Centre Number	Index Number	Name	Class
S3016			

RAFFLES INSTITUTION
2025 Preliminary Examination

PHYSICS (Higher 3) **9814/01**
Paper 1 **25 September 2025**
3 hours

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

READ THESE INSTRUCTIONS FIRST
Write your index number, name and class in the spaces provided at the top of this page.
Write in dark blue or black pen on both sides of the paper.
You may use an HB pencil for any diagrams, graphs or rough working.
Do not use staples, paper clips, glue or correction fluid.
The use of approved scientific calculator is expected, where appropriate.

Section A
Answer **all** questions.
You are advised to spend about 1 hour 50 minutes on Section A.

Section B
Answer **two** questions only.
You are advised to spend about 35 minutes on each question in 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	(a)	/ 8
	(b)	/ 7
2		/ 6
3		/ 5
4		/ 8
5		/ 6
6		/ 6
7		/ 6
8		/ 8
9		/ 20
10	(a)	/ 10
	(b)	/ 10

This document consists of **34** printed pages.

11	/ 20
Total	/100

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}
		=	$(1/(36\pi)) \times 10^{-9}$ 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} J K^{-1}
gravitational constant	G	=	6.67×10^{-11} N m^{2} kg^{-2}
acceleration of free fall	g	=	9.81 m s^{-2}

Formulae

uniformly accelerated motion	s	=	$ut + \frac{1}{2}at^2$
	v^2	=	$u^2 + 2as$
moment of inertia of rod through one end	I	=	$\frac{1}{3}ML^2$
moment of inertia of hollow cylinder through axis	I	=	$\frac{1}{2}M\left(r_1^2 + r_2^2\right)$
moment of inertia of solid sphere through centre	I	=	$\frac{2}{5}MR^2$
moment of inertia of hollow sphere through centre	I	=	$\frac{2}{3}MR^2$

work done on/by a gas	W	=	$p\Delta V$
hydrostatic pressure	p	=	ρgh
gravitational potential	φ	=	$-Gm/r$
Kepler's third law of planetary motion	T^2	=	$\dfrac{4\pi^2 a^3}{GM}$
temperature	T/K	=	$T/°C + 273.15$
pressure of an ideal gas	p	=	$\dfrac{1}{3}\dfrac{Nm}{V}\langle c^2\rangle$
mean translational kinetic energy of an ideal gas molecule	E	=	$\dfrac{3}{2}kT$
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	=	$R_1 + R_2 + \ldots$
resistors in parallel	$1/R$	=	$1/R_1 + 1/R_2 + \ldots$
capacitors in series	$1/C$	=	$1/C_1 + 1/C_2 + \ldots$
capacitors in parallel	C	=	$C_1 + C_2 + \ldots$
energy in a capacitor	U	=	$\dfrac{1}{2}CV^2$
electric potential	V	=	$\dfrac{Q}{4\pi\varepsilon_0 r}$
electric field strength due to a long straight wire	E	=	$\dfrac{\lambda}{2\pi\varepsilon_0 r}$
electric field strength due to a large sheet	E	=	$\dfrac{\sigma}{2\varepsilon_0}$
alternating current/voltage	x	=	$x_0 \sin\omega t$
magnetic flux density due to a long straight wire	B	=	$\dfrac{\mu_0 I}{2\pi d}$
magnetic flux density due to a flat circular coil	B	=	$\dfrac{\mu_0 NI}{2r}$
magnetic flux density due to a long solenoid	B	=	$\mu_0 nI$

energy in an inductor	$U = \frac{1}{2} L I^2$
RL series circuits	$\tau = \frac{L}{R}$
RLC series circuits (underdamped)	$\omega = \sqrt{\frac{1}{LC} - \frac{R^2}{4L^2}}$
radioactive decay	$x = x_0 \exp(-\lambda t)$
decay constant	$\lambda = \frac{\ln 2}{t_{\frac{1}{2}}}$

Section A

Answer **all** questions in this section.
You are advised to spend about 1 hour 50 minutes on this section.

1 **(a)** A metal sphere is dropped from a height h onto a metal plate. The sphere makes impact with the plate repeatedly, each time rebounding to a lesser height. At each impact, the sphere loses a constant fraction F of the kinetic energy possessed by the sphere just before the collision.

(i) Write down an expression for

1. F in terms of v_n and v_{n+1}, where v_n is the speed of the sphere just before the nth impact and v_{n+1} is the speed of the sphere immediately after the nth impact.

[1]

2. t, the time interval between the nth and (n + 1)th impacts in terms of v_{n+1} and g.

Neglect air resistance.

[1
]

(ii) Hence, show that the sphere comes to rest in a finite time T after being released is given by the expression

$$T=\sqrt{\frac{2h}{g}}\left(1+2\left[\frac{(1-F)^{\frac{1}{2}}}{1-(1-F)^{\frac{1}{2}}}\right]\right)$$

[Hint: for $0<x<1, \quad x+x^2+x^3+\ldots+x^n+\ldots=\dfrac{x}{1-x}$]

[4
]

(iii) Determine F for the sphere when it is dropped from a height of 1.2 m when it comes to rest 8.2 s after release.

[2
]

1 (b
) Fig. 1.1 shows two meteorites, A and B, travelling towards each other in deep space.

A, with a mass of 1.0 kg, is travelling horizontally to the right with a speed of 4.0 m s^{-1}.
B, with a mass of 3.0 kg, is travelling vertically downwards with a speed of 1.0 m s^{-1}.

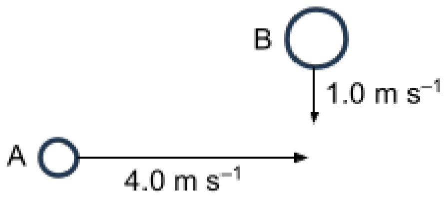

Fig. 1.1

(i) Show that the velocity of the centre of mass of the two meteorites, v_{CM}, is $\frac{5}{4}$ m s^{-1} at an angle of 36.9° clockwise below the horizontal.

[3
]

(ii) A and B then collide and stick together to form a combined meteorite.

Explain why the combined meteorite must be moving at the velocity v_{CM} after its formation.

....

....

....
[1
....]

(iii) The combined meteorite, moving at velocity v_{CM}, then strikes a spaceship travelling in space at a speed of 9.0 m s^{-1}, at an angle of ϕ anti-clockwise above the horizontal.

An astronaut on the spaceship observes the combined meteorite striking the spaceship from a vertically downwards direction (i.e. in the same direction that B was initially travelling in).

Determine ϕ .

ϕ = ... ° [3]

Total [15 marks]

2 Fig. 2.1 shows a book of mass M that is pressed against a vertical wall by a force F which makes an angle θ with respect to the horizontal. The coefficient of static friction between the book and the wall is μ. The book is stationary.

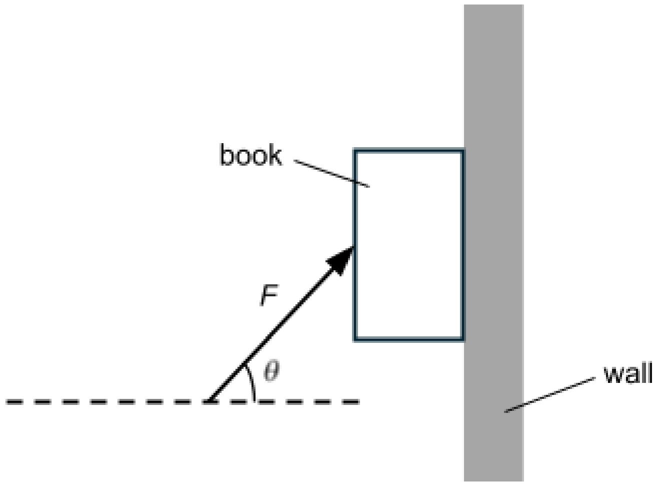

Fig 2.1

(a) On Fig. 2.1, draw and label the weight Mg, frictional force f and normal contact force N acting on the book.

[1]

(b) Show that the force F is given by

$$F \geq \frac{Mg}{\sin\theta + \mu\cos\theta}$$

[3]

(c) The minimum value of F is F_{min} and it occurs at $\theta = \theta_0$.

Determine an expression for θ_0 in terms of μ and hence, show that the corresponding expression for the minimum force is:

$$F_{\text{min}} = \frac{Mg}{\sqrt{1+\mu^2}}$$

[2]

Total [6 marks]

3 In Fig. 3.1, the top of a vertical cylindrical tank containing an ideal gas is closed by a smooth piston with negligible mass. The column of ideal gas below the piston has a height h. A liquid with density ρ is slowly poured onto the piston and the piston descends a distance y, thus compressing the gas before the liquid spills over the rim of the cylinder. The cross-sectional areas of both the tank and piston are equal to A and the atmospheric pressure is p_0.

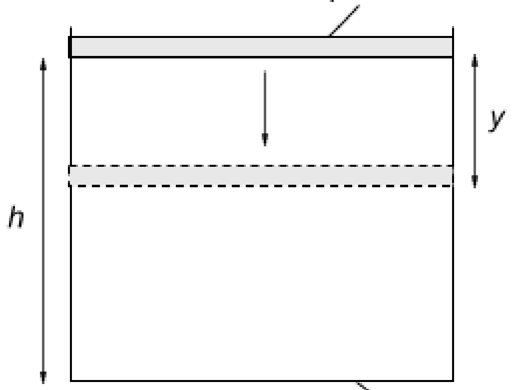

Fig. 3.1

(a) Assume that the tank and piston are well insulated.

During the compression, the pressure p and volume V of the gas are related by the equation $pV^{\gamma} = \text{constant}$, where γ is a constant for this gas.

Show that

$$h = \frac{y}{1 - \left(1 + \frac{\rho g}{p_0} y\right)^{-1/\gamma}}$$

[2
]

**(b
)** If, instead, the cylinder and piston are not well-insulated and thermal energy is readily lost from the cylinder during the slow compression, derive, in terms of p_0 , *h*, *A* and *y*, an expression for the work done *W* in compressing the gas.

[3
]

Total [5 marks]

4

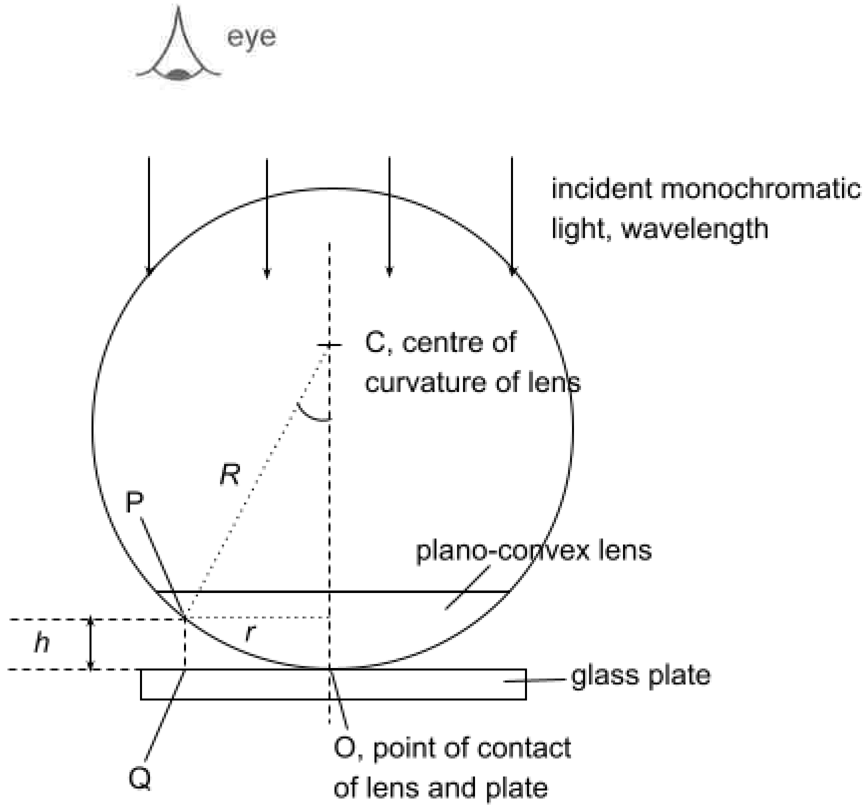

Fig. 4.1 (Diagram not to scale)

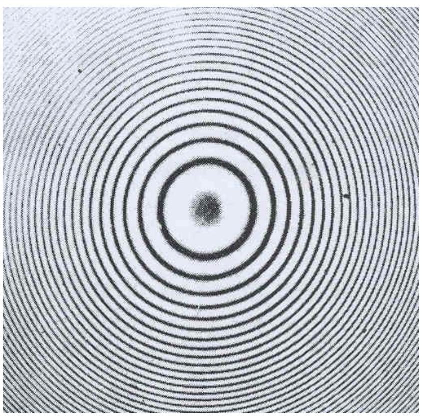

Fig. 4.2

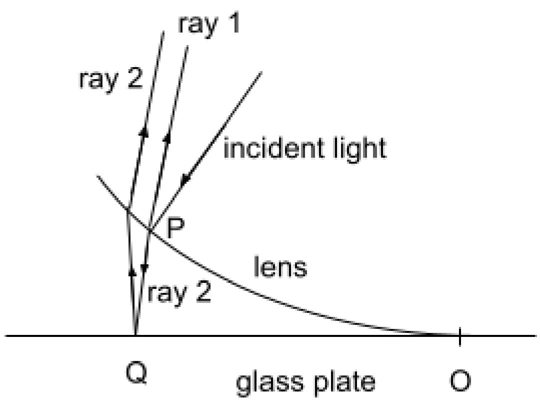

Fig. 4.3

In Fig. 4.1, a plano-convex lens (a lens that is flat on one side and spherical, with a radius of curvature R, on the other) rests on a flat glass plate, and both are illuminated vertically from above with monochromatic light of wavelength λ. When the lens and glass plate arrangement is viewed normally from above, an interference pattern of bright and dark rings centred at point O is observed (Fig. 4.2). These circular fringes are called Newton's rings.

They are formed when the incident light upon reaching the underside of the lens (point P) is split into two parts and these two parts recombine later to produce the interference effects. Part of the incident light (ray 1) is reflected upwards, and the rest of it (ray 2) is transmitted towards the glass plate (point Q) where it also gets reflected upwards and superposes with ray 1. The reflection at point Q causes the light to undergo a phase shift of 180° , whereas the reflection at point P does not produce any phase change in the light. Depending on where points P and Q are located, the optical path difference between the two reflected rays of light also depends on the thickness *h* of the air layer there. So, when the rays meet, the overall path difference will determine the resultant intensity of the fringe formed at point P.

Assuming that the radius *R* of curvature of the lens is much greater than the radius *r* of the rings formed,

(a) show that the thickness *h* of the air layer at point P is

$$h = \frac{1}{2}R\theta^2$$

Hint: Use the identity $\cos 2\alpha = 1 - 2\sin^2 \alpha$

[2]

(b) In terms of *λ* and *m*, the order of the fringe, write down an expression for *h* such that the condition for the formation of a dark ring at point P is satisfied.

[2]

(c) **(i)** Show that the radius *r* of the dark ring formed at point P is

$$r = \sqrt{m\lambda R}$$

[2]

(ii) Calculate the radius of the 16th dark ring formed when the wavelength of the incident light is 650 nm. The radius of curvature *R* of the lens is 2.8 m.

radius = ... m [1]

....

(d) Suggest a practical application of the Newton's rings set-up, apart from using it to determine the wavelength of light or the radius of curvature of a lens.

.... [1]

....

Total [8 marks]

5 Fig.5.1 shows the magnetic field produced by two identical current carrying plane coils placed co−axially.

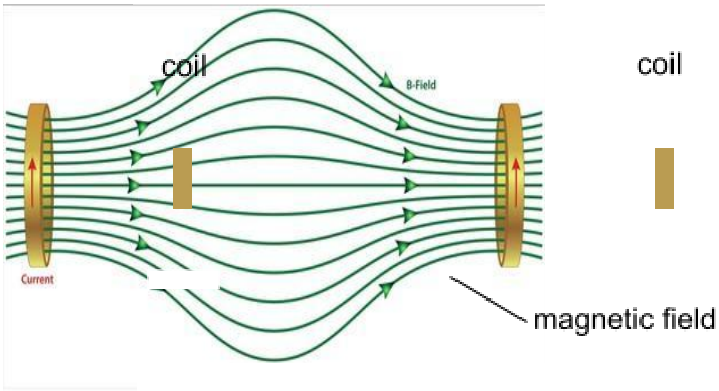

Fig. 5.1

Fig. 5.2 shows several magnetic field lines in the vertical plane passing through the centres of the coils. At an instant of time, a proton is moving perpendicularly into the page at point P.

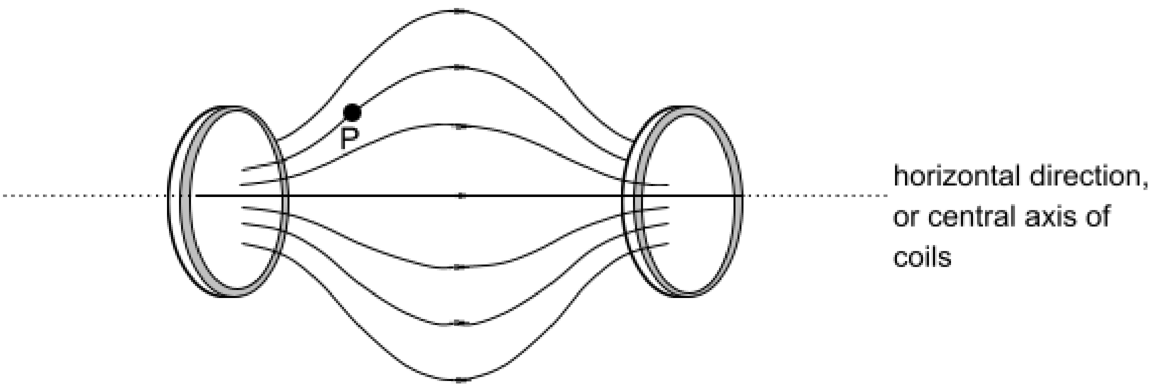

Fig. 5.2

(a) On Fig. 5.2, mark with an arrow the magnetic force acting on the proton at P, and label it with the letter **F**.

[1]

(b) (i) By considering the horizontal and vertical components of the force **F** in the plane of the page, state their effects on the motion of the proton.

vertical component:

....

....

.... [1]

horizontal component:

....

.... [1]

(ii) Considering the magnetic field region in 3-dimensions, sketch on Fig. 5.2, the path of the proton as it moves between the coils. [2]

(iii) Suggest a practical application of the set-up in Fig. 5.2 if it were to contain a highly ionized gas.

....

.... [1]

Total [6 marks]

6 The accelerating voltage of a cathode ray tube is 15.0 kV and an electron beam passes through an aperture 0.500 mm in diameter to a screen placed 0.300 m away.

(a) Determine the velocity of an electron after being accelerated from rest by a potential difference of 15.0 kV.

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

(b) Calculate the uncertainty in the component of the electron's velocity perpendicular to the line between the aperture and the screen.

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

(c) Determine the uncertainty in position of the point where the electrons strike the screen.

uncertainty in position = ... m [2]

Total [6 marks]

7 Fig. 7.1 gives the variation with time t, in years, of the total activity A_{mix}, in becquerels, of a mixture containing several radioactive nuclides of different half-lives. Each nuclide decays into a stable daughter nuclide.

t / yrs	A_{mix} / Bq	ln (A_{mix} / Bq)
0	163000	12.00
2	9900	9.20
4	4770	8.47
6	3200	8.07
8	2400	7.78
10	1830	7.51
15	934	6.84
20	478	6.17

Fig. 7.1

(a) On the graph grid in Fig. 7.2, plot the graph of ln (A_{mix} / Bq) against t / yrs and draw the line of best-fit through the points.

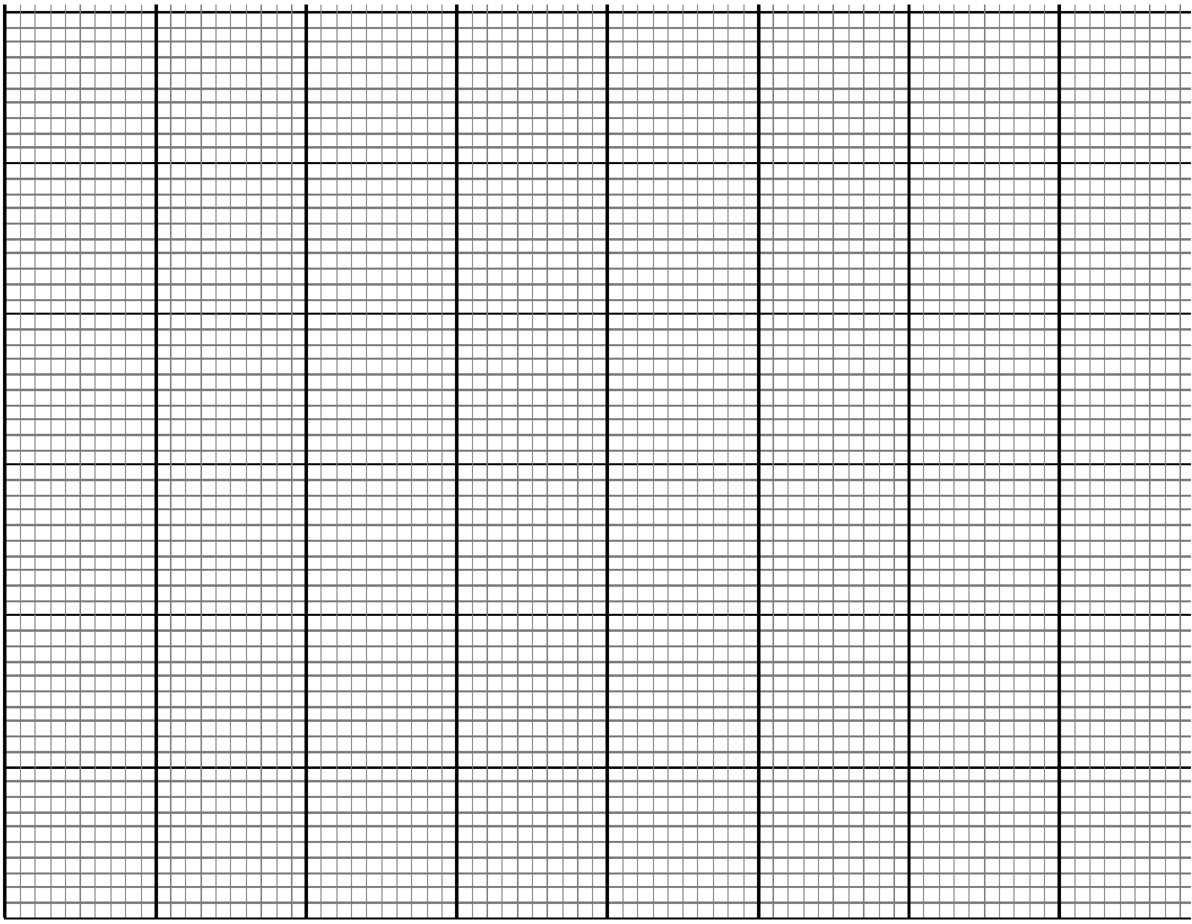

Fig. 7.2

[2]

(b) Use the graph to determine the half-life τ of one of the nuclides present in the mixture.

Explain your answer.

T = ... yrs [2]

(c) Without further calculations or plotting of graphs, explain how the number of radioactive nuclides in the mixture, as well as their respective half-lives may be determined.

....

....

....

.... [2]

Total [6 marks]

8 A satellite is launched at a velocity of 8.0×10^3 m s^{-1} parallel to the earth's surface at a height of 6.7×10^6 m from the center of the Earth. It then orbits around the Earth. Dissipative forces acting on the satellite may be neglected.

Mass of the earth = 6.0×10^{24} kg

Fig. 8.1 shows the orbit of the satellite around the earth.

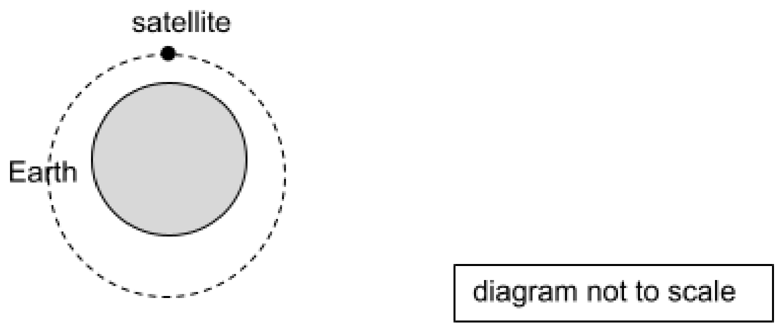

Fig. 8.1

(a) **(i)** Show that the velocity of the satellite at the subsequent greatest height achieved is 6.9×10^3 m s^{-1}

[4]

(ii) Determine the subsequent maximum distance from the center of the Earth.

maximum height = ... km [1]

(b) Determine the length *a* of the semi-major axis.

a = ... km [2]

(c) Calculate the period of revolution of the satellite, around the earth.

time of one revolution = ... s [1]

Tot
al
[8
m
ar
ks]

Section B

Answer **two** questions from this section.

You are advised to spend about 35 minutes on each question.

9 **(a)** Two circular discs with rough surfaces can rotate about the same axis perpendicular to their planes and passing through their centres. Initially the discs are not in contact. One disc, with moment of inertia I_1 is rotating with angular velocity ω_1, and the other, with moment of inertia I_2, is stationary. Both I_1 and I_2 are the moments of inertia of the discs about their axes passing through their centres and perpendicular to their planes.

(i) If the discs are brought into contact, such that their centres are coincident, they will eventually both rotate at the same angular velocity.

In terms of I_1, I_2 and ω_1, determine this common angular velocity attained by the two discs.

[2
]

(ii) In terms of I_1, I_2 and ω_1, determine the energy loss as a result of bringing the discs into contact and thereafter attaining the same angular velocity of rotation.

[2
]

**(iii
)** Explain why there is a loss in energy.

....

....

....

....

....

.... [2]

(b) With the help of an appropriate diagram, show that the moment of inertia of a hollow sphere about a diameter is

$$I = \frac{2}{3}mr^2,$$

where *m* and *r* are the mass and radius of the sphere, respectively.

[5]

(c) As shown in Fig. 9.1, the hollow sphere in **(b)** is projected with a speed *V,* without rotation, up along a rough inclined plane. The angle of inclination of the plane is *α* and the frictional force between the sphere and the plane is $\frac{1}{8}mg\sin\alpha$.

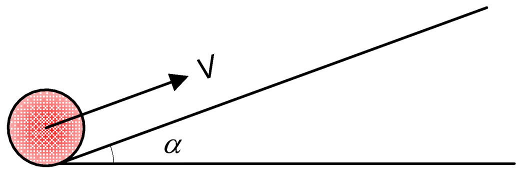

Fig. 9.1

(i) Write down the equation relating the speed of the centre of mass v_{CM} of a body to its radius r and angular velocity ω when it is undergoing pure rolling.

[1]

(ii) In terms of V, α and g, the acceleration of free fall, determine the total time during which the direction of the frictional force acting on the sphere is downward along the plane.

[5]

(iii) State and explain whether slipping will occur when the frictional force on the sphere begins to act upward along the plane.

....

....

....

....

....

....

.... [3]

Total [20 marks]

10 **(a)** A solid, non-conducting sphere of radius R has a volume charge density that varies with radial distance r from the centre as

$$\rho(r) = \rho_0\left(1 - \frac{r}{R}\right)$$

where ρ_0 is a positive constant.

(i) Show that the amount of charge $q(r)$ enclosed by a spherical volume of radius r symmetrically positioned about the centre of the solid sphere, where $r \leq R$, is given by

$$q(r) = 4\pi\rho_0\left[\frac{r^3}{3} - \frac{r^4}{4R}\right]$$

[2]

(ii) Using Gauss's Law, derive expressions for the electric field $E(r)$ due to the charge of the sphere, for both

1. $r \leq R$

[2]

2. $r \geq R$

[2]

(iii) Draw on Fig. 10.1, the variation with r of $E(r)$ for both $r \le R$ and $r > R$.

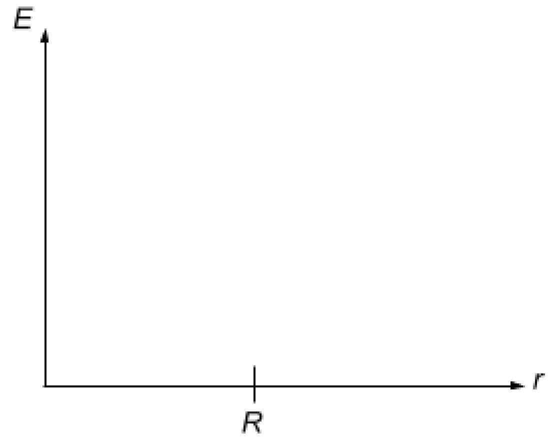

Fig. 10.1

[2]

(iv) Determine the value of r at which the electric field is maximum and find this maximum value.

[2]

Total [10 marks]

10 **(b)** An ideal transformer is shown in Fig. 10.2.

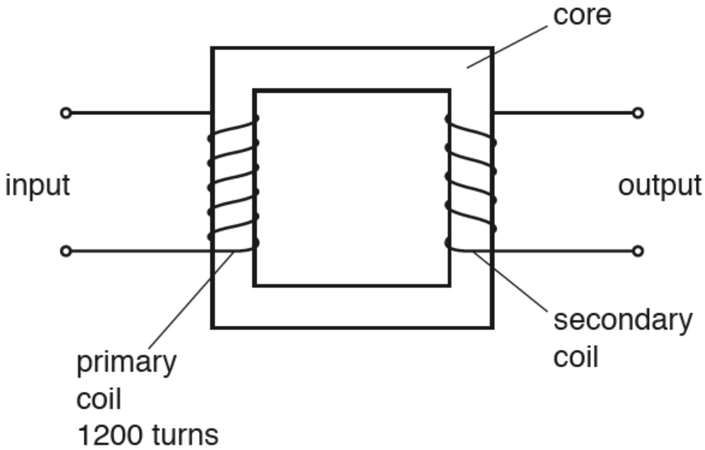

Fig. 10.2

(i) Explain:

1. why the core is made of iron

....

.... [1]

2. why an electromotive force (e.m.f.) is not induced at the output when a constant direct voltage is at the input.

....

.... [1]

(ii) An alternating voltage of peak value 150 V is applied across the 1200 turns of the primary coil. The variation with time t of the e.m.f. E induced across the secondary coil is shown in Fig. 10.3.

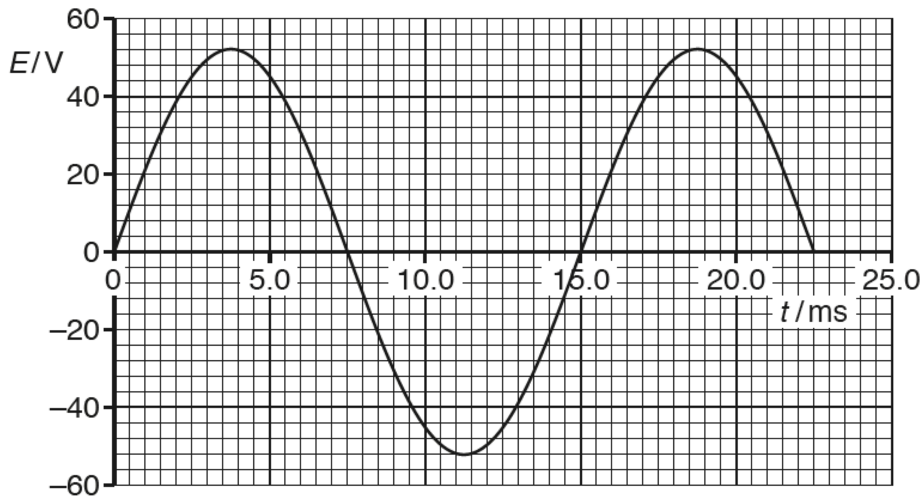

Fig. 10.3

Use data from Fig. 10.3 to:

1. calculate the number of turns of the secondary coil

number = ... [2]

2. state one time when the magnetic flux linking the secondary coil is a maximum.

time = ... ms [1]

(iii) A resistor is connected between the output terminals of the secondary coil. The mean power dissipated in the resistor is 1.2 W. It may be assumed that the varying voltage across the resistor is equal to the varying e.m.f. E shown in Fig. 10.3.

1. Calculate the resistance of the resistor.

resistance = ... Ω [2]

2. On Fig. 10.4, sketch the variation with time t of the power P dissipated in the resistor for t = 0 to t = 22.5 ms.

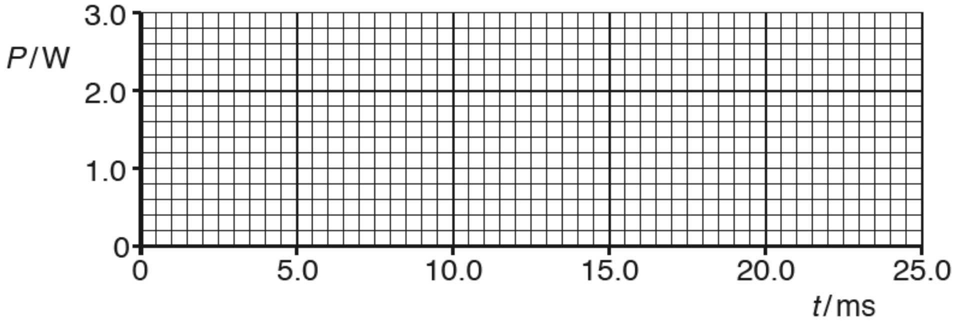

Fig. 10.4

[3]

Total [10 marks]

11 The circuit shown in Fig. 11.1 consists of a switch, a battery of e.m.f. E, a resistor of resistance R and two capacitors C_1 and C_2, each of capacitance C. The battery has no internal resistance and both the switch and wires have very low resistance. Initially, both capacitors are uncharged, and the switch is at position y.

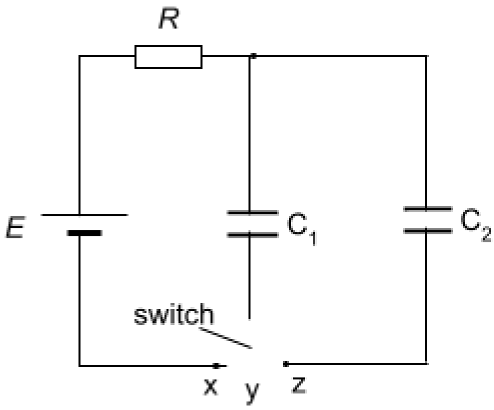

Fig. 11.1

(a) At time t = 0, the switch is moved from position y to position x to fully charge the capacitor, such that, at any time t during the charging process, the charge in the capacitor is Q and the current in the resistor is I.

(i) Show that the current I in the circuit at time t is given by

$$I = \frac{E}{R} e^{-\frac{t}{RC}}$$

[3]

(ii) On Fig. 11.2, sketch and label two graphs to show the variation with time t of the potential difference V_R across the resistor and the potential difference V_C across the capacitor, from time t = 0 to until the capacitor is fully charged.

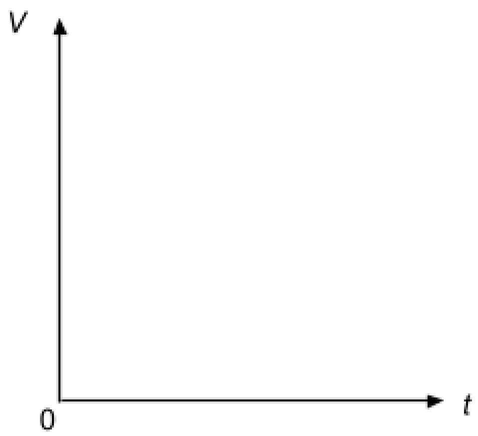

Fig. 11.2

[2]

(iii) Show that the rate P_R at which energy is being dissipated in the resistor at time t is given by

$$P_R = \frac{E^2}{R} e^{-\frac{2t}{RC}}$$

[1]

(iv) In terms of C and Q, write down an expression for the energy stored in the capacitor at time t.

[1]

(v) In terms of E, R and C, derive an expression for the rate P_C at which energy is transferred to the capacitor at time t.

[2]

(vi) On Fig. 11.3, sketch and label the variation with time t of the power P_R dissipated in the resistor and the power P_C transferred to the capacitor, from time t = 0 to until the capacitor is fully charged.

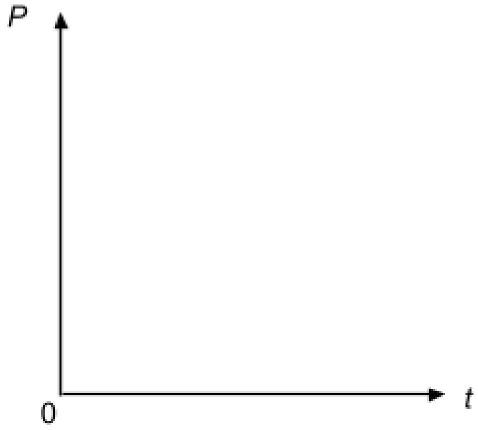

Fig. 11.3

[2]

(b) The switch is next moved from position x to position z.

(i) In terms of C and E, write an expression for the initial energy stored in C_1 when the switch is at position x.

[1]

(ii) In terms of C and E, derive an expression for the final total energy stored in both capacitors when the switch is at position z.

[3]

(iii) Comment on the difference in the energies in parts **(b)(i)** and **(b)(ii)**.

....

....

....

.... [2]

(c) One of the capacitors is replaced with an ideal inductor of inductance L and zero resistance as shown in Fig. 11.4. Initially, the switch is at position x to fully charge the capacitor.

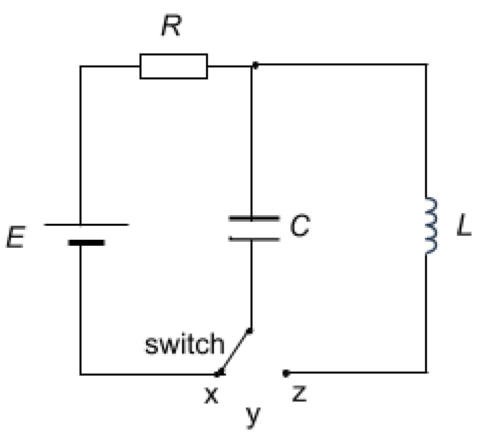

Fig. 11.4

The switch is then moved from position x to position z at time t = 0 to form an LC circuit. After a time t, the charge in the capacitor is Q and the current in the inductor is I.

(i) In terms of Q, C, L and I, write an expression for the total energy stored in the capacitor and the inductor.

[1]

(ii) You may assume that the resistance of the LC circuit is zero and no energy is radiated away from the circuit, such that the total energy of the system remains constant in time and charge Q oscillates sinusoidally with time t in the LC circuit.

By making use of the answer to part **(c)(i)** and the expression $I = \frac{dQ}{dt}$, show that the frequency f of oscillation is

$$f = \frac{1}{2\pi\sqrt{LC}}$$

[2]

Total [20 marks]

End of Paper