CANDIDATE NAME	

CIVICS GROUP	2	4	-			REGISTRATION NUMBER	

PHYSICS 9814/01

Paper 1

23 September 2025

3 hours

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

READ THESE INSTRUCTIONS FIRST

Write your name, civics group and registration number on all the work you hand in.
Write in dark blue or black pen on both sides of the paper.
You may use an HB pencil for any diagrams or graphs.
Do not use paper clips, highlighters, glue or correction fluid.

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

Section A
Answer **all** questions.
You are advised to spend about 1 hour and 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	
Section A	
1	**10**
2	**8**
3	**12**
4	**10**
5	**20**
Section B	
6	**20**
7	**20**
8	**20**
s.f.	
Total	**100**

This document consists of **30** printed pages and **2** blank pages.

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Data

speed of light in free space,	c	=	3.00×10^{8} m s^{-1}
permeability of free space,	μ_o	=	$4\pi \times 10^{-7}$ H m^{-1}
permittivity of free space,	ε_o	=	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	$= \frac{1}{2}M(r_1^2 + r_2^2)$
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	$= \rho gh$
gravitational potential,	ϕ	$= -\frac{Gm}{r}$
Kepler's third law of planetary motion	T^2	$= \frac{4\pi^2 a^3}{GM}$
temperature,	T/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	$= x_o \sin \omega t$
velocity of particle in s.h.m.	v	$= v_o \cos \omega t$
		$= \pm\omega\sqrt{(x_o^2 - x^2)}$
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	$U = \frac{1}{2}CV^2$
electric potential,	$V = \frac{Q}{4\pi\varepsilon_o r}$
electric field strength due to a long straight wire	$E = \frac{\lambda}{2\pi\varepsilon_o r}$
electric field strength due to a large sheet	$E = \frac{\sigma}{2\varepsilon_o}$
alternating current/voltage,	$x = x_o \sin \omega t$
magnetic flux density due to a long straight wire	$B = \frac{\mu_o I}{2\pi d}$
magnetic flux density due to a flat circular coil	$B = \frac{\mu_o N I}{2r}$
magnetic flux density due to a long solenoid	$B = \mu_o n I$
energy in an inductor	$U = \frac{1}{2}LI^2$
RL series circuits	$\tau = \frac{L}{R}$
RLC series circuits (underdamped)	$\omega = \sqrt{\frac{1}{LC} - \frac{R^2}{4L^2}}$
radioactive decay,	$x = x_o \exp(-\lambda t)$
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 Two objects, of masses m_1 and m_2, and two massless springs are connected as shown in Fig. 1.1. Points A and B are the points of connection between mass m_1 and the springs.

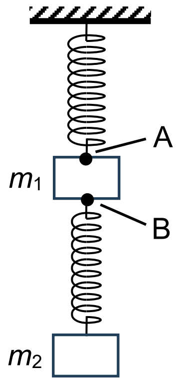


Fig. 1.1

Initially, the system is in equilibrium.

(a) The connection between m_1 and the top spring suddenly breaks at point A.

(i) In terms of m_1, m_2 and the gravitational acceleration g, determine an expression for the acceleration immediately after the breaking for

1. m_1,

acceleration =…………………….. [2]

2. m_2,

acceleration =…………………….. [1]

3. the centre of mass of m_1 and m_2.

acceleration =…………………….. [2]

(ii) Suggest an explanation for your value of acceleration in **(i)3**.

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

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

(b) The system is reconnected and in equilibrium, as shown in Fig. 1.1.

The connection between m_1 and the bottom spring suddenly breaks at point B, and m_1 accelerates upwards while m_2 accelerates downwards.

(i) Without doing any calculation, state a value for the acceleration immediately after the breaking of the centre of mass of m_1 and m_2.

acceleration = ………………… m s^{-2} [1]

(ii) Suggest an explanation for your answer in **(b)(i)**.

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

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

[Total: 10]

2 Consider 3 blocks m_A, m_B and m_C whose positions are along a straight line on a bench as shown in Fig. 2.1. m_B and m_C are slightly separated and initially at rest. m_A is moving towards m_B with an initial speed of u_A.

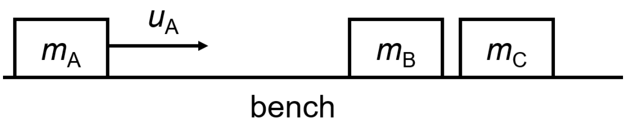


Fig. 2.1

Considering that the surfaces are frictionless and all collisions are elastic,

(a) Explain what is meant by an *elastic collision*.

....

....

.... [1]

(b) By considering the motion of the centre of masses of suitable blocks, show that the velocity of m_C after being hit by m_B can be expressed as

$$v_C = \frac{4m_A m_B}{(m_A + m_B)(m_B + m_C)} u_A .$$

[5]

(c) Hence, express m_B in terms of m_A and m_C when maximum energy is transferred from m_A to m_C.

(note: you are not required to show that it is a maximum point)

m_B = ………………………….. [2]

[Total: 8]

3 Fig. 3.1 shows a simple electric motor made up of an armature placed in between 2 permanent magnets. The region of space between the 2 magnets has a uniform magnetic flux density of 40 mT. The armature consists of a single square coil of copper wire of resistance 0.50 Ω with each side of length of 20 cm.

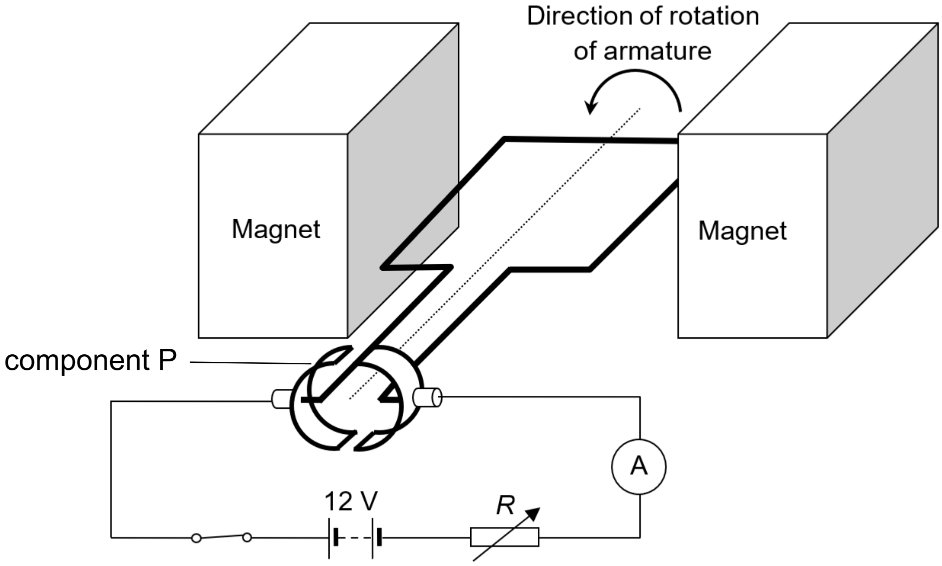


Fig. 3.1

(a) (i) State the name of the component P and explain the purpose of P in the electric motor.

....

....

.... [2]

(ii) Indicate the direction of the magnetic field in the region between the 2 permanent magnets.

[1]

(b) (i) The armature carries a current of 0.55 A just before it starts to move from the instant as shown in Fig 3.1.

Determine the magnitude of the torque acting on the armature due to the magnetic force at this instant.

torque = ... N m [2]

(ii) Describe and explain how the magnitude of the torque of the coil varies when it starts to rotate from the instant shown in Fig. 3.1 to the first time when the plane of the coil is vertical.

…………………………………………………………………………………………………

…………………………………………………………………………………………………

…………………………………………………………………………………………………

…………………………………………………………………………………………………

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

(c) (i) The current through the armature is observed to fall below 0.55 A once the motor starts rotating.

Explain why this is so.

…………………………………………………………………………………………………

…………………………………………………………………………………………………

…………………………………………………………………………………………………

…………………………………………………………………………………………………

…………………………………………………………………………………………………

…………………………………………………………………………………………………

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

(ii) When the armature is rotating at a constant rate, the minimum current in the armature is found to be 0.14 A.

Calculate the maximum rate at which the magnetic flux linkage through the armature changes.

maximum rate = ……………………………Wb s^{-1} [2]

[Total: 12]

4 A satellite of mass 10 kg is orbiting the Earth. The effective radial potential energy of the satellite-Earth system, U_{eff} is given by

$$U_{\text{eff}} = \frac{A}{r^2} - \frac{B}{r}$$

where $A = 8.39 \times 10^{22}$ J m^2, $B = 3.98 \times 10^{15}$ J m and r is the distance of the satellite from the center of Earth.

(a) **(i)** Initially, the satellite is in a circular orbit.

Show that the radius of this orbit is 4.22×10^7 m.

[2]

(ii) Show that the total energy of the system is - 4.72×10^7 J.

[3]

(iii) Determine the angular speed of the satellite.

angular speed = ……………………… rad s^{-1} [2]

(b) Now, suppose the satellite is boost to an elliptical orbit from the circular orbit originally and possess a total energy of - 3.72×10^{7} J.

With the use of the relation that $E_{tot} = -\dfrac{GMm}{2a}$, calculate the furthest distance of the satellite from the centre of the Earth.

distance = ……………………… m [3]

[Total: 10]

5 When a car approaches you with its horn sounding, the pitch seems to drop as the car passes. This phenomenon is called the Doppler effect. When a source of sound and listener are in motion relative to each other, the frequency of the sound heard by the listener is not the same as the source frequency.

(a) A source S moving with velocity v_S emits a sound wave with frequency f_S and velocity v. A moving listener L approaches S with velocity v_L and hears a frequency of f_L from the source. Taking rightwards as positive and the Earth as the frame of reference, the relationship between f_L, f_S, v, v_S and v_L is

$$f_L = \frac{v + v_L}{v + v_S} f_S$$

(i) Fig. 5.1 shows the listener L and the source S.

Draw 4 circular wavefronts emitted from S.

Fig. 5.1

[2]

(ii) A stationary observer hears a train whistle at 480 Hz as the train approaches and 420 Hz as it moves away.

Determine the speed of the train and the frequency of the sound from the source. (Speed of sound is 340 m s^{-1}.)

speed = ……………………….. m s^{-1}

frequency = ……………………… Hz [4]

(b) When the source travels through the air faster than the speed of sound it creates a characteristic conical wave front. The half-angle of this cone is known as the Mach angle α as shown in Fig. 5.2. It is also the angle between the direction of motion of the supersonic source, v_S, and the shock wave, v, it generates.

$$\sin\alpha = \frac{1}{M} = \frac{v}{v_S}$$

where M is the Mach number.

(i) During National Day Parades, the Singapore Air Force (RSAF) F-16 fighter jets fly over Mach 2.

Calculate the maximum Mach angle.

maximum Mach angle = ………………….. ° [1]

(ii) The F-16 is flying at a constant speed at an altitude H above the ground as shown in Fig. 5.2. The speed of sound in the air remains constant. A ground observer hears the sonic boom at a horizontal distance D from the point vertically below the jet.

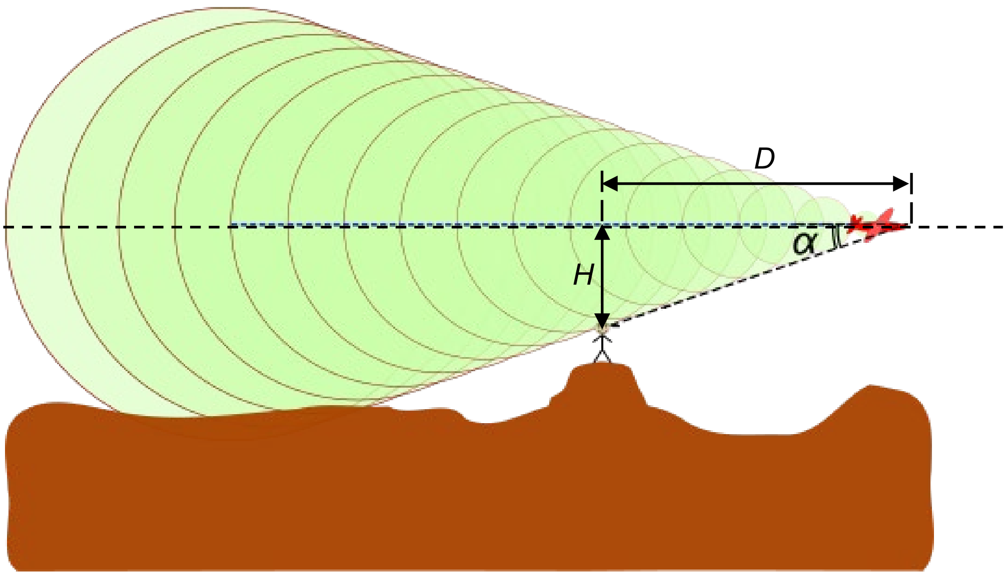


Fig. 5.2

Show that M can be expressed as $M = \sqrt{1+(\frac{D}{H})^2}$.

[2]

(c) The Doppler effect can also be seen in the measured frequencies of the electromagnetic waves emitted from galactic objects. If the wavelength of the radiation emitted is λ_0 and the change in the wavelength measured by the observer is $\Delta\lambda$, then

$$z = \frac{\Delta\lambda}{\lambda_0} = \frac{v_S}{c}$$

where c is the speed of light in a vacuum and v_S is the component of the velocity of the source of the electromagnetic radiation in the direction of the observer.

z is called the red shift parameter.

If the z observed for a star or galaxy is positive then the star is moving away from us. If z is negative, then the star is moving towards us.

The Doppler effect can be used to measure the velocity at which a whole galaxy is moving relative to the Earth for all distant galaxies, but it can only measure the speed at which stars orbit around the distant galaxy with some galaxies.

A convenient unit of distance for astronomical observations and calculations is the parsec (pc) where 1 pc = 3.09×10^{16} m.

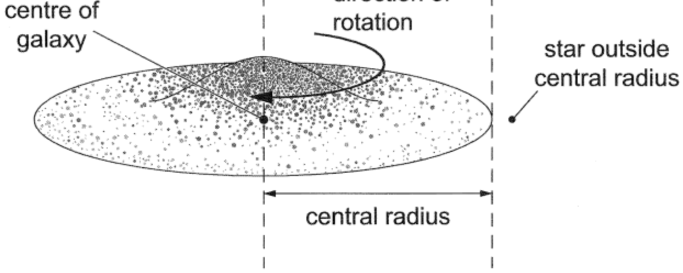


Fig. 5.3

In this question, a galaxy is thought to resemble the model shown in Fig. 5.3 where the mass of the galaxy is concentrated at the rotating centre of the galaxy and stars outside the central radius orbit the centre.

(i) State a necessary condition for the orientation of the plane of a galaxy in order that the Doppler effect be used for the measurement of orbital speed of stars around that galaxy.

You may sketch a diagram.

……………………………………………………………………………………………..

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

(ii) By considering the Doppler effect of radiation emitted from individual stars orbiting around a galaxy, explain how the orientation of a galaxy relative to the observer may be determined.

You may sketch a diagram.

……………………………………………………………………………………………..

……………………………………………………………………………………………..

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

(iii) The graph in Fig. 5.4 compares the predicted and measured speeds of stars orbiting around UGC11748 as a function of their orbital radii.

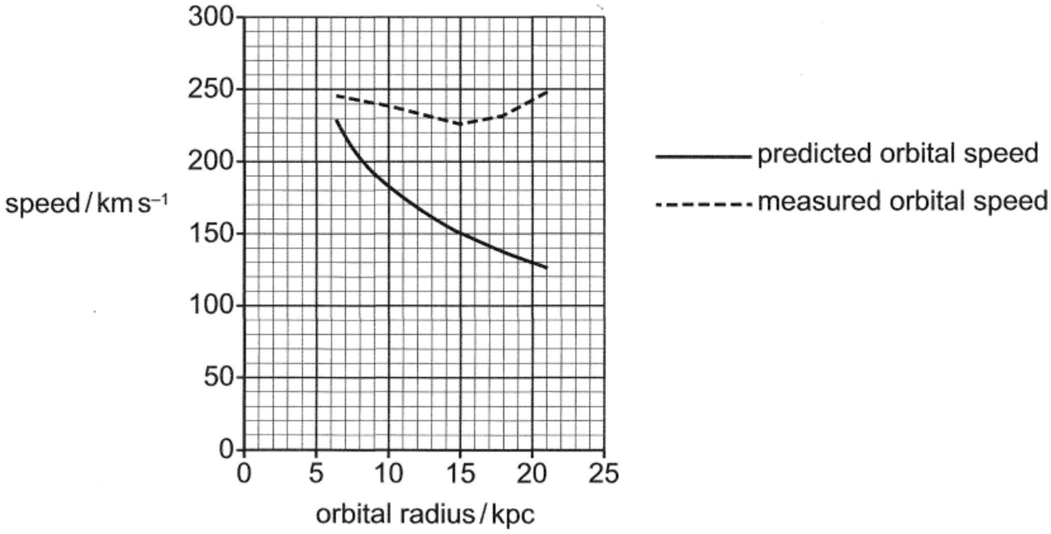


Fig. 5.4

Compare the trends shown by the predicted and measured speeds.

....

....

.... [2]

(iv) Suggest a reason for the discrepancy between the predicted and measured orbital speeds in Fig. 5.4.

Justify your suggestion.

....

....

.... [2]

(d) The Andromeda Galaxy (M31) is the closest large spiral galaxy to our Milky Way. Astronomers observe the H-alpha spectral line (rest wavelength λ_{rest} = 656.28 nm) from different regions within Andromeda's disk to study its motion and rotation.

The table in Fig. 5.5 shows the data for the H-alpha wavelength measurements from Andromeda Galaxy.

Region on Andromeda's Disk	Observed H-alpha Wavelength (λ_{obs} /nm)	z
A (Far side)	655.82	−0.00070
B (Central)	656.08	−0.00031
C (Near side)	656.34	

Fig. 5.5

(i) Complete the row for region C in Fig. 5.5.

[1]

(ii) Describe the overall motion of the Andromeda Galaxy relative to the Milky Way using evidence from Fig. 5.4.

……………………………………………………………………………………………..

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

(iii) Explain how the variation in z values across regions A and C (relative to B) provides evidence for the rotation of Andromeda.

……………………………………………………………………………………………..

……………………………………………………………………………………………..

……………………………………………………………………………………………..

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

[Total: 20]

Section B

Answer two questions from this section
You are advised to spend about 35 minutes on each question

6 (a) Two parallel metal plates are charged equally with opposite charges. The electric field strength in the space between the plates is given by

$$E = \frac{\sigma}{\varepsilon_0},$$

where σ is the surface charge density on the plates.

The area of each plate is A, and the separation between them is d.

Show that the capacitance C of such a pair of plates is

$$C = \varepsilon_0 \frac{A}{d}.$$

[2]

(b) A battery of e.m.f. ε and internal resistance r, a resistor of resistance R, two parallel-plate capacitors, of capacitances C_1 and C_2, and two switches S_1 and S_2 are connected as shown in Fig. 6.1.

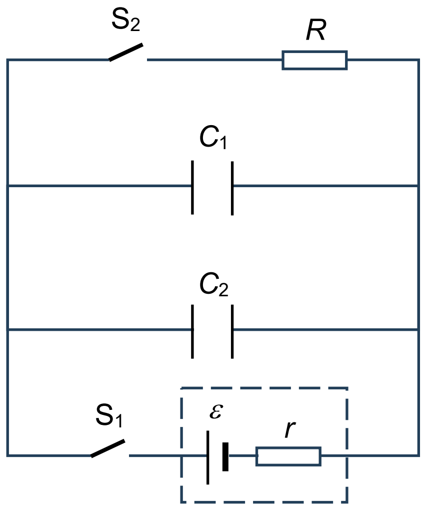


Fig. 6.1

(i) Show that the effective capacitance C_{eq} in the circuit is given by

$$C_{eq} = C_1 + C_2 .$$

[2]

(ii) Initially, S_1 is closed and S_2 is open, until the capacitors are fully charged.

1. State and explain the effect, if any, of the internal resistance of the battery on the maximum potential difference across the capacitors.

....

....[1]

Sketch,

2. on the first set of axes in Fig. 6.2, how the total charge q on the capacitors varies with time; mark the value of the maximum total charge; [1]

3. on the second set of axes in Fig. 6.2, how the current I through the battery varies with time; mark the value of the maximum total current with I_{max}. [1]

Use the same scale for the time axis for the two graphs.

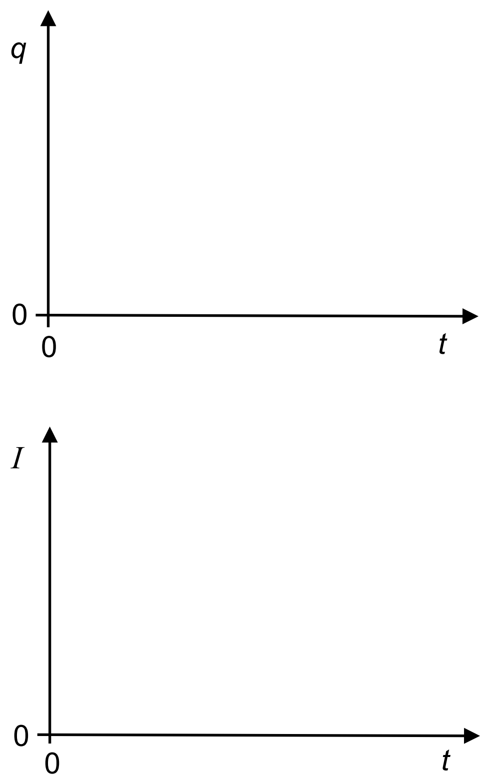


Fig. 6.2

(iii) The time is reset such that t = 0 when S_1 is opened and S_2 is closed.

1. Show that the total charge q on the capacitors satisfies the equation

$$\frac{dq}{dt} + \frac{q}{RC_{\mathrm{eq}}} = 0 .$$

[2]

2. Show, by direct substitution or otherwise, that the solution to the equation in **1.** is

$$q = A + Be^{-\frac{t}{\tau}},$$

where A, B and τ are constants.

Determine A, B and τ.

A = ……………………….

B = ……………………...

τ = ……………………[4]

(iv) **1.** State an expression for the total energy stored on the capacitors when the charge on the capacitor is q.

.... [1]

2. Determine an expression for the power dissipated in the resistor in terms of q, R and $C_{eq.}$

power = ...W [1]

3. Show that energy is conserved as the capacitor is being discharged.

Explain your answer.

....

....

....[2]

(d) The capacitor C_1 used in the circuit in Fig. 6.1 is of capacitance 25.0 μF. It is made from two parallel metal plates that are separated by 1.00 mm, with vacuum between the plates.

(i) Determine the area of each of the parallel plates.

area = ... m^2 [1]

(ii) Modern electronic devices require capacitors that are tiny in size.

Suggest two ways in which the size of the capacitors can be made smaller.

1. ……………………………………………………………………………………………..

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

2. ……………………………………………………………………………………………..

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

[Total: 20]

7 **(a)** Show, from first principles, that the moment of inertia, I, of a solid disc about its central axis is given by

$$I = \frac{MD^2}{8}$$

where M is the mass of the disc and D is the diameter of the disc.

[3]

(b) A playground merry-go-round of mass 730 kg and radius 2.40 m turns, from rest, about its central axis with negligible friction. A child applies an 18.0 N force tangentially to the edge of the merry-go-round for 15.0 s. A simplified merry-go-round is shown in Fig. 7.1.

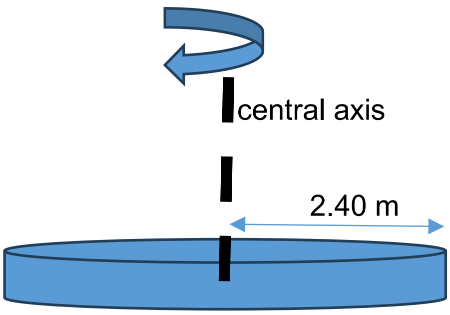


Fig. 7.1

(i) Determine the angular speed of the merry-go-round after the 15.0 s interval. State an important assumption.

angular speed = …………………… rad s^{-1} [5]

(ii) Calculate the work done by the child on the merry-go-round.

work = …………………..J [2]

(iii) Determine the average power supplied by the child.

power = ………………….. W [2]

(c) After the merry-go-round, the child went to play bowling. The bowling ball is given an initial speed v_o without any spin on an alley such that it initially slides without rolling. The coefficient of friction between the ball and alley is μ. Show that at the time pure rolling occurs,

(i) the speed of the ball's centre of mass is $\frac{5}{7}v_o$,

[6]

(ii) the distance it has travelled is $\frac{12{v_o}^2}{49\mu g}$ where g is the acceleration due to free fall.

[2]

[Total: 20]

8 (a) Fig. 8.1 shows a spherical shell of charge of uniform volume charge density ρ. It is given that a = 10 cm and b = 20 cm. The shell will produce electric field of strength E that varies with distance r from its centre.

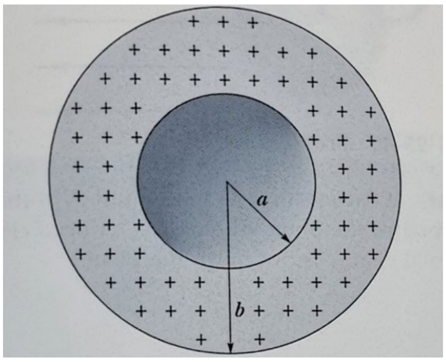


Fig. 8.1

(i) State the value of E when r is between 0 cm and 10 cm,

E = ………………… N C^{-1} [1]

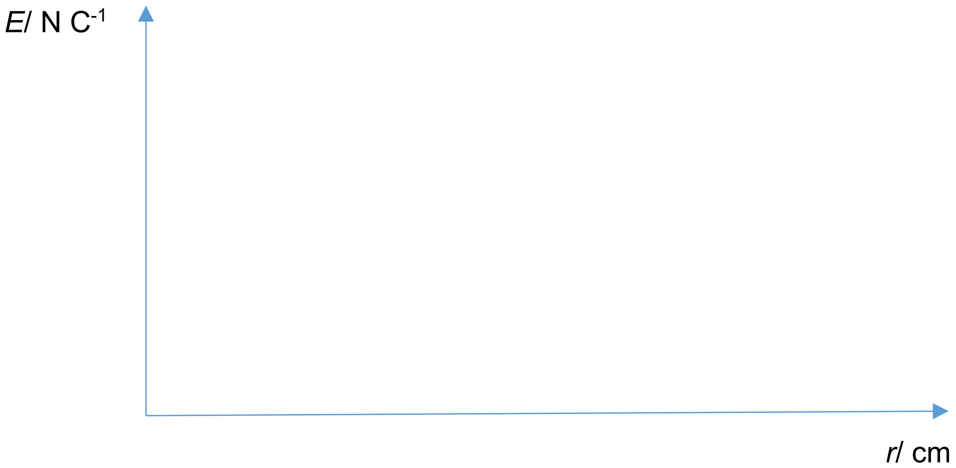
(ii) Deduce an expression of E, in terms of r, when r is between 10 and 20 cm,

E = …………………….. [2]

(iii) Deduce an expression of E, in terms of r, when r is greater than 20 cm,

E = …………………….. [2]

(iv) Hence, on the axes below, sketch a graph to show the variation of E with r when r is between 0 cm and 30 cm. Indicate the value of E at r = 20 cm on the graph. Assume $\rho = 1.0 \times 10^{-6}$ C m^{-3}



[4]

(b) A long cylindrical conductor of radius R carries a current I. The current density J is given by $J = br$, where b is a constant, and r is the distance from the centre of the cylinder as shown in Fig. 8.2.

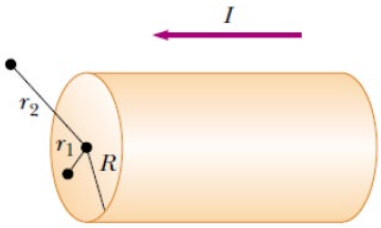


Fig. 8.2

Deduce an expression for the magnetic field B

(i) at a distance $r_1 < R$

B = ………………………… [4]

(ii) at a distance $r_2 > R$

B = ……………………… [3]

(c) An electric dipole, of dipole moment p and moment of inertial I, oscillates in *small amplitude* about its mid-point position, O, in a uniform field of magnitude E. Determine the angular frequency of the oscillation in terms of p, E and I.

angular frequency = ……….………… [4]

[Total: 20]

END OF PAPER

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