JC2 PRELIMINARY EXAMINATIONS
Higher 2

CANDIDATE NAME			
CLASS	2T	**INDEX NUMBER**	

PHYSICS

PAPER 3

9646/3
25 August 2016
2 hours

Additional Materials: Answer Papers

READ THESE INSTRUCTIONS FIRST

Write your index number and name on all the work you hand in.
Write in dark blue or black pen on both sides of the paper. **[PILOT FRIXION ERASABLE PENS ARE NOT ALLOWED]**
You may use a soft pencil for any diagrams, graphs or rough working.
Do not use staples, paper clips, highlighters, glue or correction fluid.

Answer **all** questions in **Section A**, and **TWO** out **three** questions in **Section B.**

Circle the question number of the questions that you have attempted in **Section B** in the summary table at the bottom of this page.

A **maximum** of **2 marks** will be **deducted** for wrong significant figures and incorrect/lack of units.

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

DIFFICULTY		
L1	L2	L3

SKILL			
S1	S2	S3	S4

FOR EXAMINER'S USE	
Q1	/ 6
Q2	/ 6
Q3	/ 6
Q4	/ 12
Q5	/ 10
SECTION A	/ 40
Q6	/ 20
Q7	/ 20
Q8	/ 20
SECTION B	/ 40
SF/UNITS	
TOTAL	/ 80

PHYSICS DATA:

speed of light in free space,	c	=	3.00×10^{8} m s^{-1}
permeability of free space,	μ_0	=	$4\pi \times 10^{-7}$ H m^{-1}
permittivity of free space,	ε_0	=	8.85×10^{-12} F m^{-1}
			$\approx (1/(36\pi)) \times 10^{-9}$ F m^{-1}
elementary charge,	e	=	1.60×10^{-19} C
the Planck constant,	h	=	6.63×10^{-34} J s
unified atomic mass constant,	u	=	1.66×10^{-27} kg
rest mass of electron,	m_e	=	9.11×10^{-31} kg
rest mass of proton,	m_P	=	1.67×10^{-27} kg
molar gas constant,	R	=	8.31 J K^{-1} mol^{-1}
the Avogadro constant,	N_A	=	6.02×10^{23} mol^{-1}
the Boltzmann constant,	k	=	1.38×10^{-23} mol^{-1}
gravitational constant,	G	=	6.67×10^{-11} N m^{2} kg^{-2}
acceleration of free fall,	g	=	9.81 m s^{-2}

PHYSICS FORMULAE:

uniformly accelerated motion,	s	=	$u t + ½ a t^2$
	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,	ϕ	=	$-G m / r$
displacement of particle in s.h.m.	x	=	$x_0 \sin \omega t$
velocity of particle in s.h.m.	v	=	$v_0 \cos \omega t$
		=	$\pm \omega \sqrt{x_0^2 - x^2}$
mean kinetic energy of a molecule of an ideal gas,	E	=	$\frac{3}{2} kT$
resistors in series,	R	=	$R_1 + R_2 + \ldots$
resistors in parallel,	$1/R$	=	$1/R_1 + 1/R_2 + \ldots$
electric potential,	V	=	$Q / 4 \pi \varepsilon_0 r$
alternating current / voltage,	x	=	$x_0 \sin \omega t$
transmission coefficient	T	=	$\exp(-2kd)$
	where k	=	$\sqrt{\frac{8\pi^2 m(U-E)}{h^2}}$
radioactive decay,	x	=	$x_0 \exp(-\lambda t)$
decay constant,	λ	=	$\frac{0.693}{t_{\frac{1}{2}}}$

SECTION A (40 marks)

Answer all questions in Section A.

1 A ski jumper lands 96 m from his take off point after taking off at an angle θ to the horizontal as shown in Fig. 1.1 below. The slope is at an angle of 40° and the jumper is in the air for 4.3 s.

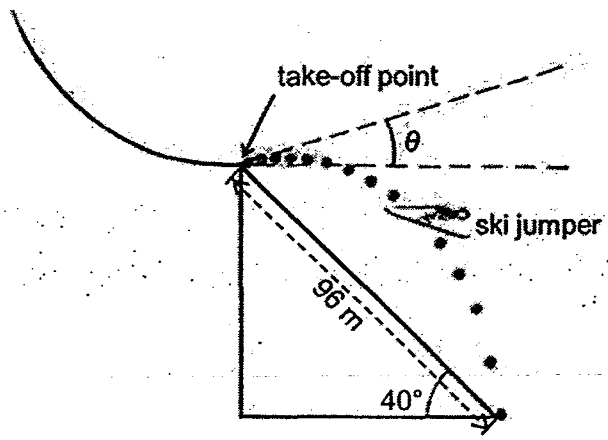

Fig. 1.1

(a) Assuming that air resistance is negligible, determine

(i) the vertical distance from take-off to landing, and,

vertical distance = ... m **[1]**

(ii) the vertical component of the take-off velocity.

velocity = ... m s^{-1} **[2]**

(b) In practice, air resistance is not negligible.

Describe qualitatively the effect of air resistance on the variation, if any, of the component of velocity

(i) in the horizontal direction, and,

....

.... **[1]**

(ii) in the vertical downward direction.

....

....

....

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

....

.... [1]

(b) An ideal gas undergoes a cycle of change, A → B → C → A, as shown in Fig. 2.1.

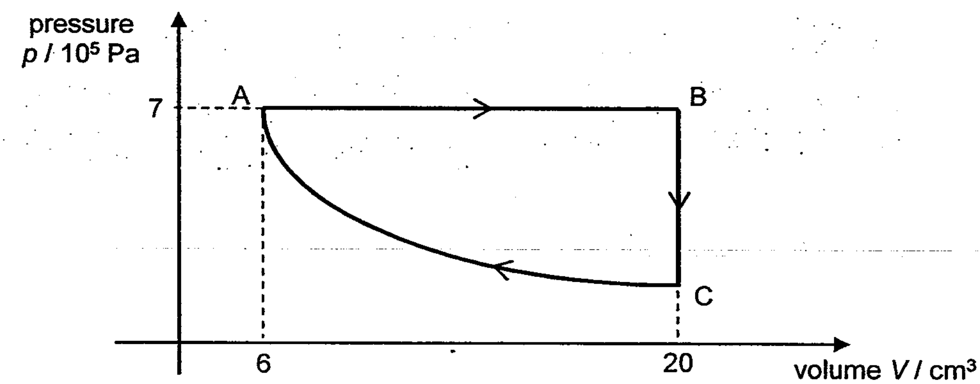

Fig. 2.1

(i) Calculate the work done by the gas during the change A → B.

work done by the gas = ... J **[2]**

(ii) Fig. 2.2 is a table of energy changes during one complete cycle. Complete Fig. 2.2.

section of cycle	heat supplied to gas / J	work done on gas / J	increase in internal energy of gas / J
A → B			
B → C	-18.0		
C → A	0.00	3.30	

[3]

Fig. 2.2

3 A charged particle of mass m and charge $-q$ is travelling through a vacuum at a constant speed v. It enters a uniform magnetic field of flux density B. The initial angle between the direction of motion of the particle and the direction of the magnetic field is 90° as shown in Fig. 3.1 below.

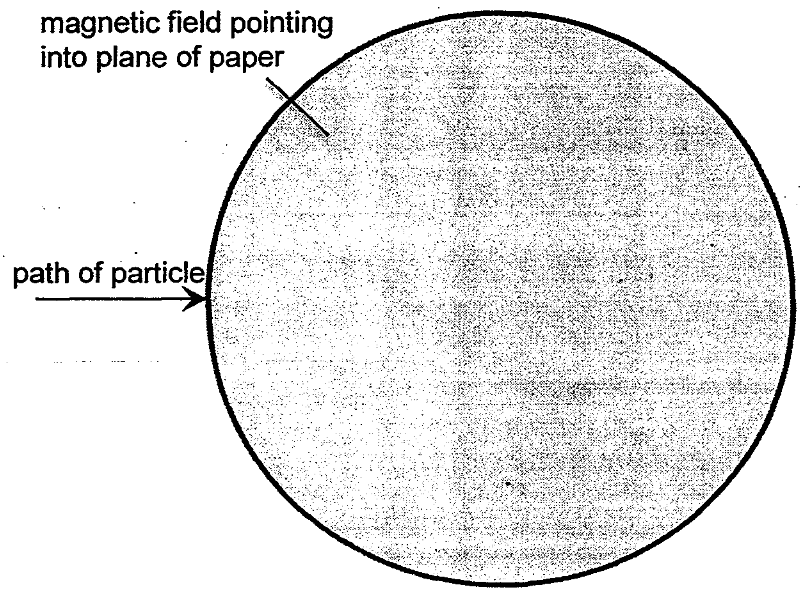

Fig. 3.1

(a) Explain why the path of the particle in the magnetic field is the arc of a circle with a fixed radius.

....

....

....

.... **[3]**

(b) The radius of the arc in **(a)** is r. Show that the specific charge of the particle (which is defined as the ratio $\frac{q}{m}$ of its charge to its mass) is given by the expression

$$\frac{q}{m} = \frac{v}{Br}.$$

[1]

(c) Sketch the path of the particle as it enters and subsequently emerges from the field on Fig. 3.1 **[2]**

4 (a) When an electric current is passed through a thin p-type semiconductor slab placed in a uniform magnetic field, a potential difference is set up across the sides of the slab. The voltage measured across both sides is known as the Hall Voltage.

Fig. 4.1 shows a slab with an electric current I passing through it placed perpendicularly to a magnetic field B and the voltmeter measures a Hall Voltage V_H across the sides X and Y.

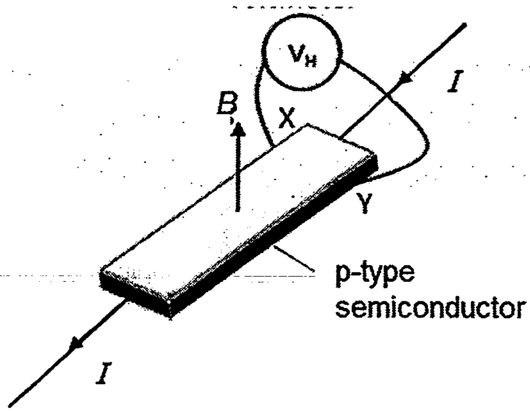

Fig 4.1

(i) Using band theory, explain why a p-type semiconductor has a higher conductivity than an intrinsic semiconductor.

....

....

....

....

....

.... **[3]**

(ii) State which side of the slab, X or Y, is at a higher potential.

.... **[1]**

(iii) Explain the reasoning for your answer in part **(ii)**.

....

....

....

.... **[2]**

(b) Describe the formation of the depletion region in a p-n junction.

....

....

....

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....

....

....

....

....

....

.... **[4]**

(c) State **two** conditions required for the production of a consistent laser beam.

....

....

....

.... **[2]**

5 **(a)** State **one** similarity and **one** difference between the properties of electric fields and gravitational fields.

similarity:..

....

difference:..

.... [2]

(b) An oil drop of mass 1.98×10^{-12} g and a charge of -1.12×10^{-18} C is initially at rest between two parallel vertical plates placed 25.0 cm apart. The plates are connected to an electrical source with an e.m.f. of 2.50 kV as shown in Fig. 5.1.

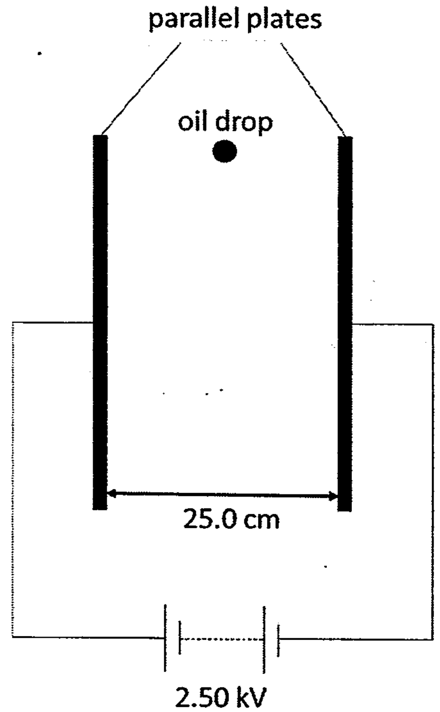

Fig. 5.1

(i) Show that the magnitude of the electric force acting on the oil drop when it is between the plates is 1.12×10^{-14} N.

[2]

(ii) Hence, determine the magnitude and direction of the initial acceleration of the oil drop.

initial acceleration = ... m s^{-2}

direction = ... **[4]**

(iii) State and explain whether the magnitude and direction of the acceleration obtained in part **(ii)** will remain constant throughout the entire motion of the oil drop as it moves between the plates.

....

....

....

.... **[2]**

SECTION B (40 marks)

Answer TWO out of THREE questions in Section B.

6 (a) Give three distinguishing characteristics between the *radioactive decay* and the *fission* of a nucleus.

....

....

....

....

....

....

....

.... **[3]**

(b) Plutonium-239 ($^{239}_{94}Pu$) is the plutonium isotope that is most useful in making nuclear weapons, and it is produced in varying quantities in virtually all operating nuclear reactors.

(i) Part of the plutonium manufacture process involves the most common isotope of uranium, Uranium-238 ($^{238}_{92}U$) absorbing a neutron. Write a nuclear equation that represents this process.

[1]

(ii) The product formed in the process in **(b)(i)** then quickly undergoes two subsequent beta decays to plutonium. An intermediate radioactive isotope X is formed after the first beta decay.

By considering the nuclear equation for this first beta decay, determine the mass and atomic numbers of X. Show your working clearly.

mass number = ...

atomic number = ... **[4]**

(iii) Hence, write the nuclear equation that represents the second beta decay.

(iv) A plutonium bomb named "Fat Man" was dropped on Nagasaki on August 9, 1945 ending World War II. At the point of detonation, the following nuclear reaction occurred, incurring a sustained chain reaction process.

$$^{239}_{94}Pu + ^{1}_{0}n \rightarrow ^{100}_{42}Mo + ^{135}_{52}Te + 4^{1}_{0}n$$

Fig. 6.1 lists the binding energy (BE) per nucleon of each of the nuclides in this nuclear reaction.

Nuclide	BE per nucleon / MeV
$^{239}_{94}Pu$	7.56
$^{100}_{42}Mo$	8.61
$^{135}_{52}Te$	8.35

Fig. 6.1

It is estimated that 5.88 kg of plutonium in Fat Man was needed to cause the deadly explosion. Determine the energy released if only 17% of the plutonium undergoes nuclear reaction during the explosion.

(c) Plutonium-239 is an alpha emitter with a half-life of 24100 years.

(i) Calculate the amount of time for the number of Plutonium-239 isotopes in a sample to reduce by 30%.

amount of time = ... years **[3]**

(ii) Suggest why plutonium-239 is more dangerous to the body when inhaled as compared to being an external radiation source.

....

....

....

....

....

.... **[3]**

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

....

.... **[2]**

(b) Describe how, for a simple harmonic motion, the direction of acceleration varies with the direction of the velocity.

....

....

....

.... **[2]**

(c) A smooth ball of mass *m* is held between two fixed points A and B by means two similar springs, each of spring constant *k*, as shown in Fig. 7.1.

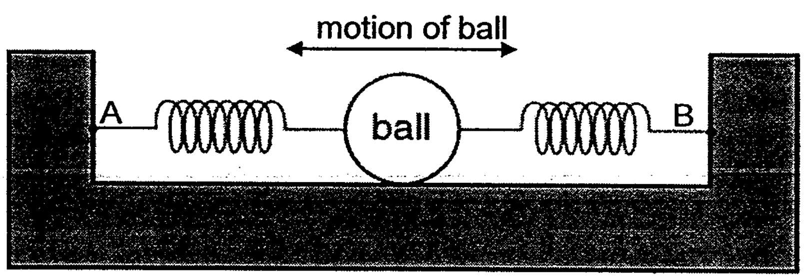

Fig. 7.1

The ball is free to oscillate along the straight line AB on the smooth surface.

When the ball is in equilibrium, the extension of each spring is *e*. The ball is then displaced a small distance *x* to the right along the axis of the springs.

(i) Show that the magnitude *F* of the restoring force acting on the ball is given by

$$F = 2kx$$

(ii) The ball is then released. Show that the acceleration a of the ball is given by

$$a = -\frac{2kx}{m}$$

[2]

(iii) The mass m of the ball is 900 g and the spring constant k is 120 N m^{-1}. By comparing the equations of an object executing simple harmonic motion and that in **(c)(ii)**, determine for the ball,

1. the frequency of oscillation,

frequency = ... Hz **[3]**

2. the amplitude if the maximum acceleration of the ball is 5.2 m s^{-2}, and,

amplitude = ... m **[2]**

3. the maximum kinetic energy of the ball.

maximum kinetic energy = ... J **[2]**

(iv) A student investigates the variation in the kinetic energy, E, of the oscillating ball as shown in Fig. 7.2.

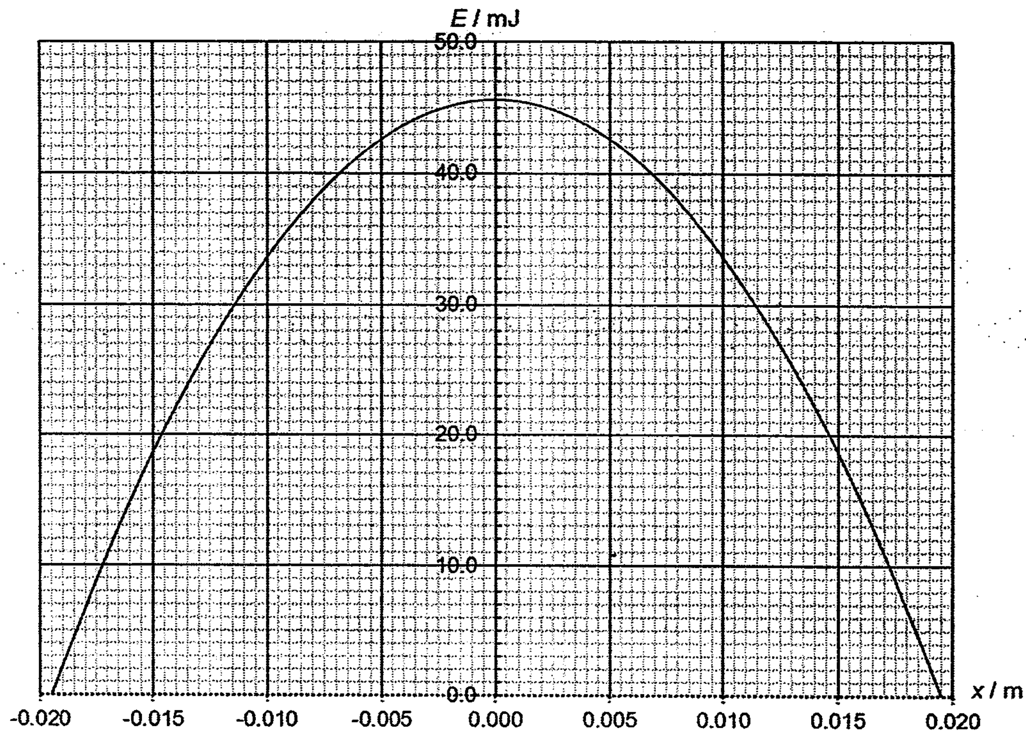

Fig. 7.2

The student repeats the investigation but with a smaller amplitude. The maximum value of E is now found to be 15 mJ.

Use Fig. 7.2 to determine the change in the amplitude. Explain your working.

change in the amplitude = ... m **[3]**

(d) The experiment was repeated with a rough ball instead. Suggest and explain the effect it would have on the ball's oscillatory motion.

....

.... **[2]**

8 (a) A rectangular coil is rotating about an axis between two magnets with uniform angular velocity ω due to the action of an external applied force. The uniform magnetic field B between the two magnets is 0.90 T. The coil is rotating at 40 revolutions per second. The number of turns N of the coil is 40. The cross-sectional area A of the coil is 3.0 m^2. A current is found going through the resistor R of resistance 30 Ω. Fig. 8.1 shows the instant when the plane of the coil is in a horizontal position.

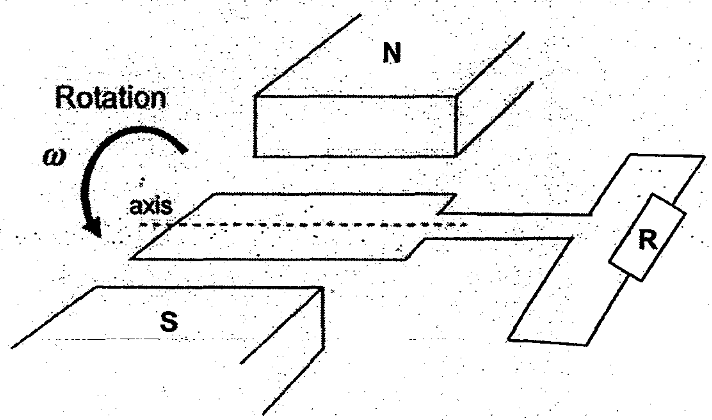

Fig. 8.1

(i) Explain how the current flowing through the resistor R is formed.

....

....

....

.... [3]

(ii) On Fig. 8.1, indicate the direction of flow of current and explain your reasoning.

....

....

....

.... [3]

(iii) The coil starts rotating when it is in the position shown in Fig. 8.1.

1. Determine the period of the rotation of the coil.

2. Determine the maximum current flowing through the coil during the rotation.

maximum current = ... A **[2]**

3. Sketch a graph on Fig. 8.2 showing the variation with time of current through the resistor. Show the values of period and peak current on the graph.

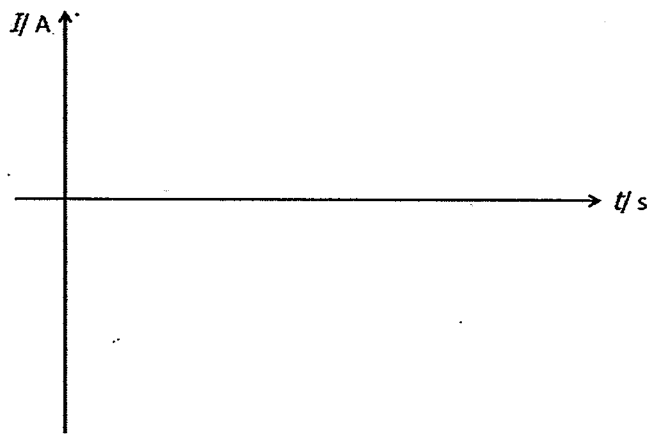

Fig. 8.2

[2]

(iv) Determine the mean power through the resistor R.

mean power = ... W **[3]**

(b) The primary coil of a transformer has 1500 turns and is connected via cables to a 250 $V_{r.m.s.}$ supply. The secondary coil has 50 turns and is connected, through a switch and a diode, to a 10.0 V rechargeable battery, as illustrated in Fig. 8.3.

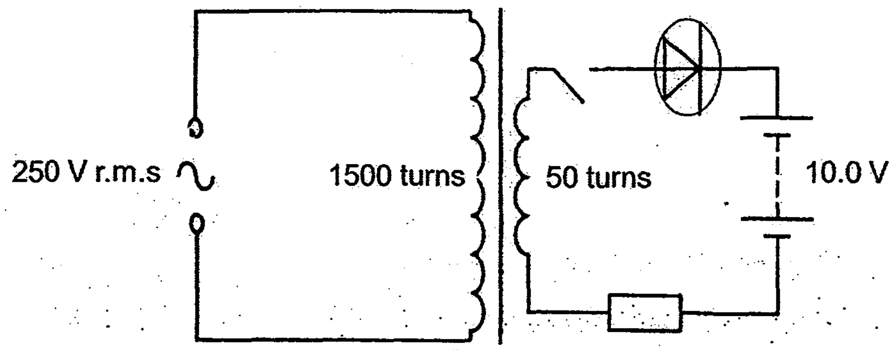

Fig. 8.3

(i) Initially, the switch is open. Considering both the transformer and the diode to be ideal, calculate the r.m.s. potential difference across the secondary coil.

$V_{r.m.s}$ = ... V **[2]**

(ii) The switch is now closed to recharge the battery.

1. Suggest why the diode is necessary in the secondary circuit.

....

....

.... **[2]**

2. Suggest why the resistor is necessary in the secondary circuit.

....

.... **[1]**

CATHOLIC JUNIOR COLLEGE
JC2 PRELIMINARY EXAMINATIONS
Higher 2

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PHYSICS [SOLUTIONS] **9646/3**

PAPER 3 **25 August 2016**
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radioactive decay,	x	=	$x_0 \exp(-\lambda t)$
decay constant,	λ	=	$\frac{0.693}{t_{\frac{1}{2}}}$

SECTION A (40 marks)

Answer all questions in Section A.

1 A ski jumper lands 96 m from his take off point after taking off at an angle θ to the horizontal as shown in Fig. 1.1 below. The slope is at an angle of 40° and the jumper is in the air for 4.3 s.

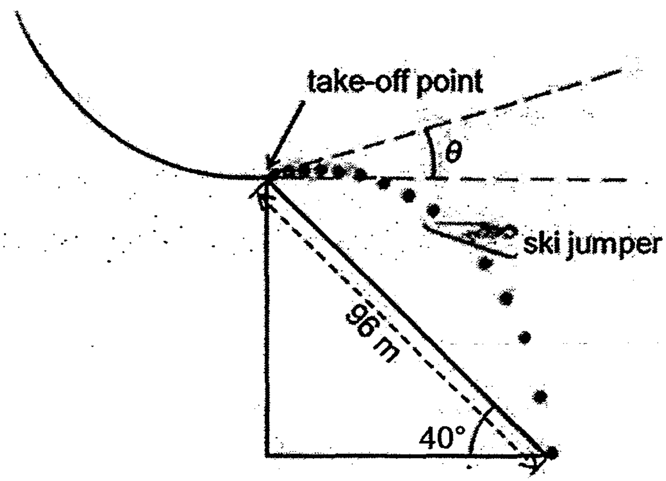


Fig. 1.1

(a) Assuming that air resistance is negligible, determine

(i) the vertical distance from take-off to landing,

vertical distance = ... m **[1]**

Solution:
$s_y = 96.0 \sin 40° = 61.7$ m (or 62 m) **B1**

(ii) the vertical component of the take-off velocity.

velocity = ... m s^{-1} **[2]**

Solution:

Taking upwards as positive,
$S_y = u_y t + ½ at^2$
$-61.7 = u_y(4.3) - ½(9.81)(4.3)^2$ **M1**
$4.3 u_y = 90.69 - 61.7 = 28.99$
$u_y = 6.74$ m s^{-1} **A1**

(b) In practice, air resistance is not negligible.

Describe qualitatively the effect of air resistance on the variation, if any, of the component of velocity in

(i) the horizontal direction.

[1]

Solution:
The magnitude of the velocity in the horizontal direction **decreases at a decreasing rate.**

(This is because air resistance becomes smaller with time due to the decreasing horizontal speed.) **B1**

(ii) the vertical downward direction.

[2]

Solution:
Component of velocity in the vertical direction at the start equals zero (when ski jumper is at highest height).

The vertical downward velocity's **magnitude increases** B1
at a decreasing rate. B1

(At the start, it increases at the acceleration of free fall, thereafter, it increases slower than the acceleration of free fall. (This is because the air resistance opposing the velocity increases as the object's speed increases, thus reducing the resultant downward force with time.)

2 (a) State the first law of thermodynamics.

[1]

Solution:
The increase in internal energy of a system is equal to sum of the thermal energy supplied to the system and external work done on the system. B1

(b) An ideal gas undergoes a cycle of change, A → B → C → A, as shown in Fig. 2.1.

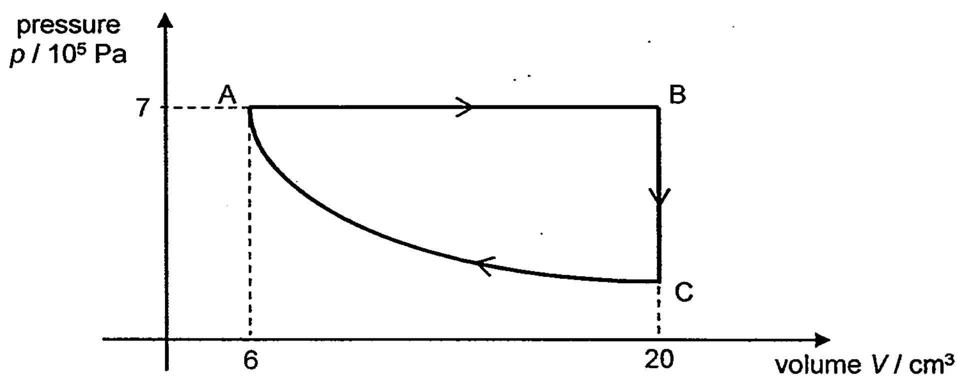


Fig. 2.1

(i) Calculate the work done by the gas during the change A → B.

work done by the gas = ... J **[2]**

Solution:

$W = p\Delta V$

$W = (7\times10^5)[(20-6)\times10^{-6}]$ M1

$W = 9.80$ J A1

(ii) Fig. 2.2 is a table of energy changes during one complete cycle. Complete Fig. 2.2.

section of cycle	heat supplied to gas / J	work done on gas / J	increase in internal energy of gas / J
A → B			
B → C	-18.0		
C → A	0.00	3.30	

[3]

Fig. 2.2

Solution:

section of cycle	heat supplied to gas / J	work done on gas / J	increase in internal energy of gas / J
A → B	ΔU=Q+W. Hence Q=ΔU-W= 14.7- (-9.80)=24.5	-9.80 (From b(i). Since it is "on" gas, a negative sign is necessary.)	As it is a cyclic process, the sum of increase of internal energy is 0. Therefore, ΔU=0+18.0-3.30=14.7
B → C	-18.0	As B → C is an isovolumetric process, W = 0.00	ΔU=Q+W=-18.0 +0.00=-18.0
C → A	0.00	3.30	ΔU=Q+W=0.00+3.30 =3.30

3 A charged particle of mass m and charge $-q$ is travelling through a vacuum at a constant speed v. It enters a uniform magnetic field of flux density B. The initial angle between the direction of motion of the particle and the direction of the magnetic field is 90° as shown in Fig. 3.1 below.

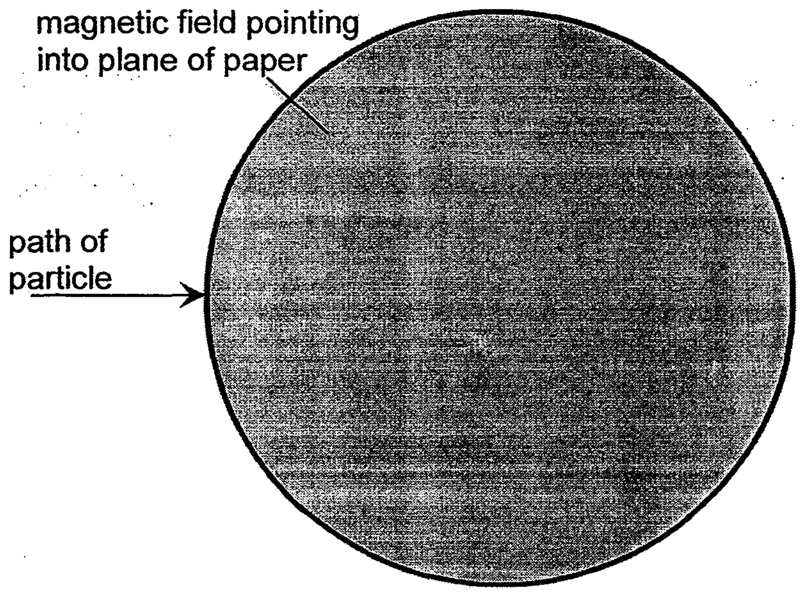


Fig. 3.1

(a) Explain why the path of the particle in the magnetic field is the arc of a circle with a fixed radius.

[3]

The magnitude of the magnetic force due to magnetic field is constant. **B1**

The direction of this force is always normal to the direction of its motion/velocity. **B1**

This force provides the centripetal force hence an arc of a circle is the path it takes **B1**

(b) The radius of the arc in **(a)** is r. Show that the specific charge of the particle (which is defined as the ratio $\frac{q}{m}$ of its charge to its mass) is given by the expression

$$\frac{q}{m} = \frac{v}{Br}$$

[1]

The magnetic force provides the centripetal force

$$Bqv = \frac{mv^2}{r}$$ **M1**

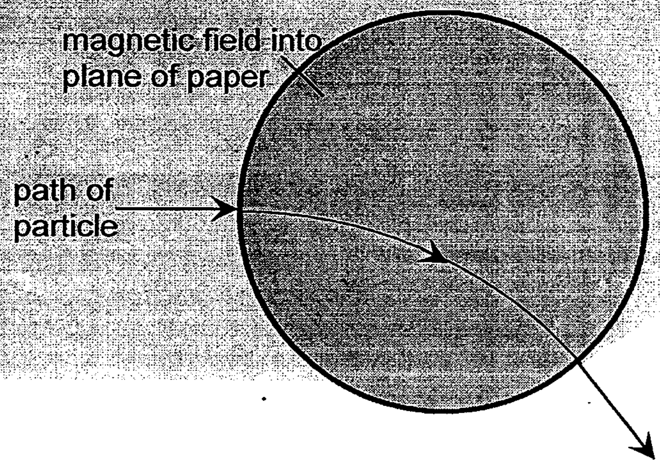
Hence, $$\frac{q}{m} = \frac{v}{Br}$$

A0

(c) Sketch the path of the particle as it enters and subsequently emerges from the field on Fig. 3.1

Path upon entering and exiting the field must be tangent to arc of the circular path in the magnetic field. **M1**

Sketch of path in the field is a curved path, with constant radius, and in the direction the towards bottom of page. **A1**



4 (a) When an electric current is passed through a thin p-type semiconductor slab placed in a uniform magnetic field, a potential difference is set up across the sides of the slab. The voltage measured across both sides is known as the Hall Voltage.

Fig. 4.1 shows a slab with an electric current I passing through it placed perpendicularly to a magnetic field B and the voltmeter measures a Hall Voltage V_H across the sides X and Y.

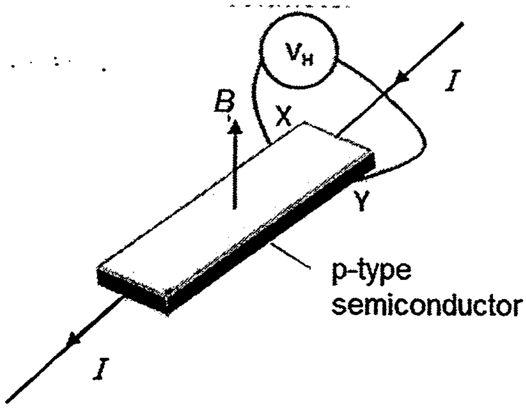


Fig 4.1

(i) Using band theory, explain why a p-type semiconductor has a higher conductivity than an intrinsic semiconductor.

Solution:

Impurities from a Group 3 element (such as Boron) is added to an intrinsic semiconductor, and this **increases the concentration of holes in the semiconductor**. B1

These holes occupy an extra energy level in the forbidden band between the valence and conduction band and B1

less energy is required to excite electrons from the valence band to fill the holes in the extra energy level B1

(ii) State which side of the slab, X or Y, is at a higher potential.

[1]

Solution:

Side X B1

(iii) Explain the reasoning for your answer in part **(ii)**.

[2]

Solution:
As the **positively-charged** holes flow through the conductor, they experience a **magnetic force towards X** as dictated by **Fleming's Left Hand Rule**. B1

The holes accumulate on Side X and therefore, **this side is more positively charged** and is at a higher potential B1

(b) Describe the formation of the depletion region in a p-n junction.

[4]

Solution:
Electrons are the majority charge carriers in n-type semiconductors. Holes, are the majority charge carrier in the p-type semiconductor. B1

Electrons near the junction diffuse into the p-type semiconductor due to the difference in concentration, while holes diffuse from the p-type into the n-type semiconductor also due to the difference in concentration. B1

The electrons and holes recombine and the **n-type semiconductor has a net positive charge and the p-type semiconductor acquires a net negative charge.** B1

Thus, **an electric field and a potential difference is established at the junction**, with the n side at a higher potential relative to the p side, and **this prevents further diffusion of electrons forming a depletion layer.** B1

(c) State **two** conditions required for the production of a consistent laser beam.

Solution (any 2 answers):

The upper energy level involved in the lasing process must be in a metastable state: electrons at this level of energy state have longer lifetime than 10^{-8} s. This is to ensure that population inversion can be established **B1**

Atoms must attain population inversion: more atoms in the excited state as compared to those in the ground state. This is to ensure that the number of photons emitted is greater than the number of photons absorbed **B1**

Stimulated emission must take place during which a second photon, with the same energy level (E2 – E1) is being emitted. This produces 2 coherent photons having the same direction, phase and plane of polarization **B1**

5 (a) State **one** similarity and **one** difference between the properties of electric fields and gravitational fields.

[2]

Solutions:

B1

Similarities (any 1):

The strength of the fields (force) varies by the inverse square of the distance between the source and point in the field.

The field strengths of both fields are **vector quantities.**

Fields around a point source are radial.

Differences (any 1):

B1

The gravitational field strength (or force) is related to the (products of the) masses of the objects while the **electric field strength (or force) is related to the (products of the) charges.**

The **gravitational force is only attractive**, but the **electric force can be either attractive or repulsive.**

The **gravitational force acts along the direction of the field lines**, but the **electric force can be either in the direction or opposite to the field line directions.**

(b) An oil drop of mass 1.98×10^{-12} g and a charge of -1.12×10^{-18} C is initially at rest between two parallel vertical plates placed 25.0 cm apart. The plates are connected to an electrical source with an e.m.f. of 2.50 kV as shown in Fig. 5.1.

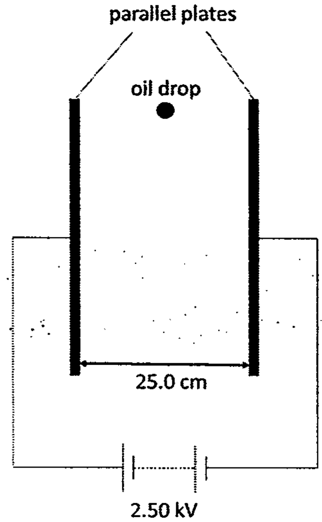


Fig. 5.1

(i) Show that the magnitude of the electric force acting on the oil drop when it is between the plates is 1.12×10^{-14} N.

Solution:

Electric field strength for uniform field, **M1**

$$E = \frac{\text{potential difference between the plates, } V}{\text{spacing between the plates, } d} = \frac{2500}{0.25} = 10000 \text{ V m}^{-1}$$

Electric force acting on oil drop, (taking right as positive),

F_E = charge of oil drop, $q \times E = (-1.12\times10^{-18})(10000) = -1.12\times10^{-14}$ N (to the left) **M1**

Answer: 1.12×10^{-14} N **A0**

(ii) Hence, determine the magnitude and direction of the initial acceleration of the oil drop.

initial acceleration = ... m s^{-2}

direction = ... **[4]**

Gravitational force acting on the oil drop (taking down as positive)

$F_G = mg = (1.98\times10^{-15}\text{ kg})(9.81) = 1.94\times10^{-14}$ N (downwards) **C1**

Resultant force acting on oil drop,

$F_R = \sqrt{F_E^2 + F_G^2} = \sqrt{(1.12\times10^{-14})^2 + (1.94\times10^{-14})^2} = 2.24\times10^{-14}$ N **M1**

$a = \frac{F_R}{m} = \frac{2.24\times10^{-14}}{1.98\times10^{-15}} = 11.3 \text{ m s}^{-2}$ **A1**

Direction of acceleration = direction of resultant force

$\theta = \tan^{-1}\left(\frac{1.94\times10^{-14}}{\ldots}\right)$ = 60.0° anti- clockwise from negative x- direction **A1**

(iii) State and explain whether the magnitude and direction of the acceleration obtained in part **(ii)** will remain constant throughout the entire motion of the oil drop as it moves between the plates. **[2]**

Solution:

The two forces on the oil drop, which **are gravitational and electric force remains constant** in both magnitude and direction **M1**

Therefore, by Newton's Second Law, the **acceleration is expected to remain constant** throughout the drops motion between the plates. **A1**

SECTION B (40 marks)

Answer TWO out of THREE questions in Section B.

6 **(a)** Give three distinguishing characteristics between the *radioactive decay* and the *fission* of a nucleus.

[3]

Solution

Radioactive decay is a **spontaneous** and **random disintegration** of **unstable nucleus**, while fission is a **deliberate process** that is usually triggered by bombarding the nucleus in question with another particle. **B1**

There are **three distinct types of emission** during a radioactive decay (emission of an alpha-particle, a beta-particle or a gamma ray photon) **and one daughter nucleus**, whereas fissions **usually result in emission of neutrons** and two or more daughter nuclei. **B1**

The **products of a fission process are approximately of the same mass, this is not usually the case for radioactive decay** **B1**

(b) Plutonium-239 ($^{239}_{94}Pu$) is the plutonium isotope that is most useful in making nuclear weapons, and it is produced in varying quantities in virtually all operating nuclear reactors.

(i) Part of the plutonium manufacture process involves the most common isotope of uranium, Uranium-238 ($^{238}_{92}U$) absorbing a neutron. Write a nuclear equation that represents this process.

[1]

$$^{238}_{92}U + ^{1}_{0}n \rightarrow ^{239}_{92}U$$ **B1**

(ii) The product formed in the process in **(b)(i)** then quickly undergoes two subsequent beta decays to plutonium. An intermediate radioactive isotope X is formed after the first beta decay.

By considering the nuclear equation for this first beta decay, determine the mass and atomic numbers of X. Show your working clearly.

Solution

As the intermediate radioactive isotope is a result of the beta decay of $^{239}_{92}U$, we need to consider the following nuclear reaction equation

$$^{239}_{92}U \rightarrow ^{a}_{b}X + ^{0}_{-1}e$$

M1

where a is the mass number of X
and b is the atomic number of X

balancing the mass and atomic numbers of the equation,

239 = a + 0
a = 239 **M1**
A1

and

92 = b + (-1)
b = 93 **B1**

(iii) Hence, write the nuclear equation representing the second beta decay. **[1]**

Solution

B1

$$^{239}_{93}X \rightarrow ^{239}_{94}Pu + ^{0}_{-1}e$$

(iv) A plutonium bomb named "Fat Man" was dropped on Nagasaki on August 9, 1945 ending World War II. At the point of detonation, the following nuclear reaction occurred, incurring a sustained chain reaction process.

$$^{239}_{94}Pu + ^{1}_{0}n \rightarrow ^{100}_{42}Mo + ^{135}_{52}Te + 4^{1}_{0}n$$

Fig. 6.1 lists the binding energy (BE) per nucleon of each of the nuclides in this nuclear reaction.

Nuclide	BE per nucleon / MeV
$^{239}_{94}Pu$	7.56
$^{100}_{42}Mo$	8.61
$^{135}_{52}Te$	8.35

Fig. 6.1

It is estimated that 5.88 kg of plutonium in Fat Man was needed to cause the deadly explosion. Determine the energy released if only 17% of the plutonium undergoes nuclear reaction during the explosion.

energy released = ... J **[5]**

Solution:

Number of fission processes
= 5.88 /(239 u) x 0.17
= 5.88 / (239 x 1.66 x 10^{-27}) x 0.17 **M1**

Energy released in a single fission process
$= BE_{products} - BE_{reactants}$
$= BE_{Mo} + BE_{Te} - BE_{Pu}$ **M1**
$= 8.61\ (100) + 8.35\ (135) - 7.56\ (239)$ **M1**
$= 181.41$ MeV

Total amount of energy released
$= 2.52 \times 10^{24} \times 181.41 \times 10^{6} \times 1.6 \times 10^{-19}$
$= 7.31 \times 10^{13}$ J **A1**

(c) Plutonium-239 is an alpha emitter with a half-life of 24100 years.

(i) Calculate the amount of time for the number of Plutonium-239 isotopes in a sample to reduce by 30%.

amount of time = ... years **[3]**

Solution

$$N = N_0 e^{-\lambda t}$$

$$\frac{N}{N_0} = e^{-\lambda t}$$

$$-\lambda t = ln\frac{N}{N_0}$$

$$-\left(\frac{ln2}{t_{1/2}}\right)t = ln\frac{N}{N_0}$$

$$t = -ln\frac{N}{N_0}\left(\frac{t_{1/2}}{ln2}\right)$$ **M1**

$$t = -ln(0.7)\left(\frac{24100}{ln2}\right) = 12400\ years$$ **M1** **A1**

(ii) Suggest why plutonium-239 is more dangerous to the body when inhaled as compared to being an external radiation source.

[3]

Solution

As **alpha particles are not very penetrative**, it has a **low chance of getting into the body through human skin**. Therefore, when inhaled, plutonium dust and therefore the **subsequent energetic alpha particles can access the internal body tissues more directly** to cause cancer. **B1** **B1** **B1**

7 (a) State what is meant by *simple harmonic motion*. **[2]**

Simple harmonic motion is defined as the motion of an object whose acceleration a is **proportional** to its displacement x from a fixed point (equilibrium position) and **B1**
is always **directed towards** that fixed point. **B1**

The defining equation of simple harmonic motion is

$$a = -\omega^2 x$$

(The minus sign indicates that a is always in the opposite direction to x.)

(b) Describe how, for a simple harmonic motion, the direction of acceleration varies with the direction of the velocity **[2]**

When the object is moving **towards** the equilibrium position, its acceleration and velocity are in the **same** direction. **B1**
When the object is moving **away from** the equilibrium position, its acceleration and velocity are in **opposite** direction. **B1**

(c) A smooth ball of mass m is held between two fixed points A and B by means two similar springs, each of spring constant k, as shown in Fig. 7.1.

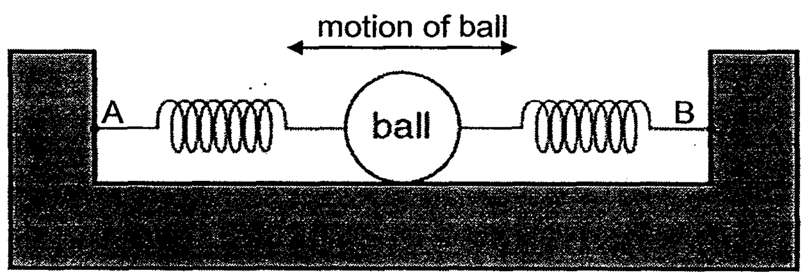


Fig. 7.1

The ball is free to oscillate along the straight line AB on the smooth surface.

When the ball is in equilibrium, the extension of each spring is e. The ball is then displaced a small distance x to the right along the axis of the springs.

(i) Show that the magnitude F of the restoring force acting on the ball is given by

$$F = 2kx$$

[2]

forces in springs are $k(e + x)$ and $k(e - x)$ **C1**

resultant $= k(e + x) - k(e - x)$ **M1**

$= 2kx$ **A0**

(ii) The ball is then released. Show that the acceleration a of the ball is given by

$$a = -\frac{2kx}{m}$$

[2]

By Newton's Second Law,

A0

$a = -\frac{2kx}{m}$ B1

negative sign explained as the acceleration is always oppositely directed to the displacement.

(iii) The mass *m* of the ball is 900 g and the spring constant *k* is 120 N m^{-1}. By comparing the equations of an object executing simple harmonic motion and that in **(c)(ii)**, determine for the ball,

1. the frequency of oscillation,

[3]

$\omega^2 = \frac{2k}{m}$ C1

$(2\pi f)^2 = \frac{2\cdot(120)}{0.900}$ C1

f = 2.60 Hz A1

2. the amplitude if the maximum acceleration of the ball is 5.2 m s^{-2} a

[2]

$\omega^2 x_0 = 5.2$ C1

$x_0 = \frac{5.2}{\frac{2\cdot(120)}{0.900}}$

$= 1.95 \times 10^{-2}$ m or 1.95 cm A1

3. the maximum kinetic energy of the ball. **[2]**

Max kinetic energy $= \frac{1}{2} m(\omega x_0)^2$ M1

$= \frac{1}{2}(0.900)\frac{2\cdot(120)}{0.900}(0.0195)^2$

$= 0.0456$ J A1

(iv) A student investigates the variation in the kinetic energy, E, of the oscillating ball as shown in Fig. 7.2.

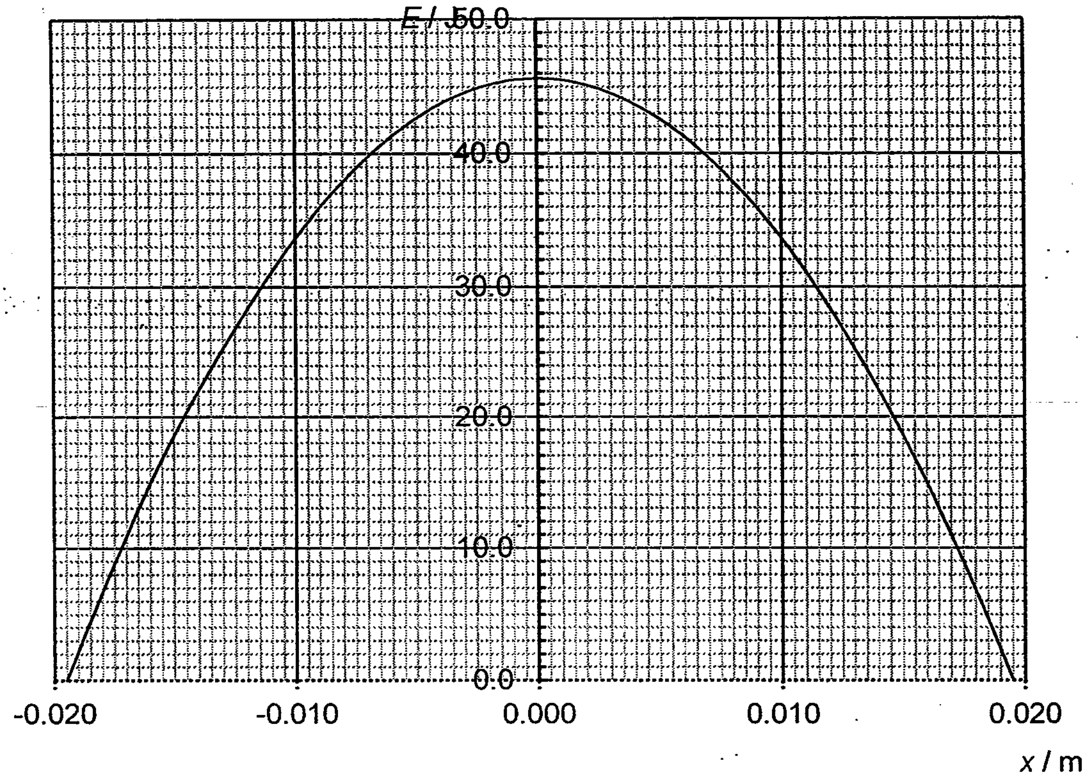


Fig 7.2

The student repeats the investigation but with a smaller amplitude. The maximum value of E is now found to be 15 mJ.

Use Fig. 7.2 to determine the change in the amplitude. Explain your working.

change in the amplitude = ... m **[3]**

either change in energy = 30.6 mJ **C1**

then obtain answer from graph with a shift of the KE graph to read off a value of approximately 0.011± 0.0005 m **C1**

Change in amplitude = 0.0195 – 0.0110 = 0.0085 m **A1**

or max E proportional to (amplitude)^2 **OR**

So $\dfrac{(KE_{max})_1}{(KE_{max})_2} = \left(\dfrac{0.0195}{x}\right)^2$ **C1**

new amplitude, x = 0.0112 m **C1**

Change in amplitude = 0.0195 – 0.0112 = 0.0083 m **A1**

(d) The experiment was repeated with a rough ball instead. Suggest and explain the effect it would have on the ball's oscillatory motion. **[2]**

There will now be damping and its **amplitude will gradually decrease** **B1**

while **its period would increase** **B1**

8 (a) A rectangular coil is rotating about an axis between two magnets with uniform angular velocity ω due to the action of an external applied force. The uniform magnetic field B between the two magnets is 0.90 T. The coil is rotating at 40 revolutions per second. The number of turns N of the coil is 40. The cross-sectional area A of the coil is 3.0 m^2. A current is found going through the resistor R of resistance 30 Ω. Fig. 8.1 shows the instant when the plane of the coil is in a horizontal position.

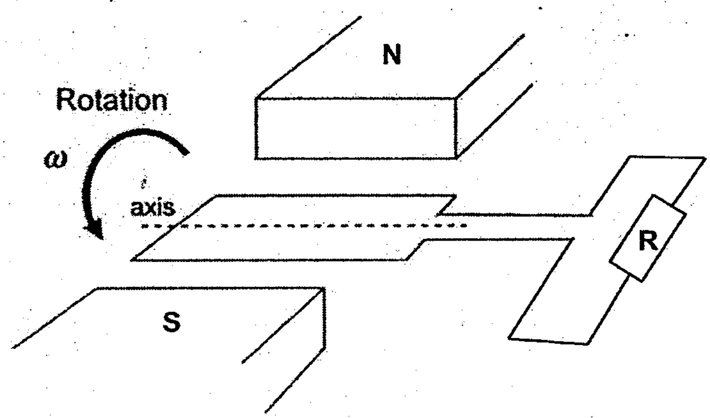


Fig. 8.1

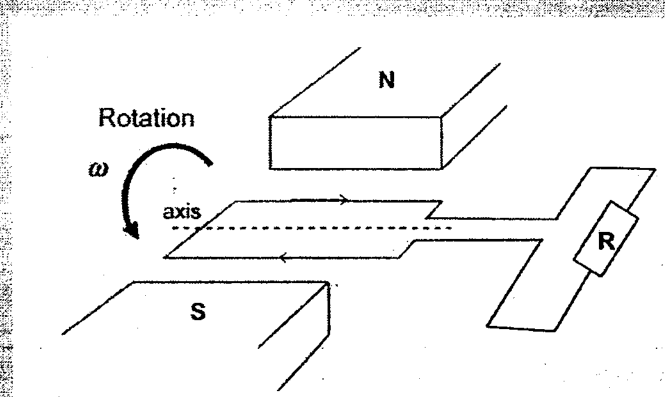
(i) Explain how the current flowing through the resistor R is formed. **[3]**

Solution:
As the coil rotates, there is a continuous **change in effective area of the coil exposed to the magnetic field**. Therefore, there is a **changing magnetic flux linkage**. By **Faraday's Law, an e.m.f. will be induced**. **B1** **B1**

Since the **circuit is closed**, induced current will flow through resistor R. **B1**

(ii) On Fig. 8.1, indicate the direction of flow of current and explain your reasoning. **[3]**

Solution:



B1

[direction of current must be correct] **B1**

As the coil rotates, the area exposed to the external magnetic field increases. Hence magnetic flux linkage increases. By **Lenz's law** and using the **right hand grip rule,** **B1** induced current will flow in such a way so as to **produce a magnetic field to restore the magnetic flux linkage to the original state.**

(iii) The coil starts rotating when it is in the position shown in Fig. 8.1.

1. Determine the period of the rotation of the coil

period = ... s **[2]**

Solution:

Angular velocity, $\omega = 2\pi f = 2\pi(40) = 80\pi$ **M1**

$\omega = \frac{2\pi}{T} = 80\pi$ **A1**

$T = 0.025$ s

2. Determine the maximum current flowing through the coil during the rotation.

maximum current = ... A **[2]**

Solution:

Magnetic flix linkage, $\Phi = NBA \sin \omega t$ (since at $t = 0$ s, $\Phi = 0$ Wb)

$= (40)(0.9)(3) \sin(80\pi t)$

$= 108 \sin(80\pi t)$

Induced e.m.f., $E = -\frac{d\phi}{dt}$

$= -\frac{d[108 \sin(80\pi t)]}{dt}$

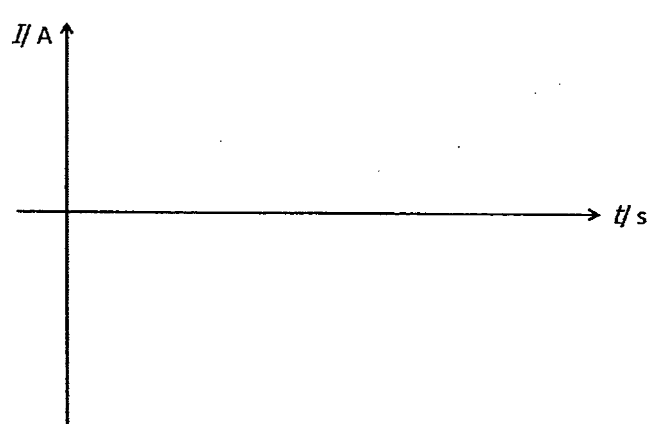
$= -108\pi(80) \cos(80\pi t)$

$= -8640\pi \cos(80\pi t)$ **M1**

Maximum $E = 8640\pi$ V

Max current $= \frac{8640\pi}{30} = 905$ A **A1**

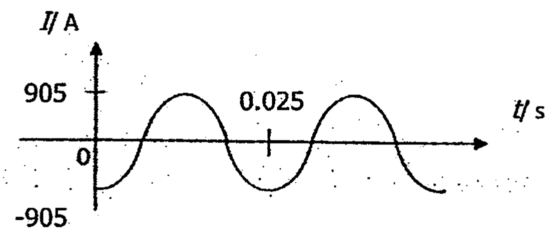
3. Sketch a graph on Fig. 8.2 showing the variation with time of current through the resistor. Show the values of period and peak current on the graph.



Solution:

B1 mark for shape of graph (-cos) **B1**

B1 mark for correct value of peak current and period **B1**



(iv) Determine the mean power through the resistor.

mean power = ... W **[3]**

Solution:

$I_{rms} = \frac{I_o}{\sqrt{2}} = \frac{905}{\sqrt{2}} = 640\ A$ **M1**

M1

$P_{mean} = I_{rms}^2 R = 640^2\ (30)$

$= 1.23 \times 10^7\ W$ **A1**

(b) The primary coil of a transformer has 1500 turns and is connected via cables to a 250 $V_{r.m.s.}$ supply. The secondary coil has 50 turns and is connected, through a switch and a diode, to a 10.0 V rechargeable battery, as illustrated in Fig. 8.3.

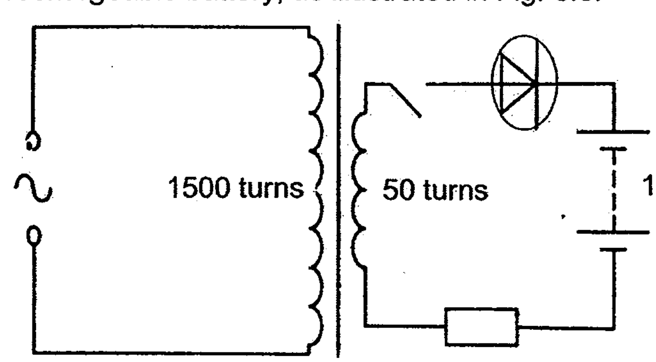


Fig. 8.3

(i) Initially, the switch is open. Considering both the transformer and the diode to be ideal, calculate the r.m.s. potential difference across the secondary coil.

$V_{r.m.s}$ = ... V **[2]**

Solution:

$$\frac{V_s}{V_p} = \frac{N_s}{N_p}$$

$$\frac{V_s}{250} = \frac{50}{1500}$$ **M1**

$$V_s = 8.3V$$ **A1**

(ii) The switch is now closed to recharge the battery.

1. Suggest why the diode is necessary in the secondary circuit.

[2]

Solution:

The battery can only be charged with a DC with the **current going into the positive terminal**. (If current comes out from the positive terminal, the battery will discharge.) **B1**

The diode **rectifies the AC to DC** for charging the battery. **B1**

2. Suggest why the resistor is necessary in the secondary circuit.

[1]

Solution:

The resistor is connected in series to **prevent a large current** which may damage the battery. **B1**