br	35	81						
Kr	36	86	87	88	89			
Rb	37	85	87					
Sr	38	88	89	90				
Y	39	89	90	91				
Zr	40	90	91	92	93	94	95	96

(This question continues on the following page)

(Question 10 continued)

(ii) In a fission, two nuclei are produced together with several neutrons. One of the products is a $^{147}_{56}Ba$ nucleus.

State the nuclear reaction for the fission that has this product. [2]

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On average, the fission of an atom of Uranium-235 releases 200 MeV. The energy density of coal is approximately 25 MJ kg^{-1}.

(iii) Estimate the ratio

$$\frac{\text{energy density of } ^{235}U}{\text{energy density of coal}}$$ [3]

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(iv) The energy in a star arises from nuclear fusion. Attempts are being investigated to use fusion on Earth to provide electrical energy on a large scale.

Identify **one** advantage and **one** difficulty for this to become a reality on Earth. [2]

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(Question 10 continued)

(e) Four methods for energy production are mentioned in this question. These methods are sea waves, coal, nuclear fission and nuclear fusion.

Discuss these methods.

In your answer you should refer to

- efficiency of the methods
- their environmental impacts
- availability of the resources. [3]

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