Name: ________________________________ Class: ______________

JURONG PIONEER JUNIOR COLLEGE
JC2 Preliminary Examination 2021

PHYSICS **9749/03**
Higher 2 **22 September 2021**

Paper 3 Longer Structured Questions **2 hours**

Candidates answer on the Question Paper.
No additional Materials are required.

READ THESE INSTRUCTIONS FIRST

Write your name, class and index number on all the work you hand in.
Write in dark blue or black pen.
You may use a soft pencil for any diagrams, graphs or rough working.
Do not use staples, paper clips, highlighters, glue or correction fluid.

Section A
Answer **all** questions.

Section B
Answer any **one** question only.

You are advised to spend about one and half hours on Section A and half an hour on Section B.

At the end of the examination, fasten all your work securely together.
The number of marks is given in brackets [ ] at the end of each question or part question.

For Examiner's Use	
1	/ 8
2	/ 11
3	/ 8
4	/ 8
5	/ 8
6	/ 8
7	/ 9
8	/ 20
9	/ 20
Total	/ 80

Data

speed of light in free space	$c = 3.00 \times 10^{8}\ \mathrm{m s^{-1}}$
permeability of free space	$\mu_0 = 4\pi \times 10^{-7}\ \mathrm{H m^{-1}}$
permittivity of free space	$\varepsilon_0 = 8.85 \times 10^{-12}\ \mathrm{F m^{-1}}$
	$= (1/(36\pi)) \times 10^{-9}\ \mathrm{F m^{-1}}$
elementary charge	$e = 1.60 \times 10^{-19}\ \mathrm{C}$
the Planck constant	$h = 6.63 \times 10^{-34}\ \mathrm{J s}$
unified atomic mass constant	$u = 1.66 \times 10^{-27}\ \mathrm{kg}$
rest mass of electron	$m_e = 9.11 \times 10^{-31}\ \mathrm{kg}$
rest mass of proton	$m_p = 1.67 \times 10^{-27}\ \mathrm{kg}$
molar gas constant	$R = 8.31\ \mathrm{J K^{-1} mol^{-1}}$
the Avogadro constant	$N_A = 6.02 \times 10^{23}\ \mathrm{mol^{-1}}$
the Boltzmann constant	$k = 1.38 \times 10^{-23}\ \mathrm{J K^{-1}}$
gravitational constant	$G = 6.67 \times 10^{-11}\ \mathrm{N m^{2} kg^{-2}}$
acceleration of free fall	$g = 9.81\ \mathrm{m s^{-2}}$

Formulae

uniformly accelerated motion	$s = ut + \frac{1}{2}at^2$
	$v^2 = u^2 + 2as$
work done on/by a gas	$W = p\Delta V$
hydrostatic pressure	$p = \rho gh$
gravitational potential	$\varphi = -\frac{GM}{r}$
temperature	$T / \text{K} = T / {}^\circ\text{C} + 273.15$
pressure of an ideal gas	$p = \frac{1}{3}\frac{Nm}{V}\langle c^2 \rangle$
mean translational kinetic energy of an ideal gas molecule	$E = \frac{3}{2}kT$
displacement of particle in s.h.m.	$x = x_0 \sin \omega t$
velocity of particle in s.h.m.	$v = v_0 \cos \omega t$
	$= \pm\omega\sqrt{{x_0}^2 - x^2}$
electric current	$I = Anvq$
resistors in series	$R = R_1 + R_2 + ...$
resistors in parallel	$1/R = 1/R_1 + 1/R_2 + ...$
electric potential	$V = \frac{Q}{4\pi\varepsilon_0 r}$
alternating current/voltage	$x = x_0 \sin \omega t$
magnetic flux density due to a long straight wire	$B = \frac{\mu_0 I}{2\pi d}$
magnetic flux density due to a flat circular coil	$B = \frac{\mu_0 NI}{2r}$
magnetic flux density due to a long solenoid	$B = \mu_0 nI$
radioactive decay	$x = x_0 \exp(-\lambda t)$
decay constant	$\lambda = \frac{\ln 2}{t_{\frac{1}{2}}}$

Section A

Answer **all** the questions in this section.

1 (a) A buoy is held partially submerged in sea water by a rope anchored to the sea bed as shown in Fig. 1.1. A fifth of the volume of the buoy is above the sea surface.

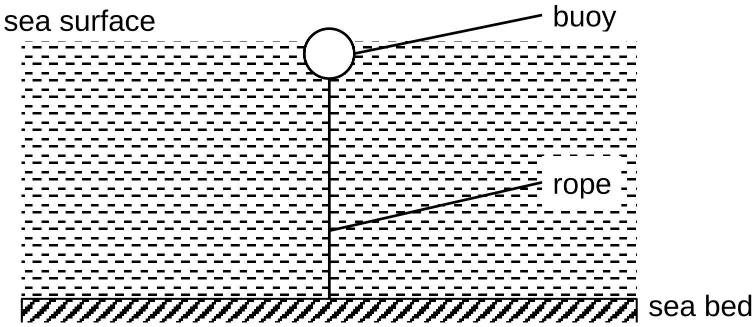

Fig. 1.1

The buoy has volume 7.5×10^{-2} m^3 and mass 8.0 kg. The mass of the rope may be neglected. The density of sea water is 1.03×10^3 kg m^{-3}.

(i) Explain what is meant by *upthrust*.

....

....

.... [1]

(ii) Calculate the value of the upthrust U on the buoy.

U = ... N [2]

(iii) Show that the tension in the rope is 530 N.

[1]

(b) Current in the sea water during high tide cause the buoy in **(a)** to be displaced so that it is fully submerged and the rope makes an angle of 35° with the vertical, as shown in Fig. 1.2.

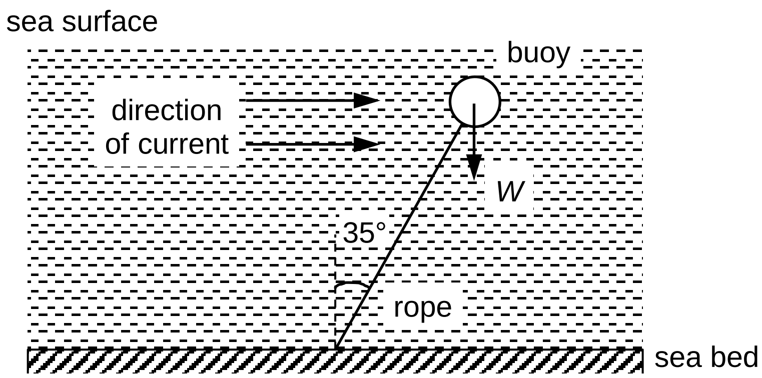

Fig. 1.2 (not to scale)

The buoy may be considered to be acted upon by four forces, tension *T* in the rope, a horizontal force *D*, upthrust *U* and weight of buoy, *W*.

(i) The force *W* is shown in Fig. 1.2.

On Fig. 1.2, sketch and label the forces *T*, *U* and *D*.

[1]

(ii) By resolution of forces, determine the magnitude of the force *D*.

D = ……….……………..…..... N [3]

2 **(a)** **(i)** Define *gravitational potential* at a point.

……………………………………………………………………………………………………

………………………………………………………………………………..……….. [1]

(ii) Use your answer in **(i)** to explain why gravitational potential near an isolated mass is always negative.

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…………………………………………………………………………………………… [2]

(b) An isolated solid sphere of radius r may be assumed to have its mass M concentrated at its centre. The magnitude of the gravitational potential at the surface of the sphere is ϕ.

On Fig. 2.1, sketch the variation of the gravitational potential with distance d from the centre of the sphere for values from $d = r$ to d = 4r.

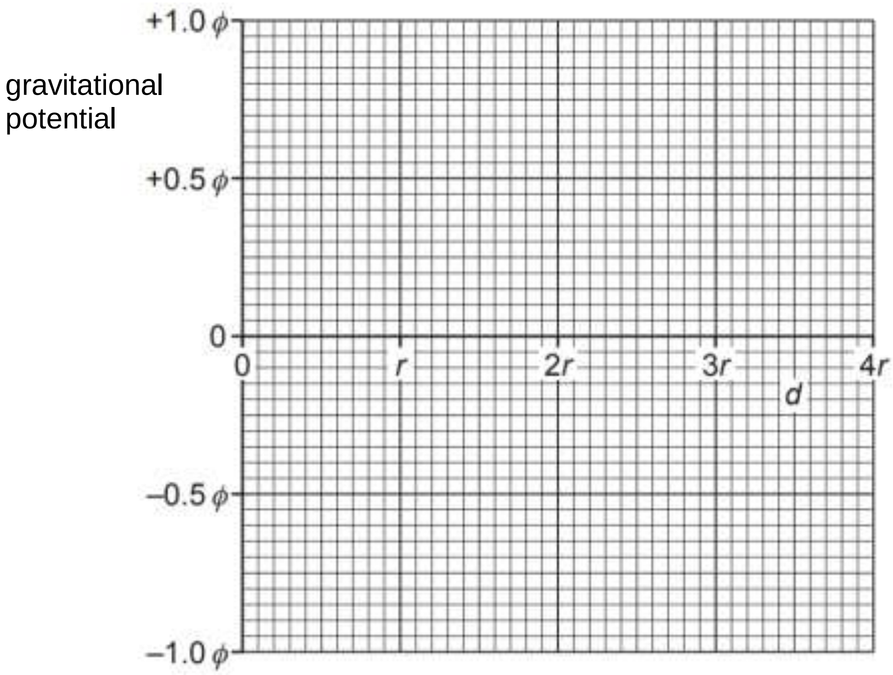

Fig. 2.1

[2]

(c) The sphere in **(b)** is a planet with radius *r* of 6400 km and mass *M* of 6.0×10^{24} kg. The planet has no atmosphere.

A spacecraft of mass 8600 kg is to be put into circular orbit about this planet. It orbits at a distance 4*r* from the centre of the planet.

(i) Show that the speed of the spacecraft at this orbit is 4.0×10^{3} m s^{-1}.

[2]

(ii) The spacecraft then moves to another orbit. Its distance from the centre of the planet changes from 4*r* to 3*r*.

1. Calculate the change in gravitational potential energy of the spacecraft.

change = ………..…………..…..... J [2]

2. By considering changes in gravitational potential energy and in kinetic energy of the spacecraft or otherwise, determine quantitatively whether the total energy of the spacecraft increases, decreases or remains the same.

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……………………………………………………………………………………….. [2]

3 **(a)** State the first law of thermodynamics.

………………………………………………………………………………………………..

………………………………………………………………………………………………..

……………………………………………………………………………………………… [1]

(b) An adiabatic process is one in which no heat is supplied to or extracted from a system.

(i) Determine the change in the internal energy of an ideal gas when the gas expands and does 500 J of work in an adiabatic process.

change in internal energy = ... J [1]

(ii) Hence, describe how the temperature of the gas in **(i)** will change at the end of the adiabatic process.

…………………………………………………………………………………………

………………………………………………………………………………………..... [1]

(c) 2.5 mol of an ideal gas in another system is heated up from 300 K to 500 K without any change in volume.

The molar heat capacity of the gas is numerically equal to the quantity of thermal energy required to raise the temperature of 1.0 mol of the gas by 1.0 K.

(i) Determine the molar heat capacity of the gas.

molar heat capacity = ... J mol^{-1} K^{-1} [3]

(ii) Explain why the molar heat capacity would be larger if the heating takes place at constant pressure rather than at constant volume.

…………………………………………………………………………………………

…………………………………………………………………………………………

……………………………………………………………………………………...….. [2]

4 Fig. 4.1 shows an electron with a horizontal velocity of 5.0×10^7 m s^{-1} entering a region midway between two flat parallel metal plates, each of length 12.0 cm. The plates are separated by a distance of 2.8 cm.

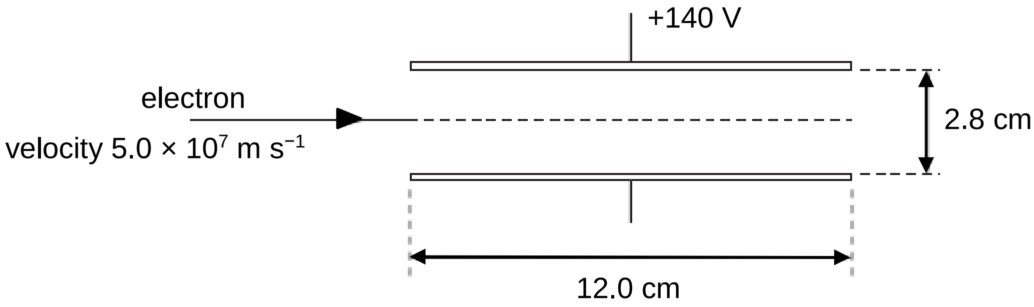


Fig. 4.1

The space between the plates is a vacuum. An upward electric field of field strength 1.40×10^4 N C^{-1} may be assumed to be uniform in the region between the plates and zero outside this region. The potential of the top plate is +140 V.

(a) Determine potential of the bottom plate.

potential = ……….……………..…..... V [2]

(b) For the electron between the plates,

(i) show that the magnitude of the acceleration is 2.5×10^{15} m s^{-2},

[1]

(ii) determine the time to travel a horizontal distance equal to the length of the plates.

time = ………..…………..…..... s [2]

(c) Use your answers in **(b)** to determine whether the electron will hit one of the plates or emerge from between the plates.

…..…………………………………………………………………………………………...

………………………………………………………………………………………….... [3]

5 An electron enters a region R perpendicularly to a uniform magnetic field which is directed into the plane of the paper. The electron's initial velocity is also perpendicular to a uniform electric field which is directed downwards as shown in Fig. 5.1.

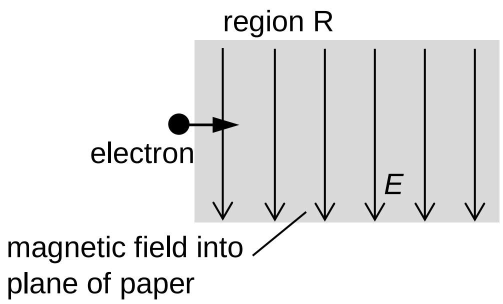
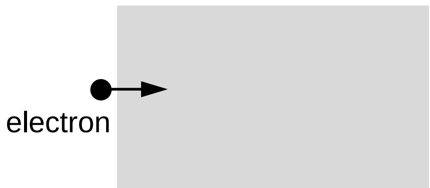


Fig. 5.1

The magnetic flux density B of the magnetic field and electric field strength E are adjusted such that the electron emerges undeviated.

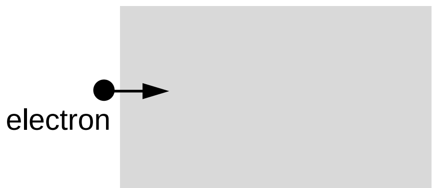
(a) Sketch and describe the path of the electron when

(i) only the magnetic field is turned on,



.... [1]

(ii) only the electric field is turned on.



.... [2]

(b) When the electric field is turned off and a magnetic field of constant flux density *B* is maintained, the electron moves in a circular path of radius 1.2 cm with a speed of 1.8×10^{8} m s^{-1}.

Calculate the magnitude of the electric field strength *E* such that the electron emerges undeviated when the electric field is turned on.

E = ………..………..…..... V m^{-1} [3]

(c) In Fig. 5.1, the electron is replaced with a proton with a speed of 9.0×10^{7} m s^{-1}.

Describe and explain the path of the proton if both *E* and *B* remain at the same magnitude and direction as in **(b)**.

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…………………………………………………………………………………………… [2]

6 **(a)** Explain what is meant by the term 'root-mean-square value' as applied to an alternating current.

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………………………………………………………………………………………………… [1]

(b) An alternating current varies with time as shown in Fig. 6.1.

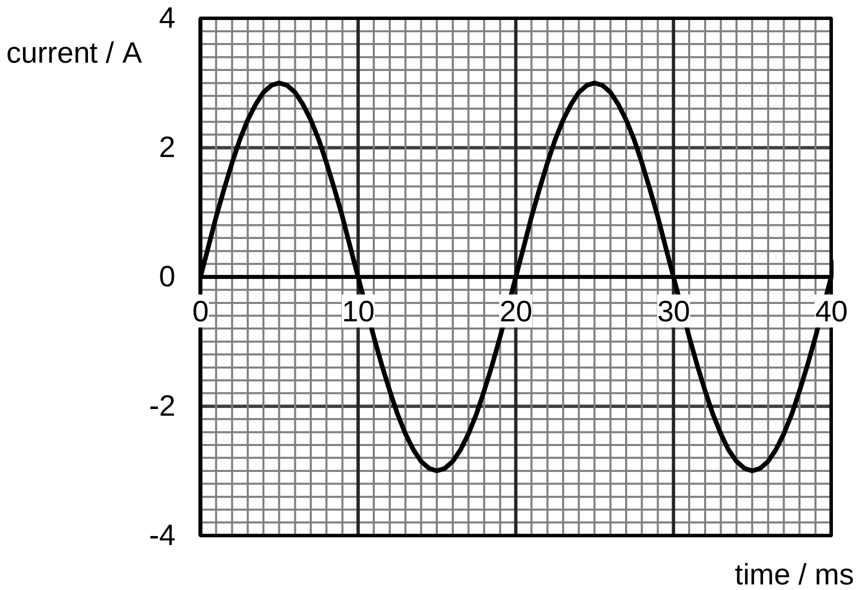

Fig. 6.1

Use the graph to determine, for this alternating current,

(i) the frequency,

frequency = ………..……………..…..... Hz [1]

(ii) the peak value,

peak value = ………..……………..…..... A [1]

(iii) the root-mean-square value.

root-mean-square value = ………..……………..…..... A [1]

(c) On Fig. 6.2, sketch a graph which shows how the power supplied by this current to a resistor of resistance 5.0 Ω varies with time from 0 to 40 ms. Mark on the vertical axis the maximum value of the power.

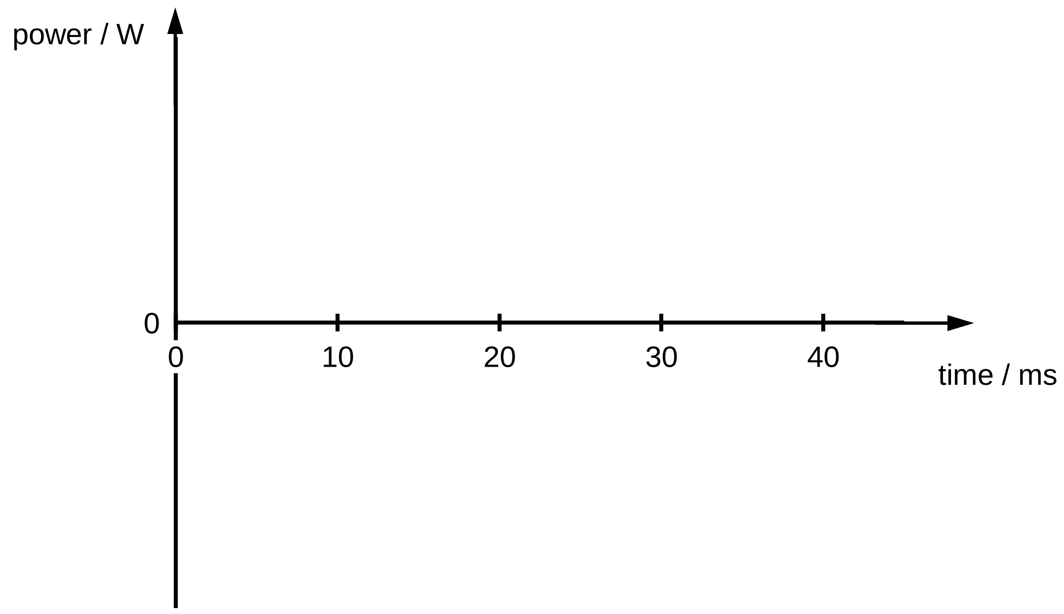

Fig. 6.2

[2]

(d) The current shown in Fig. 6.1 is in the 300-turn primary coil of an ideal transformer. The secondary coil of the transformer has 6000 turns.

Calculate the transformer's peak output current.

peak output current = …………..……………..…..... A [2]

7 (a) (i) State what is meant by a photon.

……………………………………………………………………………………………...………

……………………………………………………………………………………………. [1]

(ii) The first excitation energy of the hydrogen atom is 10.2 eV.

Explain what is meant by this statement.

…………………………………………………………………………………………………

……………………………………………………………………………………………. [1]

(b) Some electron energy levels of a particular atom are illustrated in Fig. 7.1.

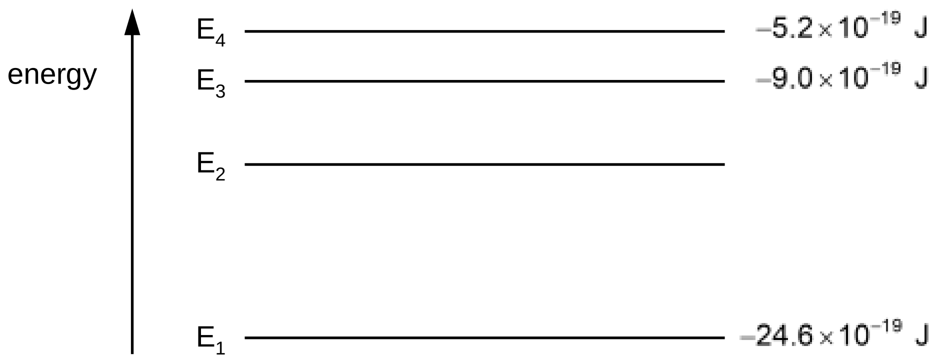

Fig. 7.1 (not to scale)

(i) Calculate the frequency of the electromagnetic radiation emitted when an electron makes a transition between energy levels E_3 and E_1.

frequency = ………..…………..…..... Hz [2]

(ii) The frequency of radiation emitted when an electron makes a transition between energy levels E_3 and E_2 is 1.09×10^{15} Hz.

Determine the wavelength of the electromagnetic radiation when an electron makes a transition between energy levels E_2 and E_1.

wavelength = ………..…………..…..... nm [2]

(c) An X-ray spectrum is shown in Fig. 7.2.

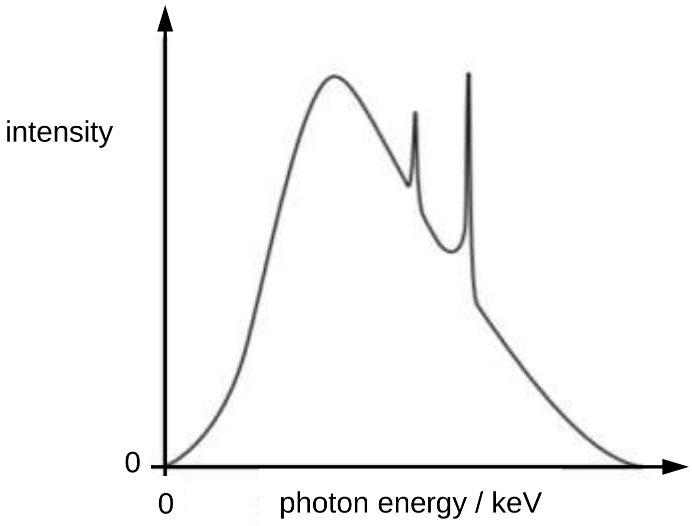

Fig. 7.2

Explain the process which gives rise to the characteristic peaks at certain photon energies.

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……………………………………………………………………………………………..

……………………………………………………………………………………………..

…………………………………………………………………………………………… [3]

Section B

Answer **one** question from this section.

8 **(a)** State what is meant by simple harmonic motion.

....

....

.... [2]

(b) A block of mass m is held on a smooth horizontal surface by means of two identical springs, each of spring constant k. The springs are attached to fixed points, as shown in Fig. 8.1.

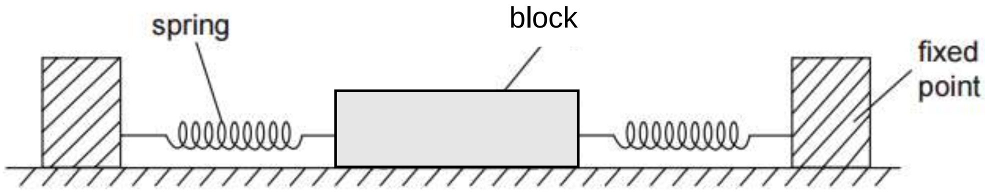

Fig. 8.1

When the block is in equilibrium, the extension of each spring is e.

The block is displaced a small distance x to the right along the axis of the springs. Both springs remain extended.

(i) The block is then released.

Show that the expression for the acceleration of the block is given by

$$a = -\frac{2k}{m}x \ .$$

[3]

(ii) The mass of the block is 600 g and the spring constant of the springs is 50 N m^{-1}.

Determine the frequency of oscillation of the block.

frequency = ... Hz [2]

(iii) If the block has a speed of 1.4 m s^{-1} when passing the equilibrium position, determine the amplitude of the oscillations.

amplitude = ... m [2]

(iv) For the oscillations of the block, determine

1. the total energy E_T ,

E_T = ... J [2]

2. the displacement x at which the potential energy E_P and the kinetic energy E_K of the oscillations are equal.

x = ... m [2]

(v) On Fig. 8.2, sketch graphs, with appropriate values, to show the variation with displacement x of

1. the total energy (label this line E_T),
2. the kinetic energy (label this line E_K),
3. the potential energy (label this line E_P).

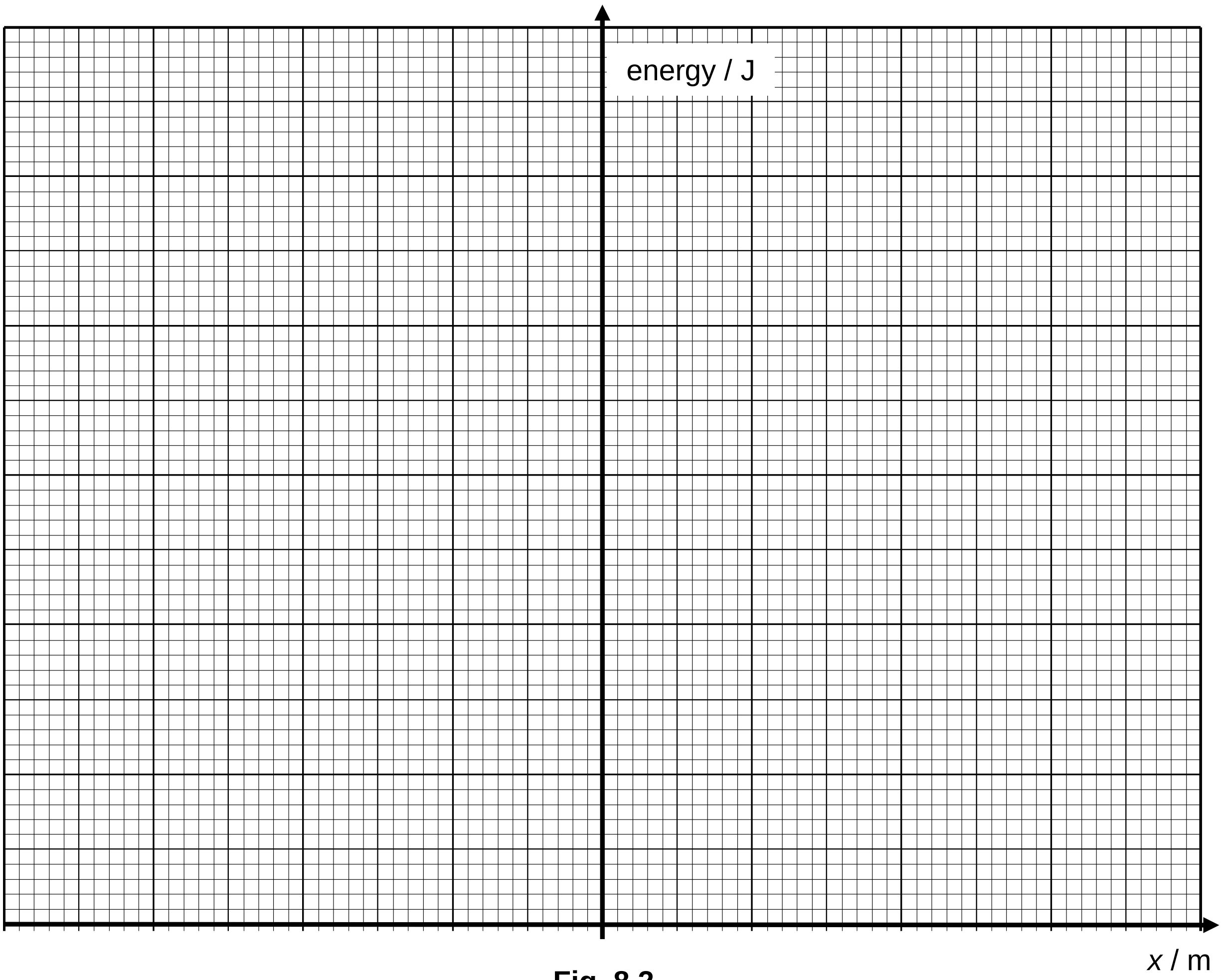

Fig. 8.2

[3]

(vi) State and explain how the oscillation is affected by replacing

1. the block with one of larger mass,

……………………………………………………………………………………………

……………………………………………………………………………………………

…………………………………………………………………………………….... [2]

2. the smooth surface with a rough one.

……………………………………………………………………………………………

……………………………………………………………………………………………

…………………………………………………………………………………….... [2]

9 **(a)** Radioactive decay is a random and a spontaneous process.

Explain what is meant by

(i) *radioactive decay*,

....

.... [2]

(ii) a *random process,*

....

.... [1]

(iii) a *spontaneous process*.

....

.... [1]

(b) In a voyager spacecraft, electrical power is provided using plutonium-238 ($^{238}_{94}Pu$).

Plutonium-238 nuclei emit α-particles of energy 5.48 MeV. The half-life of plutonium-238 is 86.4 years.

Some of the energy of the emitted α-particles is converted into thermal energy and then into electrical energy.

Calculate

(i) the probability per second of the decay of a plutonium-238 nucleus,

probability = ... s^{-1} [3]

(ii) the mass of plutonium-238 required for the energy per unit time of the emitted α-particles to be 2400 W.

Explain your working.

mass = ... kg [6]

(c) Initially, of the 2400 J of energy produced per second by the decay of the plutonium-238, 160 J of electrical energy is generated per second.

(i) Calculate the efficiency of the conversion process.

efficiency = ... % [1]

(ii) Use data in **(b)** to determine the electrical power that is generated after 3.2 years.

power = ... W [2]

(d) Some data for three radioactive isotopes are given in Fig. 9.1.

isotope	half-life	principal radiation
plutonium-238	86.4 years	α-particles
polonium-210	138 days	α-particles
strontium-90	27.7 years	β-particles

Fig. 9.1

Suggest and explain, for a space flight lasting several years, one advantage of plutonium-238 as compared with

(i) polonium-210,

....

....

.... [2]

(ii) strontium-90.

....

....

.... [2]

End of paper