Class	Index Number	Name
20S		

ST. ANDREW'S JUNIOR COLLEGE
JC 2 2021
Preliminary Examination

PHYSICS, Higher 2 **9749/03**

Paper 3 Longer Structured Questions **16th September 2021**
2 hours

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

READ THESE INSTRUCTIONS FIRST

Write your name, index number and Civics Group on all the work you hand in.
Write in dark blue or black pen on both sides of the paper.
You may use a pencil for any diagrams or graphs.
Do not use staples, paper clips, glue or correction fluid.

The use of an approved scientific calculator is expected, where appropriate.

Section **A**
Answer **all** questions.

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

You are advised to spend one and a 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	
Section A	
1	/ 12
2	/ 9
3	/ 10
4	/ 11
5	/ 18
Section B	
6	/ 20
Total	/ 80

This document consists of **21** printed pages including this page.

Data

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

Formulae

uniformly accelerated motion	$s = u t + \frac{1}{2} a t^2$
	$v^2 = u^2 + 2 a s$
work done on/by a gas	$W = p \Delta V$
hydrostatic pressure	$p = \rho g h$
gravitational potential	$\phi = -\frac{Gm}{r}$
temperature	$T/\text{K} = T/°\text{C} + 273.15$
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.	$x = x_o \sin \omega t$
velocity of particle in s.h.m.	$v = v_0 \cos \omega t$
	$v = \pm \omega \sqrt{x_0^2 - x^2}$
electric current	$I = Anvq$
resistors in series	$R = R_1 + R_2 + \ldots$
resistors in parallel	$1/R = 1/R_1 + 1/R_2 + \ldots$
electric potential	$V = \frac{Q}{4\pi\varepsilon_0 r}$
alternating current/voltage	$x = x_o \sin \omega t$
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	$B = \frac{\mu_0 N I}{2r}$
magnetic flux density due to a long solenoid	$B = \mu_0 n I$
radioactive decay	$x = x_o \exp(-\lambda t)$

decay constant $\lambda = \dfrac{\ln 2}{t_{1/2}}$

Section A

Answer **all** questions in the spaces provided

1 **(a)** Phobos is one of the two moons orbiting Mars. Fig. 1.1 shows Phobos and Mars.

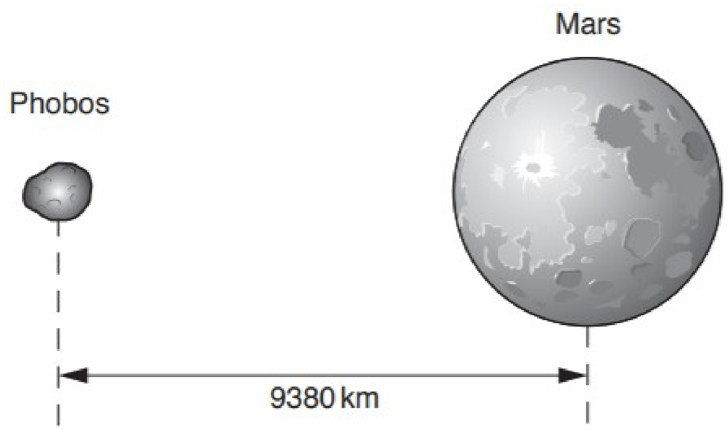


Fig. 1.1

The orbit of Phobos may be assumed to be a circle. The centre of Phobos is at a distance 9380 km from the centre of Mars and it has an orbital speed 2.14×10^3 m s^{-1}.

(i) On Fig. 1.1, draw a cross to show the point where the net force acting on a third mass placed at that point is zero. [1]

(ii) Calculate the mass M of Mars.

M = ………………………….. kg [4]

(b) The Earth and Mars move in elliptical orbits around the Sun. In July 2018, the closest distance between the centre of Mars and the centre of Earth will be 5.8×10^{10} m.

Fig. 1.2 shows the variation of the resultant gravitational field strength *g* between the two planets with distance *r* from the centre of the Earth.

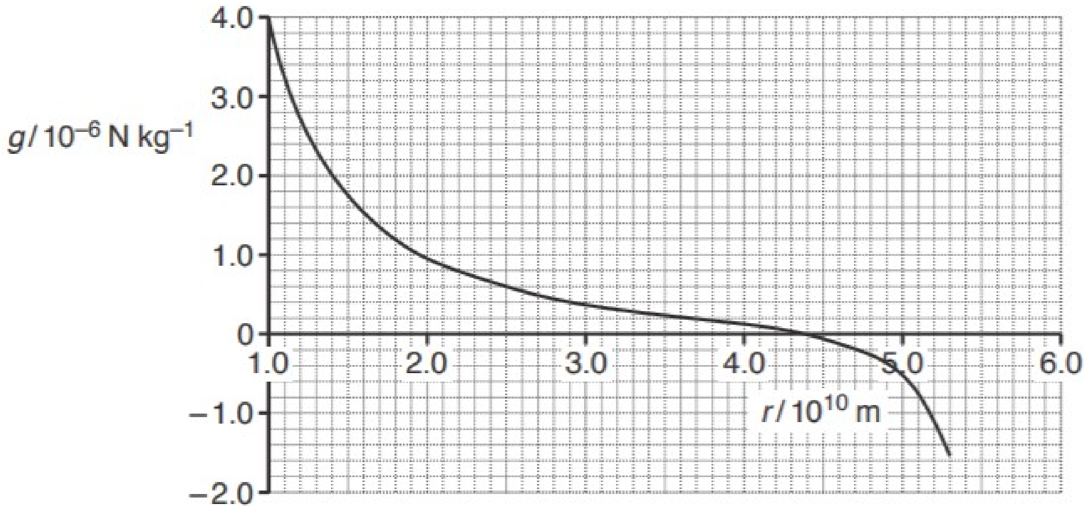


Fig. 1.2

(i) Explain briefly the overall shape of the graph in Fig. 1.2.

……………………………………………………………………………………………

……………………………………………………………………………………………

……………………………………………………………………………………………

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

(ii) Determine the ratio $\dfrac{\text{mass of Earth}}{\text{mass of Mars}}$.

$\dfrac{\text{mass of Earth}}{\text{mass of Mars}}$ = ………………………….. [2]

(iii) After successfully collected some geological samples on the surface of Mars, a space rover with a total mass of 200 kg, wants to return to Earth.

Estimate the minimum energy required to return to Earth, assuming that it starts from the distance of 5.3×10^{10}m from the centre of the Earth.

minimum energy = ………………………….. J [3]

2 **(a)** Explain why a real gas approaches ideal behaviour at very low pressure.

……

……

……

…… [2]

(b) The variation with pressure p of the volume V of a fixed mass of an ideal gas is shown in Fig. 2.1. The gas undergoes a cycle of changes A to B to C to A.

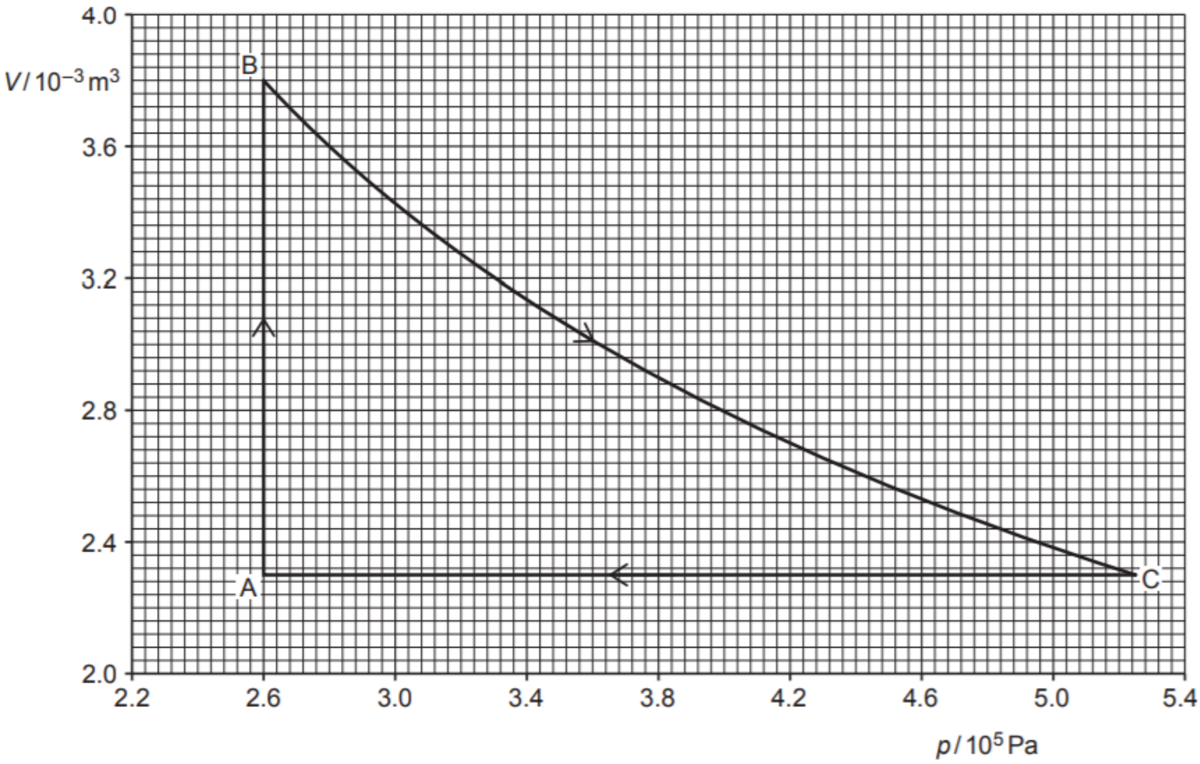


Fig. 2.1

(i) Show that the change from B to C is not an isothermal process.

[1]

(ii) Calculate the work done on the gas during the change A to B and C to A.

work done from A to B = ………………………….. J

work done from C to A = ………………………….. J [2]

(iii) During the change A to B, 1370 J of thermal energy is transferred to the gas. During the change B to C, no thermal energy enters or leaves the gas. The work done on the gas during this change is 550 J.

Complete the table below.

Process	Heat supplied, Q /J	Work done on gas, W / J	Change in internal energy, ΔU / J
A to B	1370		
B to C	0	550	
C to A			

[2]

(iv) The cycle of change is now reversed from A to C to B to A. It is now operating as a heat engine, converting some heat energy to useful work. The efficiency of this heat engine is defined as the

$$\text{Efficiency} = \frac{\text{net work done in a cycle}}{\text{heat absorbed in a cycle}}$$

Calculate the efficiency of this engine.

efficiency = …………………………… [2]

3 **(a)** Define simple harmonic motion

……

……

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

(b) A spring, which hangs from a fixed support, extends by 40 mm when a mass of 0.25 kg is suspended from it.

(i) Determine the spring constant k of the spring.

spring constant = ………………… N m^{-1} [1]

(ii) An additional mass of 0.44 kg is then placed on the spring and the system is set into vertical oscillations with an amplitude of 20 mm.

Given that $a = -$

where a is the acceleration of the mass, x is the displacement of the mass from equilibrium and m is the total mass of the oscillating system.

1. Show that the oscillation frequency is 1.5 Hz. [2]

2. Determine the displacement at which the potential energy and the kinetic energy of the oscillations are equal.

displacement = ……………… mm [2]

3. With both masses still in place, the spring is now suspended from a horizontal support rod that can be made to oscillate vertically at varying frequencies, as shown in Fig. 3.1.

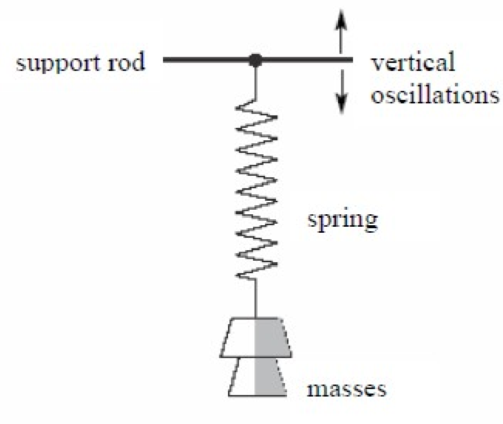


Fig. 3.1

The response of the masses suspended from the spring to the vertical oscillations of the support rod varies with frequency.

Describe and explain the motion of the masses when the support rod oscillates at a frequency from 0.2 Hz to 3.0 Hz.

…………………………………………………………………………………………

…………………………………………………………………………………………

…………………………………………………………………………………………

…………………………………………………………………………………………

…………………………………………………………………………………………

…………………………………………………………………………………………

…………………………………………………………………………………………

………………………………………………………………………………….. [4]

4 **(a)** Define *electric potential* at a point.

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

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

(b) Two point charges A and B are separated by a distance of 12.0cm in a vacuum, as illustrated in Fig. 4.1.

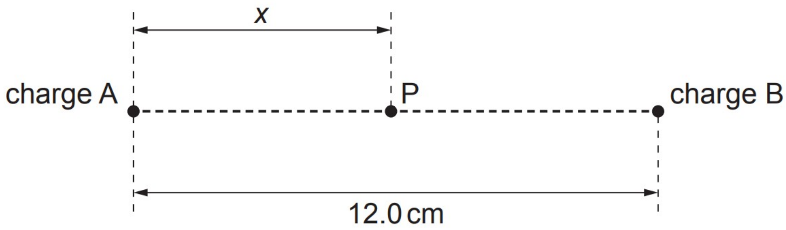


Fig. 4.1

The charge of A is $+2.0 \times 10^{-9}$ C.

A point P lies on the line joining charges A and B. Its distance from charge A is x.

The variation with distance x of the electric potential V at point P is shown in Fig. 4.2.

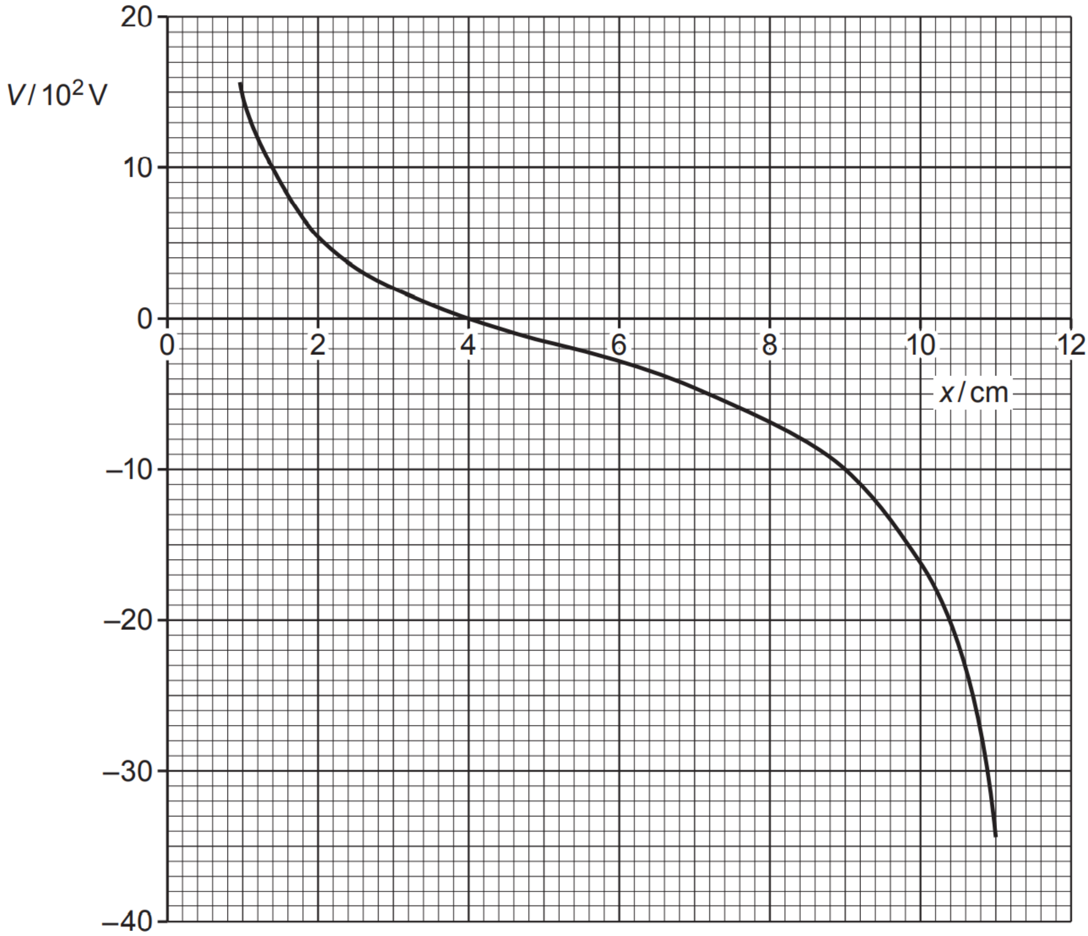


Fig. 4.2

(i) Using Fig. 4.2, determine the charge of B.

charge = …………………………… C [2]

(ii) An alpha-particle (mass $4u$, charge $+2e$) moves along the line joining point charges A and B in Fig. 4.1.

The alpha-particle moves from the position where x = 9.0 cm and just reaches the position where x = 3.0 cm.

Calculate the speed v of the alpha-particle at the position where x = 9.0 cm.

v = …………………………… m s^{-1} [2]

(c) **(i)** State what is meant by an *electric field*.

……………………………………………………………………………………………

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

(ii) State one similarity and one differences between an electric field due to a point charge and the gravitational field due to a point mass.

similarity: ……………………………………………………………………………

……………………………………………………………………………………………

……………………………………………………………………………………………

difference: ……………………………………………………………………………

……………………………………………………………………………………………

……………………………………………………………………………………………

[2]

(d) An isolated solid metal sphere of radius 0.15m is situated in a vacuum, as illustrated in Fig. 4.3.

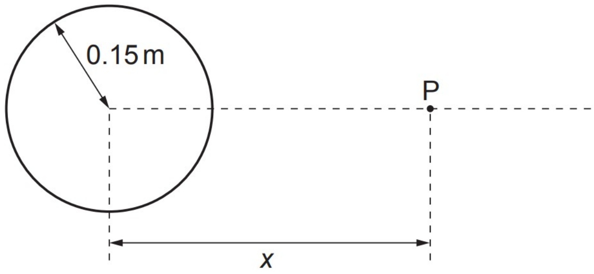


Fig. 4.3

The electric field strength at the surface of the sphere is 84 V m^{-1}.

Determine:

(i) the charge Q on the sphere

charge = …………………………… C [1]

(ii) the electric field strength at a distance 0.10 m from the centre of the sphere.

electric field strength = …………………………… N C^{-1} [1]

5 **(a)** Electrons are accelerated through a potential difference of 15 kV. The electrons collide with a metal target and a spectrum of X-rays is produced. The variation with wavelength λ of the intensity I of the emitted X-ray radiation is shown in Fig. 5.1.

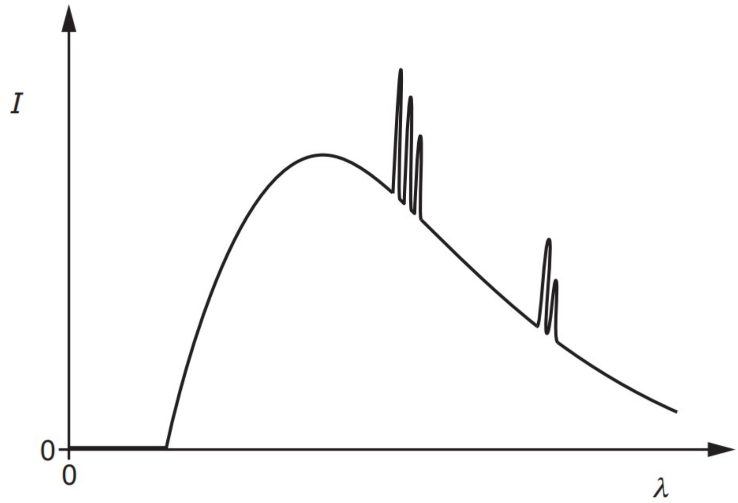


Fig. 5.1

(i) Explain why there is a continuous distribution of wavelengths.

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

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

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

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

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

(ii) Explain why at certain wavelengths, there are narrow peaks of increased intensity.

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

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

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

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

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

(iii) Calculate the wavelength of the highest energy X-ray photon produced.

wavelength = …………………………. m [2]

(iv) Draw, on Fig. 5.1, the spectrum of X-ray produced if the potential difference is increased. [2]

(b) An electron of mass 9.11×10^{-31} kg travelling at 3.00×10^{7} m s^{-1} passes through a narrow slit of width 1.00×10^{-10} m (comparable to the spacing of atoms in a crystal).

(i) Calculate the uncertainty in momentum of the electron along the slit as it passes through the slit.

uncertainty in momentum = …………………………. kg m s^{-1} [2]

(ii) Suggest the significance of this uncertainty.

……………………………………………………………………………………………..

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

(c) Explain how Einstein's photon model of light differs from the classical description of light as an electromagnetic wave in the way it explains

(i) light intensity,

classical explanation: ………………………………………………………………………

…………………………………………………………………………………………………

quantum explanation: ………………………………………………………………………

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

(ii) the absorption of light energy by a metal surface.

classical explanation: ………………………………………………………………………

…………………………………………………………………………………………………

quantum explanation: ………………………………………………………………………

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

(d) The maximum kinetic energy E_{MAX} of electrons emitted from a metal surface is determined for different wavelengths λ of the electromagnetic radiation incident on the surface.

The variation with $\frac{1}{\lambda}$ of E_{MAX} is shown in Fig. 5.2.

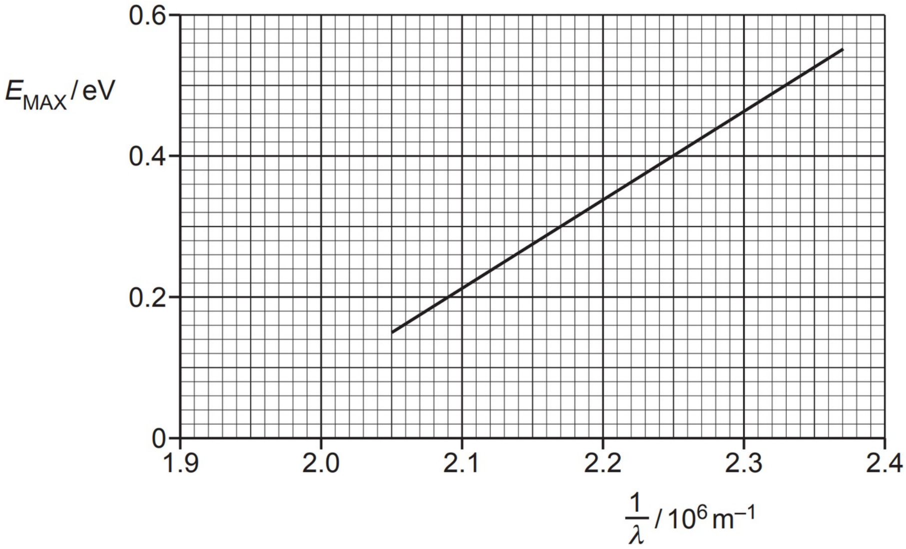


Fig. 5.2

(i) Use Fig. 5.2 to determine the threshold frequency f_0.

f_0 = ………………………….. Hz [2]

(ii) The electromagnetic radiation is now incident on a metal with a larger work function energy than the metal in (d)(i).

On Fig. 5.2, sketch the variation with $\frac{1}{\lambda}$ of E_{MAX}. [1]

Section B

Answer **all** question from this Section in the spaces provided.

6 **(a)** A slice of a conducting material has its face QRLK normal to a uniform magnetic field of flux density B, as illustrated in Fig. 6.1.

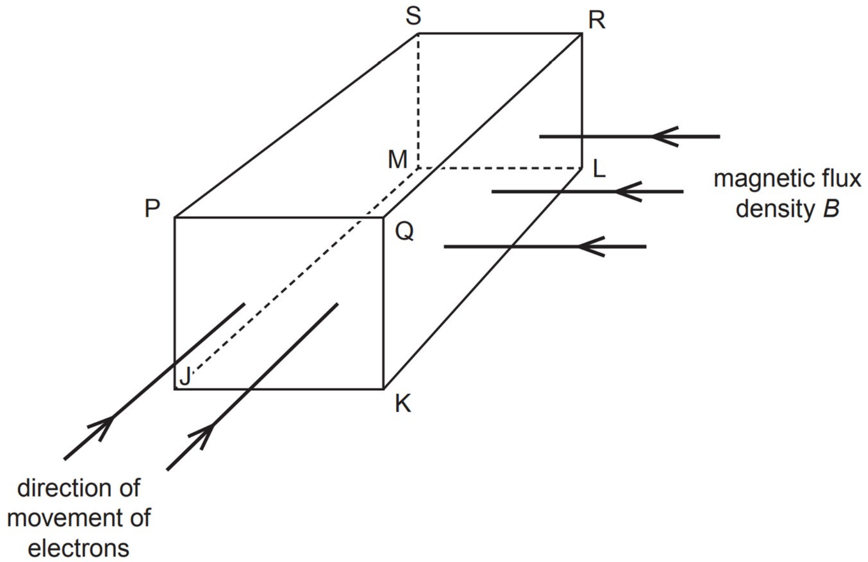


Fig. 6.1

Electrons enter the slice travelling perpendicular to face PQKJ.

(i) For the free electrons moving in the slice:

1. identify the faces, using the letters on Fig. 6.1, between which a potential difference is developed. State its polarity.

face: ………………, polarity: ………………

and face: ………………, polarity: ……………… [2]

2. Explain your answers above.

…………………………………………………………………………………………

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

(ii) Considering the forces acting on the electrons, explain why the potential difference between the faces identified reaches a maximum value.

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

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

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

(iii) The number of free electrons per unit volume n in the slice of conducting material is 1.3×10^{29} m^{-3}.
The thickness PQ of the slice is 0.10 mm.
The magnetic flux density B is 4.6×10^{-3} T.
The current I is 6.3×10^{-4} A.

Using $I = nAve$, where A is the cross-sectional area PQJK, and v is the drift velocity of the electron,

calculate the maximum potential difference across the slice.

maximum potential difference = ……………………….. V [3]

(b) A thin copper sheet X is supported on a rigid rod so that it hangs between the poles of a magnet as shown in Fig. 6.2.

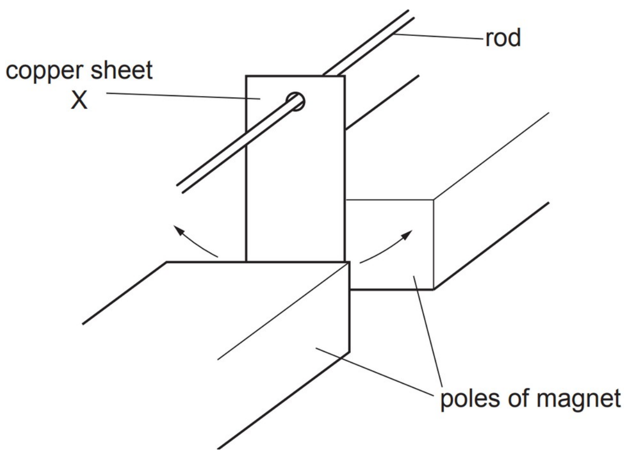


Fig. 6.2

Sheet X is displaced to one side and then released so that it oscillates. A motion sensor is used to record the displacement of X.

A second thin copper sheet Y replaces sheet X. Sheet Y has the same overall dimensions as X but is cut into the shape shown in Fig. 6.3.

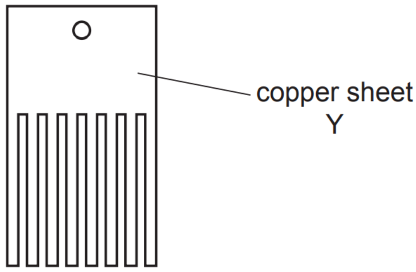


Fig. 6.3

The motion sensor is again used to record the displacement.

The graph in Fig. 6.4 shows the variation with time t of the displacement s of each copper sheet.

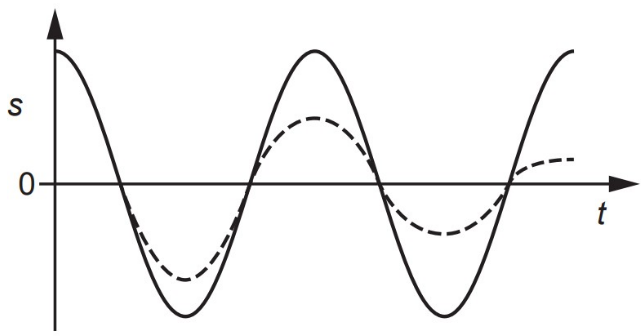


Fig. 6.4

(i) State the name of the phenomenon illustrated by the dashed line.

.... [1]

(ii) Deduce which copper sheet is represented by the dashed line. Explain your answer using the principles of electromagnetic induction.

....

....

....

....

....

....

.... [4]

(c) Fig. 6.5 shows a simple alternating current generator, consisting of a coil of 500 turns rotating at a constant frequency of 50 Hz in a uniform magnetic flux density 5.0×10^{-2} T. The coil has an area of 2.5×10^{-2} m^2.

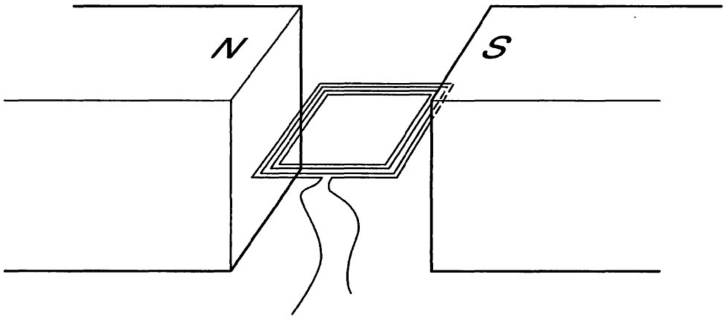


Fig. 6.5

(i) Show that the root-mean-square electromotive force (emf) induced across the coil is 140 V.

[2]

(ii) The output of the generator is connected to the input of a transformer as shown in Fig 6.6. The transformer has 2000 turns in the primary coil and 50 turns on its secondary coil.

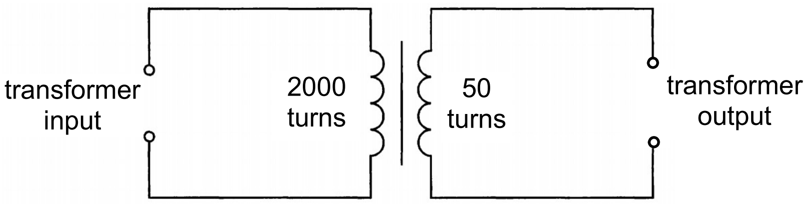


Fig. 6.6

Calculate the maximum voltage across the secondary coil.

maximum voltage across secondary coil = …………………….. V [1]

(iii) The transformer output is connected to four identical diodes W, X, Y and Z which do not conduct in the reverse direction. In the forward direction, each diode conducts when the potential difference across the diode is greater than 0.70 V. This setup, shown in Fig. 6.7, is used to recharge a nickel-cadmium cell with an emf of 1.2 V.

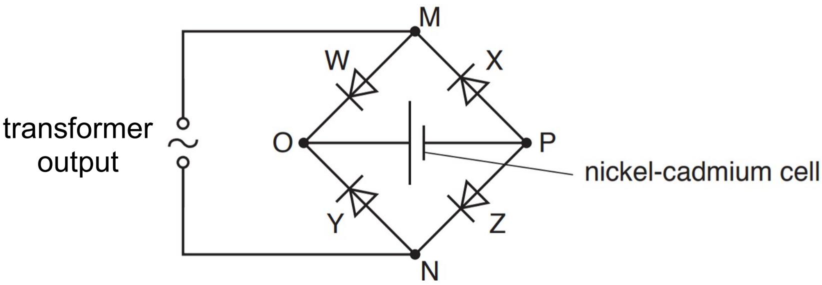


Fig. 6.7

Fig. 6.8 shows how the emf of the transformer output and the current in the cell vary with time. The current in the cell during each half-cycle of the transformer output is always in the same direction.

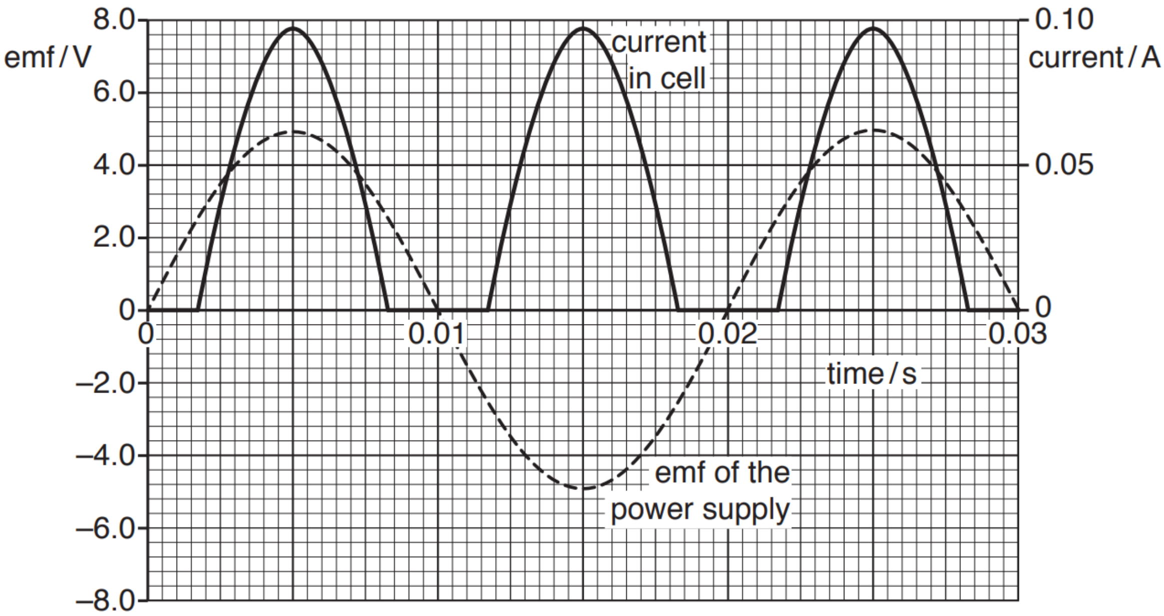


Fig. 6.8

1. At certain times, there is no current in the cell, even though the emf of the power supply is greater than zero. Suggest why, at these times, there is no current in the cell.

....

.... [2]

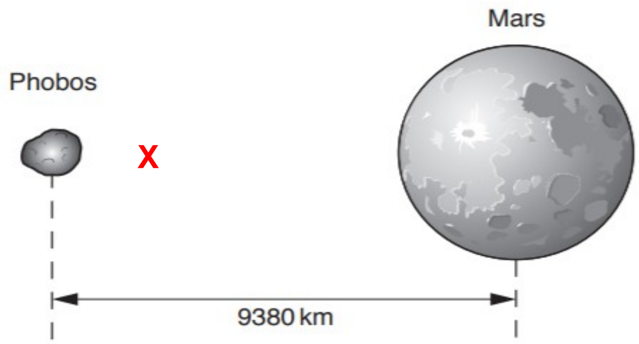
2. Use Fig. 6.8 to estimate the quantity of charge that flows in the cell in a 0.010 s period of time.

charge = …………………………….. C [2]

End of Paper

Solution for 2021 SAJC H2 Physics Prelim Paper 3

1 **(a)** **(i)** Nearer to Phobos [1]



(ii) Gravitational force provides centripetal force [1]

$$\frac{GMm}{r^2} = \frac{m v^2}{r}$$ [1]

$$M = \frac{v^2 r}{G} = \frac{(2.14 \times 10^3)^2 \times (9380 \times 10^3)}{6.67 \times 10^{-11}}$$ [1]

$= 6.44 \times 10^{23}$ kg [1]

(b) **(i)** The g-field of the Earth and Mars are pointing in opposite directions [1]

the magnitude of the Earth's field is greater than that of Mars. The sum of the 2 fields gives a non-symmetrical shape. [1]

(ii) At the point where the net force / field is zero, $r = 4.4 \times 10^{10}$ from the Earth.

Distance from Mars $= 5.8 \times 10^{10} - 4.4 \times 10^{10} = 1.4 \times 10^{10}$ m [1]

$$\frac{G M_E}{r_e^2} = \frac{G M_M}{r_m^2}$$

$$\frac{M_E}{M_m} = \left(\frac{4.4 \times 10^{10}}{1.4 \times 10^{10}}\right)^2 = 9.88$$ [1]

(iii) Min energy = mass × min change in potential [1]

Min change in potential = area from Mars to zero point of g. [1]

Min energy = 20 square × $(0.1 \times 10^{10})(0.2 \times 10^{-6})$ × 200 kg
= 200 × 53000
= 8.0×10^5 J [1]

2 **(a)** (at very low pressure,) gas occupies very large volume / particles are further apart
OR larger volume of gas means (finite) volume of particles becomes negligible [M1]

(large distance between particles) means any (finite) forces between them become negligible [A1]

(b) **(i)** Show that pV at B is not equal to pV at C. [1]

(ii) WD from C to A $= 0$ [1]
WD from A to B $= -2.6 \times 10^5 \times (3.8 - 2.3) \times 10^{-3}$
$= -390$ J [1]

(iii)

Process	Heat supplied, Q /J	Work done on gas, W / J	Change in internal energy, ΔU / J
A to B	1370	**- 390**[0, from bii]	**980**[1]
B to C	0	550	**550**[1]
C to A	**- 1530**[2]	**0**[0, from bii]	**- 1530**[2]

[2, ecf]

(iv) Net work done on gas = −550 + 390 = -160 J
Heat absorbed = 1530
[1m for either net WD or Q, ecf from (iii)]
Efficiency = 160 / 1530 = 0.105 or 10.5% [1]

3 **(a)** Oscillatory motion where the acceleration is proportional to the displacement from the equilibrium position, and directed towards the equilibrium position. [1]

(b) **(i)** mg = kx => k = =

= 61.3 N m^{-1} [1]

(ii) **1.**

a = -

ω^2 = [1]

$2\pi f$ = √()

f = √

= √ [1]

= 1.5 Hz [0]

2.

PE = KE

$\frac{1}{2}m\omega^2x^2$ = $\frac{1}{2}m\,\omega^2(x_o^2 - x^2)$ [1]

x^2 = $x_o^2 - x^2$

$2x^2$ = 0.020^2

x = 0.0141 m

= 14.1 mm [1]

3.

Increasing amplitude from 0.2 Hz to 1.5 Hz [1]

Decreasing amplitude from 1.5 Hz to 3.0 Hz [1]

Maximum energy transfer when driver frequency is equal to spring-mass's natural frequency [1]

Hence, maximum amplitude at 1.5 Hz due to resonance [1]

4 **(a)** work done per unit positive charge [1]
moving a small test charge from infinity to that point [1]

(b) **(i)** $\frac{1}{4\pi\varepsilon_0}\frac{2.0\times10^{-9}}{4.0\times10^{-2}}+\frac{1}{4\pi\varepsilon_0}\frac{Q}{8.0\times10^{-2}}=0$ [1]

Solving, $Q = -4.0 \times 10^{-9}$ C [1]

(ii) Loss in KE = Gain in EPE
$\frac{1}{2}mv^2 = q\Delta V$
$\frac{1}{2}(4 \times 1.66 \times 10^{-27})(v^2) = (2 \times 1.6 \times 10^{-19})(200 - (-1000))$ [1]

Solving, $v = 3.4 \times 10^5$ m s^{-1} [1]

(c) **(i)** a region of space where a charge experiences an electric force [1]

(ii) similarity – any one point from:
- both have an inverse square function
- both decrease with distance
- both are radial

[1]

difference – any one point from:
- gravitational field is always towards the mass
- electric field can be towards or away from the charge

[1]

(d) **(i)** $\frac{1}{4\pi\varepsilon_0}\frac{Q}{0.15^2} = 84$

Solving, $Q = 2.1 \times 10^{-10}$ C [1]

(ii) 0 N C^{-1} (electric field strength = 0 N C^{-1} inside a metal sphere) [1]

5 **(a)** **(i)** X-ray photons produced when electrons decelerate [1]

Photon energy (and hence wavelength) varies continuously since electrons decelerate across a continuous range / lose a continuous range of KE [1]

(ii) Electrons in the inner shell / lower energy level are knocked out and outer shell electrons de-excites causing an emission of a photon [1]

Energy levels are discrete and therefore, energy, and hence wavelength, of photon emitted are discrete [1]

(iii) $eV = hc / \lambda$ [1]

$(1.6 \times 10^{-19})(15000) = (6.63 \times 10^{-34})(3.0 \times 10^{8}) / \lambda$

$\lambda = 8.3 \times 10^{-11}$ m [1]

(iv) lower λ_{min} [1]

Higher intensity everywhere else and same characteristic λ [1]

(b) **(i)** $\Delta x \Delta p \geq h$

$(1.00 \times 10^{-10})(\Delta p) \geq h$ [1]

$\Delta p = 6.63 \times 10^{-24}$ kg m s^{-1} [1]

(ii) Electrons are likely to be scattered through a significant angle **OR** Emerging electrons will be travelling in a range of directions [1]

(c) **(i)** **classical explanation:** intensity proportional to wave amplitude-squared **or** intensity is energy delivered per second per unit area of wave front [1]

(accept depends on / determined by amplitude, but not proportional)

quantum explanation: intensity proportional to the rate of arrival of photons or photons per second [1]

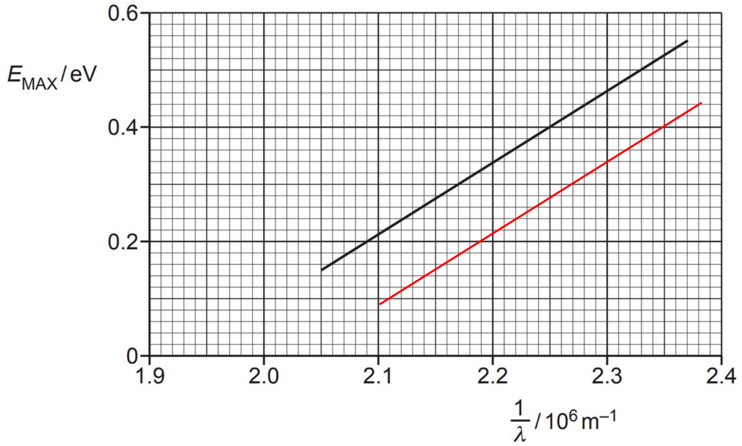
(ii) **classical explanation:** continuous absorption of energy from wave [1]

quantum explanation: absorption in quanta or photons [1]

(d) **(i)** x-intercept = 1.93×10^{6} [1]

$f_0 = c / \lambda_0 = (c)(1 / \lambda_0) = (3.0 \times 10^{8})(1.93 \times 10^{6}) = 5.79 \times 10^{14}$ [1]

(ii) correct line [1]



6 **(a)** **(i)** **1.** face: <u>PQRS</u>, polarity: <u>positive</u>
face: <u>JKLM</u>, polarity: <u>negative</u>

[1 for both correct faces
or 1 for corresponding face & polarity correct]

2. Using <u>Fleming's Left Hand Rule</u>, force on electrons is downward / electrons will accumulate on the face JKLM. [1]

(ii) **(**As charges separates,) an <u>electric field is created</u> between PQRS and JKLM [1]

Maximum value is reached when electric force on electron is equal and opposite to magnetic force on electron. [1]

(iii) Using

$$I = nAvq$$

$$6.3 \times 10^{-4} = (1.3\times10^{29})(d)(0.10\times10^{-3})(E / B)(1.6\times10^{-19})$$ [1 for v = E/B]

$$3.0288 \times 10^{-10} = (d)(E)(1 / B)$$

$$3.0288 \times 10^{-10} = (d)(\Delta V / d)(1 / B)$$ [1 for E = ΔV/d]

$$\Delta V = (3.0288 \times 10^{-10})(B)$$

$$= (3.0288 \times 10^{-10})(4.6 \times 10^{-3})$$

$$= 1.4 \times 10^{-12}\ V$$ [1]

(b) **(i)** Light damping [1]

(ii) Oscillating sheets cuts magnetic flux and hence by Faraday's law, an emf is induced. [1]

Induced emf causes eddy currents to flow in sheets. [1]

By Lenz's law,
either currents in sheets cause resistive force to oppose motion
or currents in sheets dissipate heat energy resulting in loss in KE [1]

Smaller currents in Y or larger currents in X, so dashed line is X. [1]

(c) **(i)** Max emf $= NBA\omega = (500)(5.0 \times 10^{-2})(2.5 \times 10^{-2})(2\pi \times 50) = 196$ V [1]
r.m.s. emf $= 196 / (\sqrt{2})$ [1]
$= 140$ V (Shown)

(ii) max emf across secondary coil = (50 / 2000)(196) = 4.9 V [1]

(iii) **1.** The supply voltage is less than emf of cell (1.2 V) **or** less than voltage needed across diodes (1.4 V) [1]

less than 2.6 V, the sum of emf and voltage need across diodes [1]

2. $3.75 – 4.35 \times 10^{-4}$ C [1]
OR
$3.90 – 4.20 \times 10^{-4}$ C [2]