



	Course: Applied Physics	Course Code: NS109
Program:	BS (CS), BS(DS) & BS (SE)	Semester: Fall 2023
Duration:	3 Hours	Total Marks: 100, WI: 50%
Date:	27-12-2023	Exam: Final
Section(s):	All	Page(s): 7
Type:	Objective & Subjective	Roll No:
Name:		Section:

KEY

Instructions/Notes:

Attempt all Questions. Please write your answers within the space provided. You can use rough sheet, but that won't be marked.

constants: $g=9.8 \text{ m/s}^2$; $\epsilon_0 = 8.85 \times 10^{-12} \text{ C}^2 \cdot \text{N}^{-1} \text{ m}^{-2}$; $e = \text{charge of electron/proton}=1.60 \times 10^{-19} \text{ C}$; Speed of Light= $3 \times 10^8 \text{ m/s}$; mass of proton= $1.67 \times 10^{-27} \text{ kg}$; mass of electron= $9.11 \times 10^{-31} \text{ kg}$; $\mu_0 = 4\pi \times 10^{-7} \text{ T.m/A}$

Question No.	1	2	3	4	5	6	Total
Maximum Marks	20	15	15	15	15	20	160
Marks Obtained							

Question 1. Circle only ONE correct choice: (10 marks)

(i) A 912-kg car is being driven down a straight, level road at a constant speed of 31.5 m/s. When the driver sees a police cruiser ahead, she removes her foot from the accelerator. After 8.00 s, the speed of the car is 24.6 m/s, which is the posted speed limit. What is the magnitude of the average net force acting on the car during the 8.00 s interval?

- a) 55.2 N
- b) 445 N
- c) 629 N

(d) 787 N
(e) 864 N

(ii) If an object at the surface of the Earth has a weight W , what would be the weight of the object if it was transported to the surface of a planet that is one-sixth the mass of Earth and has a radius one third that of Earth?

- a) $3W$
- b) $4W/3$
- c) W

(d) $3W/2$
(e) $W/3$

(iii) An astronaut, whose mass on the surface of the Earth is m , orbits the Earth in the space shuttle at an altitude of 450 km. What is her mass while orbiting in the space shuttle?

- a) $0.125m$
- b) $0.25m$
- c) $0.50m$

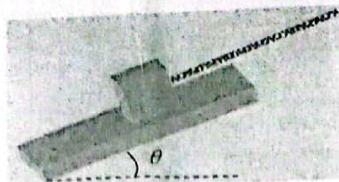
(d) $0.75m$
(e) m

(iv) While working on a project in very-low gravity on the orbiting space station, an engineer finds that when a force F is applied to a 2.0-kg book, it accelerates at 0.50 m/s^2 . If the same force is then applied to a 6.0-kg instruction manual, what would the manual's acceleration be?

- a) 0.17 m/s^2
- b) 0.25 m/s^2
- c) 0.33 m/s^2

(d) 0.50 m/s^2
(e) 1.50 m/s^2

(v) A box is held by a rope on a frictionless inclined surface as shown. What will the magnitude of the acceleration of the box be if the rope breaks?



- a) g
b) $g \sin \theta$
c) $g \cos \theta$
d) $g \tan \theta$
e) zero m/s^2

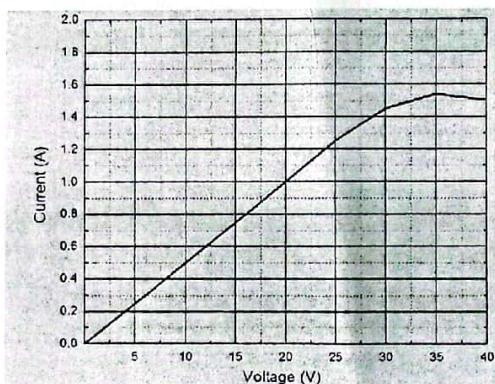
(vi) When a potential difference is applied to a certain copper wire, a current of 1.5 A passes through the wire. If the wire was removed from the circuit and replaced with a copper wire of twice the diameter, what current would flow through the new wire? Assume the wires are identical in all other aspects.

- a) 0.38 A
b) 0.75 A
c) 1.5 A
d) 3.0 A
e) 6.0 A

(vii) A circuit contains a battery and a resistor of resistance R . For which one of the following combinations of current and voltage does R have the smallest value?

- a) $V = 9 \text{ V}$ and $i = 0.002 \text{ A}$
b) $V = 12 \text{ V}$ and $i = 0.5 \text{ A}$
c) $V = 1.5 \text{ V}$ and $i = 0.075 \text{ A}$
d) $V = 6 \text{ V}$ and $i = 0.1 \text{ A}$
e) $V = 4.5 \text{ V}$ and $i = 0.009 \text{ A}$

(viii) A certain circuit contains a battery and a resistor. An instrument to measure the current in the circuit, an ammeter, is connected in between one of the terminals of the battery and one end of the resistor. The graph shows the current in the circuit as the voltage is increased. Which one of the following statements best describes the resistor in this circuit?



- a) The resistor does not obey Ohm's law.
b) The resistor obeys Ohm's law for voltages between zero and twenty-five volts.
c) The resistor obeys Ohm's law for voltages between zero and thirty-five volts.
d) The resistor obeys Ohm's law for voltages between zero and forty volts.

(ix) The drift speed within a certain conductor is 0.10 mm/s. How many electrons move through a unit cross-sectional area in the circuit each second if the current is 2.5 A?

- a) 2.5×10^4
b) 1.6×10^{15}
c) 1.6×10^{23}
d) 2.5×10^{22}
e) 6.4×10^{28}

(x) How does the resistivity of a metal wire change if either the number of electrons per unit volume increases or the mean free time increases?

- a) In both cases, the resistivity will increase.
b) In both cases, the resistivity will decrease.
c) Increasing the number of electrons will increase the resistivity, but it will decrease if the mean free time increases.
d) Increasing the number of electrons will decrease the resistivity, but it will increase if the mean free time increases.

Question 2 (a). Derive an expression of time-period of a simple pendulum. Draw an illustration for free-body/force diagram. (10 marks)

$$\tau = r \perp F$$

$$\tau = -L(F_g \sin\theta)$$

$$\tau = -Lmg \sin\theta$$

$$\tau = I\alpha \therefore \alpha = \frac{d^2\theta}{dt^2}$$

$$\tau = -Lmg \sin\theta$$

$$I \frac{d^2\theta}{dt^2} = -Lmg \sin\theta$$

$$\sin\theta \approx \theta$$

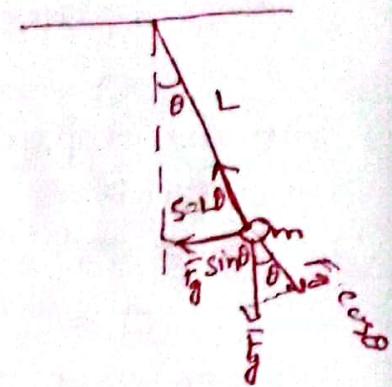
$$I \frac{d^2\theta}{dt^2} + Lmg\theta = 0$$

$$\frac{d^2\theta}{dt^2} + \frac{Lmg\theta}{I} = 0$$

$$I = mL^2$$

$$\frac{d^2\theta}{dt^2} + \frac{Lwhg\theta}{mL^2} = 0$$

$$\frac{d^2\theta}{dt^2} + \frac{g}{L}\theta = 0$$



compare with

$$\frac{d^2x}{dt^2} + \omega^2 x = 0$$

we get

$$\omega^2 = \frac{g}{L}$$

$$\boxed{\omega = \sqrt{g/L}}$$

$$\omega = 2\pi f \Rightarrow \omega = \frac{2\pi}{T}$$

$$T = \frac{2\pi}{\omega} = \frac{2\pi}{\sqrt{g/L}}$$

$$\boxed{T = 2\pi \sqrt{L/g}}$$

Question 2 (b). Find the time period of oscillations of a torsional pendulum, if the torsional constant of the wire is $10\pi^2$ (J/rad). The moment of inertia of rigid body is 10Kgm^2 about the axis of rotation. (5 marks)

$$I = 10\text{Kgm}^2, K = 10\pi^2$$

$$T = 2\pi \sqrt{\frac{I}{K}} = 2\pi \sqrt{\frac{10}{10\pi^2}}$$

$$\boxed{T = 2s}$$

Question 3 (a). Apply Gauss's law and derive an expression of net electric field for the charge (q') enclosed in the Gaussian surface of radius ' r '. Where, ' R ' is the radius of the total charge inside the sphere. (10 marks)

By Gauss's law,

$$\Phi = \alpha / \epsilon_0$$

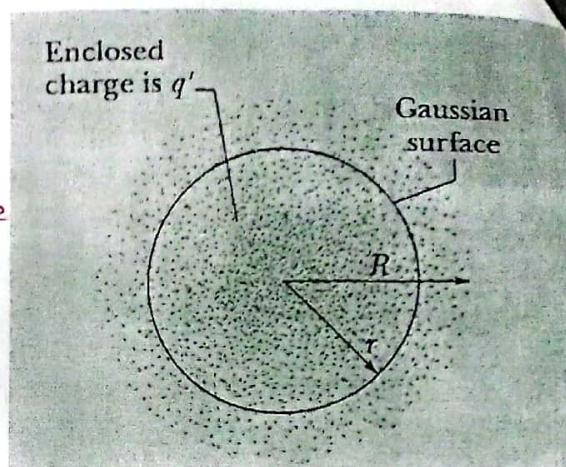
We are applying Gauss's law on the surface of radius r , which encloses charge q' . So,

$$\Phi = \alpha' / \epsilon_0$$

$$\Phi = E \cdot ds = E ds = E (4\pi r^2)$$

$$E (4\pi r^2) = \alpha' / \epsilon_0$$

$$E = \frac{1}{4\pi\epsilon_0} \frac{\alpha'}{\epsilon_0}$$



If the full charge α enclosed within radius R is uniform then α' is proportional to α .

$$\frac{\alpha'}{4\pi r^3} = \frac{\alpha}{4\pi R^3} \Rightarrow \alpha' = \alpha \frac{r^3}{R^3}$$

This gives us:

$$E = \left(\frac{\alpha}{4\pi\epsilon_0 R^3} \right) r \quad (r \leq R)$$

Question 3 (b). Determine the charge density of an electric field, if a charge of 6 C per meter is present in a cube of volume 3 m^3 . (5 marks)

$$\alpha = 6 \text{ C per meter}$$

$$\text{Volume } V = 3 \text{ m}^3$$

Charge density formula computed by volume is given by,

$$\rho = \alpha / V = 2 \text{ C/m}^3$$

$$\rho = 2 \text{ C/m}^3$$

Question 4 (a) Derive an expression of Capacitance in the case of a spherical capacitor with inner radius 'a' and outer radius 'b'. Use Gauss's law for the calculations. Draw an illustration as well. (7 marks)

$$Q = \epsilon_0 E A \quad \therefore 4\pi r^2 \text{ is area of sphere}$$

$$Q = \epsilon_0 E (4\pi r^2)$$

$$E = \frac{Q}{4\pi \epsilon_0 r^2}$$

$$V = - \int E dr$$

$$= - \int \frac{Q}{4\pi \epsilon_0 r^2} dr$$

$$= \frac{Q}{4\pi \epsilon_0} \left[\frac{1}{r} \right]_a^b$$

$$V = \frac{Q}{4\pi \epsilon_0} \left(\frac{1}{b} - \frac{1}{a} \right)$$

$$V = \frac{Q}{4\pi \epsilon_0} \left(\frac{b-a}{ab} \right)$$

$$C = \frac{Q}{V} = \frac{4\pi \epsilon_0 ab}{b-a}$$

Question 4 (b) Determine the net capacitance C of the capacitor combination shown in Figure below. Values of the capacitances are as follows: $C_1 = 12 \mu F$, $C_2 = 20 \mu F$, and $C_3 = 4 \mu F$. When a 12-volt potential difference is maintained across the combination, find the charge and the voltage across each capacitor. (8 marks)

$$C_{23} = C_2 + C_3 = 2.0 \mu F + 4.0 \mu F = 6.0 \mu F$$

$$\frac{1}{C_{eq}} = \frac{1}{12.0 \mu F} + \frac{1}{6.0 \mu F} = \frac{1}{8.0 \mu F}$$

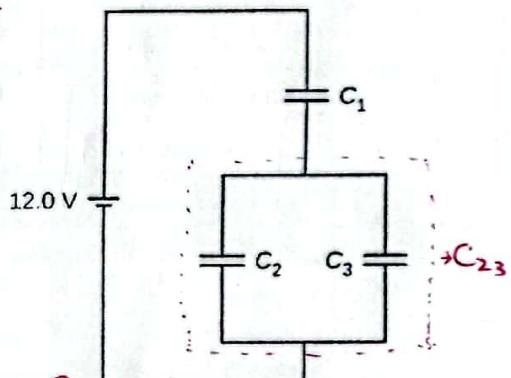
$$C_{eq} = 8.0 \mu F$$

Since the capacitors are in series, they have the same charge.

$$Q_1 = Q_{23}$$

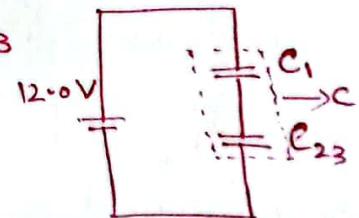
$$12.0 V = V_1 + V_{23} = \frac{Q_1}{C_1} + \frac{Q_{23}}{C_{23}} = \frac{Q_1}{C_1} + \frac{Q_1}{C_{23}}$$

$$12.0 V = \frac{Q_1}{12 \mu F} + \frac{Q_1}{6.0 \mu F} \Rightarrow Q_1 = 96 \mu C$$



$$\text{Now, } V_1 = \frac{Q_1}{C_1} = \frac{96}{12} = 8 V \Rightarrow V_1 = 8 V$$

Because C_2 and C_3 are connected in parallel, they have same V.
 $V_2 = V_3 = 12 - 8 = 4 V \Rightarrow V_2 = 4 V, V_3 = 4 V$



Now,

$$Q_2 = C_2 V_2 = (20)(4) = 80 \Rightarrow Q_2 = 80 \mu C$$

$$Q_3 = C_3 V_3 = (4)(4) = 16 \Rightarrow Q_3 = 16 \mu C$$

C_2 and C_3 are in parallel,

$$Q_{23} = Q_2 + Q_3 = 16 + 80 = 96 \mu C$$

Question 5 (a). What was the basic purpose of the Hall's effect? Derive an expression for potential difference created across the width of a current carrying copper strip immersed in the magnetic field. Draw an illustration of the Hall's effect and indicate vectors for electrostatic and magnetic forces. (8 marks)

The Hall's effect can be used to measure the density of current carriers and their freedom of movement as well as to detect the presence of a current on a magnetic field.

$$F_E = F_B$$

$$\epsilon E = eVd/B$$

$$E = Vd/B \rightarrow \text{eq } (1)$$

$$J = enVd$$

$$V_d = \frac{J}{ne}$$

$$\therefore J = \frac{i}{A}$$

$$N_d = \frac{i}{enA}$$

where

$$A = l \times d$$

l = thickness

d = width

$$V = Ed$$

$$E = \frac{V}{d}$$

Putting the value of E and V_d in eq (1). we get

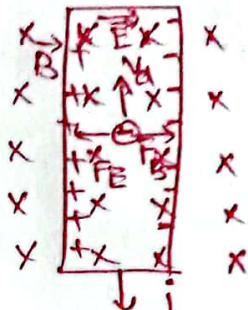
$$\frac{V}{d} = \frac{iB}{lne}$$

$$V = \frac{iB}{lne}$$

This is the Hall Potential.

$$n = \frac{iB}{Vde}$$

This is the number density of current carriers.



Question 5 (b). A straight, horizontal length of copper wire has a current $i = 28 \text{ A}$ through it. What are the magnitude and direction of the minimum magnetic field needed to suspend the wire—that is, to balance the gravitational force on it? The linear density (mass per unit length) of the wire is 46.6 g/m . (7 marks)

$$F_B = F_g$$

$$F_B = iLB \sin 90^\circ = iLB$$

$$F_B = iLB$$

$$F_B = F_g$$

$$iLB = mg$$

$$B = \frac{mg}{iL} \Rightarrow$$

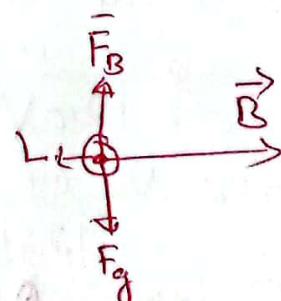
$$i = 28 \text{ A}$$

$$m/L = 46.6 \text{ g/m}$$

$$B = \frac{(m/L)g}{i}$$

$$B = \frac{(46.6 \times 10^{-3} \text{ kg/m})(9.8 \text{ m/s}^2)}{28 \text{ A}}$$

$$B = 1.6 \times 10^{-2} \text{ T}$$



Question 6 (a). Derive an expression for internal magnetic field \mathbf{B} of a solenoid. (5 marks)

We will use the Amperian loop abcd.

$$\oint \bar{B} \cdot d\bar{s} = \int_a^b \bar{B} \cdot d\bar{s} + \int_c^d \bar{B} \cdot d\bar{s} + \int_d^a \bar{B} \cdot d\bar{s} + \int_b^c \bar{B} \cdot d\bar{s}$$

$$\int_b^c \bar{B} \cdot d\bar{s} = \int_b^c B \cdot ds \quad \int_b^c B \cdot ds = 0$$

$I_{enc} = nhi$

Now we have only one side (ab) inside solenoid.

$$\int_a^b \bar{B} \cdot d\bar{s} = \int_a^b B ds \cos 0 = B \int_a^b ds = Bh \Rightarrow B = \mu_0 ni$$

Question 6 (b). Two parallel wires, 4 cm apart, carry currents of 2 A and 4 A respectively, in the same direction. Find the force per unit length of one wire on the other is [$\mu_0 = 4\pi \times 10^{-7} \text{ T.m/A}$]. (5 marks)

$$\frac{F}{L} = \frac{\mu_0 i_1 i_2}{2\pi d} = \frac{4\pi \times 10^{-7} \times 2 \times 4}{2\pi \times 4 \times 10^{-2}}$$

$$\boxed{\frac{F}{L} = 4 \times 10^{-5} \text{ N/m}}, \text{ attractive}$$

Question 6 (c). Figure below shows the cross section of a long conducting cylinder with inner radius $a = 2.0 \text{ cm}$ and outer radius $b = 4.0 \text{ cm}$. The cylinder carries a current out of the page, and the magnitude of the current density in the cross section is given by $J = cr^2$, with $c = 3.0 \times 10^6 \text{ A/m}^4$ and r in meters. What is the magnetic field at the dot in Figure below, which is at radius $r = 3.0 \text{ cm}$ from the central axis of the cylinder? (10 marks)

$$I_{enc} = \int J dA = \int_a^r cr^2 (2\pi r dr)$$

$$= 2\pi c \int_a^r r^3 dr = 2\pi c \left[\frac{r^4}{4} \right]_a^r$$

$$= \frac{\pi c (r^4 - a^4)}{2}$$

$$\oint \bar{B} \cdot d\bar{s} = \mu_0 I_{enc}$$

gives us

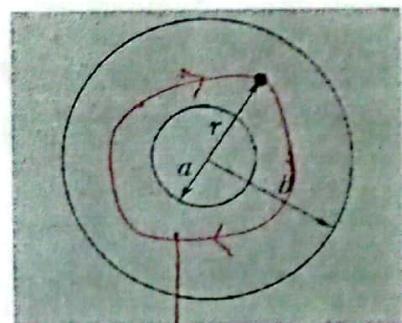
$$B(2\pi r) = -\frac{\mu_0 \pi c (r^4 - a^4)}{2}$$

$$B = -\frac{\mu_0 c (r^4 - a^4)}{4\pi r}$$

$$= -\frac{(4\pi \times 10^{-7} \text{ T.m/A})(3.0 \times 10^6 \text{ A/m}^4) \times [(0.03)^4 - (0.02)^4]}{4\pi (0.03)}$$

$$B = -2.0 \times 10^{-5} \text{ T}$$

$$\boxed{B = 2.0 \times 10^{-5} \text{ T}} \text{ magnitude of magnetic field.}$$



Amperian Loop
(clockwise direction)