UNIVERSITY OF FORT HARE

ELECTRICITY AND MAGNETISM
PHY 121

SUPPLEMENTARY EXAMINATIONS

NOVEMBER / JANUARY

2024

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Time: 3 Hours

Subject: PHY 121

Marks: 100

This paper consists of 8 pages including the cover page

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Moderator

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INSTRUCTIONS

1. Answer all questions.
2. Write neatly and legibly.
3. Unless otherwise stated, all symbols retain their usual meanings.
4. Values of constants, formulae sheet and periodic table elements appear at the end of the question paper.

Question 1 [25 Marks]

1.1. Define the following terms

1.1.1. Coulomb's law (2)

1.1.2. Conservation of charge (2)

1.2. Differentiate between Conductors, semiconductors and insulators. (3)

1.3. When a dipole changes direction in an electric field, the electric-field torque does work on it, with a corresponding change in potential energy. Show that the potential energy of a dipole is given as: (8)

$$U = -\vec{p}.\vec{E}$$

1.4. An average human weighs about 650 N. If two such generic humans each carried 1.0 C of excess charge, one positive and one negative, how far apart would they have to be for the electric attraction between them to equal their 650-N weight? (3)

1.5. A particle has charge $-3nC$,

1.5.1. Find the magnitude and direction of the electric field due to this particle at a point 0.25 m directly above it. (2)

1.5.2. At what distance from this particle does its electric field have a magnitude of 12.0 N/C? (3)

[25]

Question 2 [25 Marks]

2.1. Define the following terms:

2.1.1. Electromotive force (2)

2.1.2. Power (2)

2.2. Consider Figure 1 (a and b) and comment on the movement of charge, electric field and work done. (6)

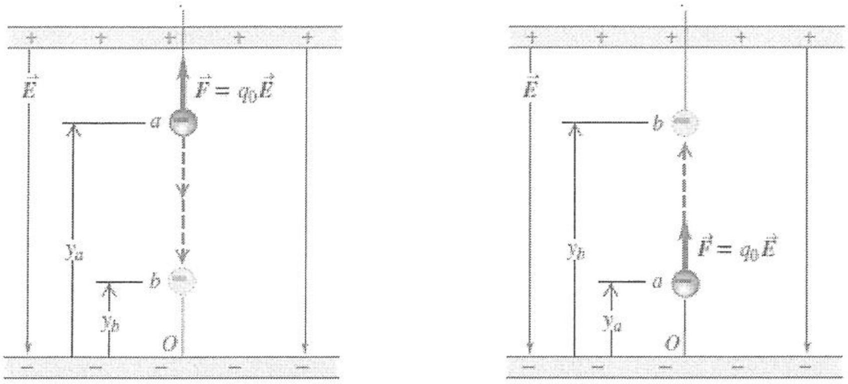


Figure 1

2.3. In the absence of electric field, the electrons move in straight lines between collisions; the directions of their velocities are random, and on average they never get anywhere (Figure 1a). But if an electric field is present, the paths curve slightly because of the acceleration caused by electric-field forces (Figure 1b). (8)

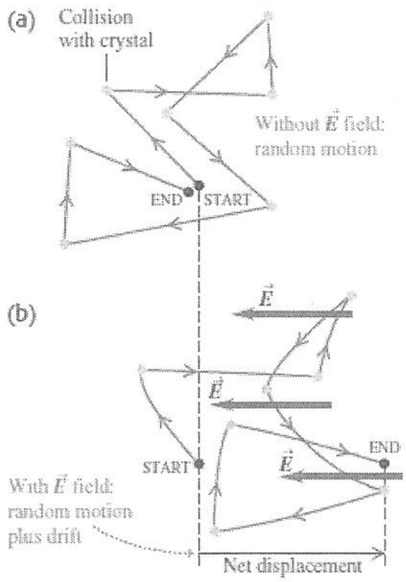


Figure 2

Show that the resistivity is given as:

$$\rho = \frac{m}{ne^2\tau}$$

2.4. Copper has 8.5×10^{28} free electrons per cubic meter. A 71.0-cm length of 12-gauge copper wire that is 2.05 mm in diameter carries 4.85 A of current.

2.4.1. How much time does it take for an electron to travel the length of the wire? (4)

2.4.2. Repeat part (a) for 6-gauge copper wire (diameter 4.12 mm) of the same length that carries the same current. (3)

[25]

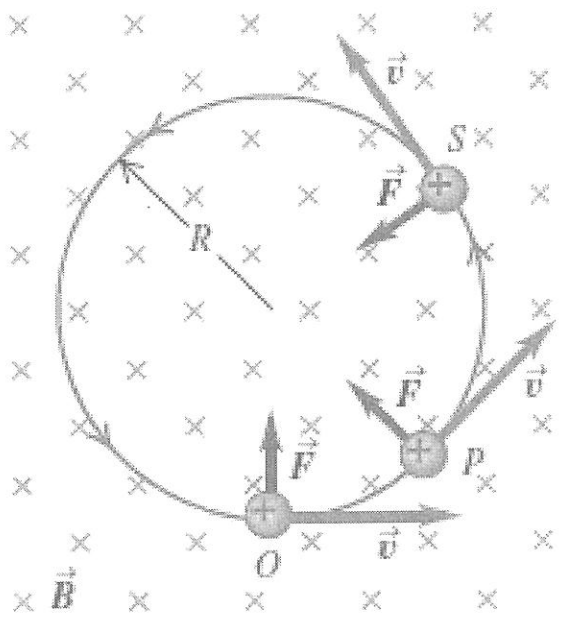
Question 3 [25 Marks]

3.1. Name and discuss the four electrical measuring instruments. (8)

3.2. State the two Kirchhoff's rules in words and equation forms. (4)

3.3. Figure 3 shows the orbit of a charged particle in a uniform magnetic field. Show that the angular speed of the particle is given as:

$$\omega = \frac{|q|B}{m}$$



(6)

Figure 3

3.4. In the circuit shown in the Figure 4 below, find

3.4.1. the current in each branch and (5)

3.4.2. the potential difference V_{ab} of point a relative to point b. (2)

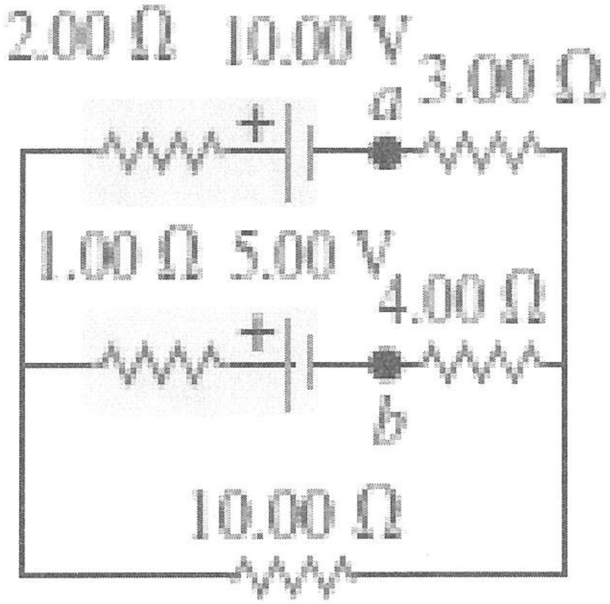


Figure 4

[25]

Question 4 [25 Marks]

4.1. Define the following terms:

4.1.1. The principle of superposition of magnetic fields (2)

4.1.2. Source Point (2)

4.2. Figure 5 shows magnetic-field vectors due to a short current element $d\vec{l}$ of a current-carrying conductor. Derive the law of Biot and Savart.

$$d\vec{B} = \frac{\mu_0}{4\pi}\frac{Id\vec{l} \times \hat{r}}{r^2}$$ (6)

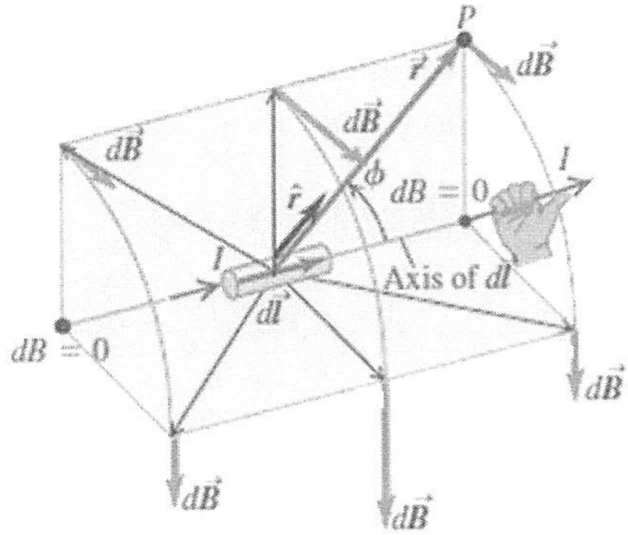


Figure 5

4.3. Figure 6 shows a circular conductor with radius a. A current I is led into and out of the loop through two long, straight wires side by side; the currents in these straight wires are in opposite directions, and their magnetic fields very nearly cancel each other. Using the law of Biot and Savart, show that the magnetic field at a point P on the axis of the loop is given as:

$$B_x = \frac{\mu_0 N I a^2}{2(x^2 + a^2)^{3/2}}$$ (8)

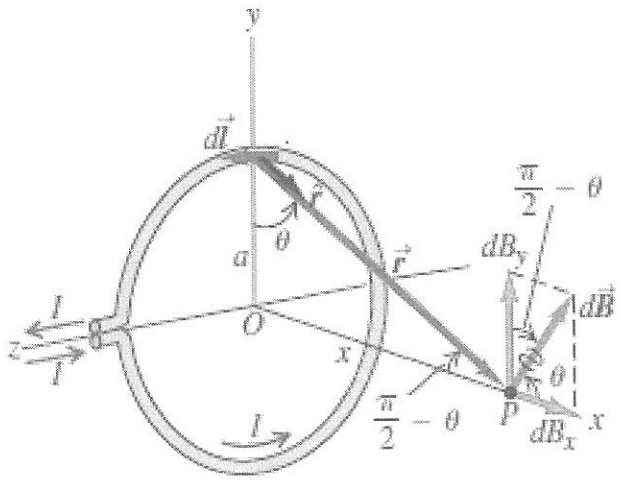


Figure 6

4.4. A closely wound, circular coil with radius 2.40 cm has 800 turns.

4.1.3. What must the current in the coil be if the magnetic field at the center of the coil is 0.0580 T? (2)

4.1.4. At what distance x from the center of the coil, on the axis of the coil, is the magnetic field half its value at the center? (5)

[25]

Useful formulae

$$\oint \vec{B}.d\vec{l} = \mu_0 I_{encl};\ B = \frac{\mu_0 I}{2\pi r};\ B_x = \frac{\mu_0 NI}{2a};\ \frac{F}{L} = \frac{\mu_0 II\prime}{2\pi r};\ \vec{F} = I'\vec{L} \times \vec{B};\ d\vec{B} =$$

$$\frac{\mu_0}{4\pi}\frac{Id\vec{l}\times\hat{r}}{r^2};\ I = n|q|v_d A;\ dQ = nqAdl;\ \vec{B} = \frac{\mu_0}{4\pi}\frac{q\vec{v}\hat{r}}{r^2};\ nq = \frac{-J_x B_y}{E_z};$$

$$U = -\vec{\mu}.\vec{B};\ F = IaB;\ \frac{I_1}{I_2} = \frac{R_2}{R_1};\ \vec{v}_{av} = \vec{a}\tau;\ P = \frac{W}{t};\ I = \frac{\varepsilon}{R+r};\ R(T) =$$

$$R_0[1 + \alpha(T - T_0)];\ \rho(T) = \rho_0[1 + \alpha(T - T_0)];\ dQ = qnA|v_d|dt;$$

$$-dV = \vec{E}.d\vec{l};\ V = \frac{U}{q_0};\ U = \frac{1}{4\pi\epsilon_0}\frac{qq_0}{r};\ U = q_0 Ey;\ E_\perp = \frac{\sigma}{\epsilon_0};\ \Phi_E = \oint \vec{E}.d\vec{A};$$

$$dW = \tau d\phi;\ F = k\frac{|q_1 q_2|}{r^2}$$

Constants

Fundamental Physical Constants*

Name	Symbol	Value
Speed of light in vacuum	c	2.99792458×10^8 m/s
Magnitude of charge of electron	e	$1.602176487(40) \times 10^{-19}$ C
Gravitational constant	G	$6.67428(67) \times 10^{-11}$ N · m²/kg²
Planck's constant	h	$6.62606896(33) \times 10^{-34}$ J · s
Boltzmann constant	k	$1.3806504(24) \times 10^{-23}$ J/K
Avogadro's number	N_A	$6.02214179(30) \times 10^{23}$ molecules/mol
Gas constant	R	8.314472(15) J/mol · K
Mass of electron	m_e	$9.10938215(45) \times 10^{-31}$ kg
Mass of proton	m_p	$1.672621637(83) \times 10^{-27}$ kg
Mass of neutron	m_n	$1.674927211(84) \times 10^{-27}$ kg
Permeability of free space	μ_0	$4\pi \times 10^{-7}$ Wb/A · m
Permittivity of free space	$\epsilon_0 = 1/\mu_0 c^2$	$8.854187817\ldots \times 10^{-12}$ C²/N · m²
	$1/4\pi\epsilon_0$	$8.987551787\ldots \times 10^{9}$ N · m²/C²

Other Useful Constants*

Mechanical equivalent of heat		4.186 J/cal (15° calorie)
Standard atmospheric pressure	1 atm	1.01325×10^5 Pa
Absolute zero	0 K	−273.15°C
Electron volt	1 eV	$1.602176487(40) \times 10^{-19}$ J
Atomic mass unit	1 u	$1.660538782(83) \times 10^{-27}$ kg
Electron rest energy	$m_e c^2$	0.510998910(13) MeV
Volume of ideal gas (0°C and 1 atm)		22.413996(39) liter/mol
Acceleration due to gravity (standard)	g	9.80665 m/s²