Electromagnetism and Optics: Class Exam III

15 April 2026

Name: SOLUTION **Total:** /80

Instructions

- There are 9 questions on 6 pages.
- Show your reasoning and calculations and always explain your answers.

Physical constants and useful formulae

$$e = 1.60 \times 10^{-19}\,\mathrm{C} \qquad q_{\text{electron}} = -e \qquad q_{\text{proton}} = +e$$

$$m_{\text{electron}} = 9.11 \times 10^{-31}\,\mathrm{kg} \qquad m_{\text{proton}} = 1.67 \times 10^{-27}\,\mathrm{kg} \qquad c = 3.0 \times 10^{8}\,\mathrm{m/s}$$

$$k = 8.99 \times 10^{9}\,\mathrm{Nm^2/C^2} \qquad \epsilon_0 = 8.85 \times 10^{-12}\,\mathrm{C^2/Nm^2}$$

✓ **Question 1**

The Earth's magnetic field at a particular location is horizontal, pointing north with magnitude $3.36 \times 10^{-5}\,\mathrm{T}$. A circular loop of wire with radius $0.150\,\mathrm{m}$ carries a current so that at this location the net magnetic field at the center of the loop is zero. Aside from the loop and the Earth there are no other significant sources of magnetic field at this location.

a) Determine the current in the loop.

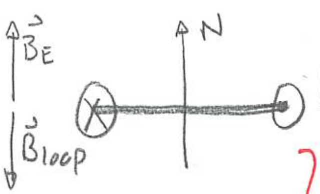
$\vec{B} = \vec{B}_E + \vec{B}_{loop} = 0 \Rightarrow \vec{B}_{loop} = -\vec{B}_E$ +1 or equiv

Magnitudes equal

$B_{loop} = B_E \qquad \frac{\mu_0 I}{2R} = B_E \Rightarrow I = \frac{2 R B_E}{\mu_0}$ +1

So $I = \frac{2 \times 0.150\,\mathrm{m} \times 3.36 \times 10^{-5}\,\mathrm{T}}{4\pi \times 10^{-7}\,\mathrm{Tm/A}} = 8.02\,\mathrm{A}$ +3

b) Describe how the loop should be oriented so that the net magnetic field at its center is zero at this particular location.



loop is perpendicular to Earth's field +2

sense +1

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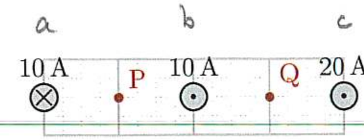
$\vec{B} = \vec{B}_a + \vec{B}_b + \vec{B}_c$

✓ **Question 2**



Three infinitely long wires pointing perpendicular to the page carry currents as illustrated. Let B_P be the magnitude of the net magnetic field at location P, and B_Q be the magnitude of the net magnetic field at location Q. Which of the following (choose one) is true regarding the net magnetic fields?

At P

$\vec{B}_a \downarrow \downarrow \vec{B}_b \downarrow \vec{B}_c$

All add

At Q

$\vec{B}_b \uparrow \downarrow \vec{B}_c \downarrow \vec{B}_c$

partly cancel.

i) $B_P = B_Q = 0$

ii) $B_P = B_Q \neq 0$

iii) $B_P > B_Q$

iv) $B_P < B_Q$

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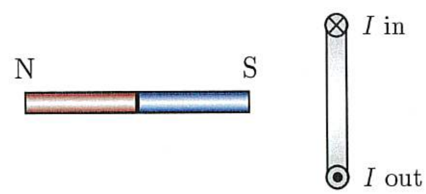
✓ **Question 3**

A bar magnet is placed next to a loop that carries a current. The axis of the loop lies along the axis of the bar magnet. A side view is illustrated. Which of the following (choose one) represents the direction of the force exerted by the magnet on the loop?



i) →

ii) ←

iii) ↑

iv) ↓

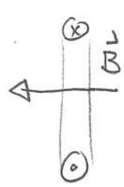
v) ⊗

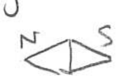
vi) ⊙

vii) Zero force

Briefly explain your choice.

The loop produces its own magnetic field. This corresponds to a magnet oriented as illustrated





The external magnet will attract this

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Question 5

A charged particle orbits in a circle perpendicular to a uniform magnetic field. Suppose that the magnetic field strength is B, the charge of the particle is q, its mass is m and the radius of orbit is r. **Starting with and using Newton's Second Law,** determine an expression for the time taken to complete on orbit, T, in terms of B, q and m.

$\underbrace{\vec{F}_{net} = m\vec{a}}_{+1} \Rightarrow F_{mag} = ma$

But $\underbrace{a = \frac{v^2}{r}}_{(+2)}$

$\vec{F}_{mag} = \underbrace{q\vec{v} \times \vec{B}}_{\cancel{(+2)}(+1)}$

$F_{mag} = qvB \cancel{\sin 90°}$

$\cancel{(+2)}\ \cancel{(+3)}\ \cancel{(+2)}\ (+3)$

So $q\cancel{v}B = m v^{\cancel{2}}/r$

Then $\underbrace{v = \frac{2\pi r}{T}}_{(+3)} \Rightarrow qB = \frac{m\, 2\pi r/T}{r} \Rightarrow qB = \frac{m 2\pi}{T}$

assemble (+2)

$\Rightarrow T = 2\pi \frac{m}{qB}$

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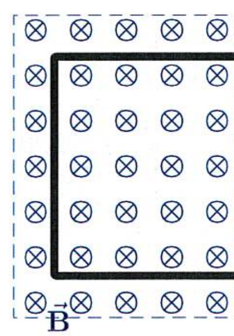
Question 6

A square loop is placed in a uniform magnetic field as illustrated. The magnetic field decreases over time.



a) Which of the following (choose one) is true while the magnetic field decreases?

Flux decreases inward $\Rightarrow$ current exists

i) There is no current in the loop.

ii) The current in the loop is clockwise (as viewed in the diagram). (+4)

iii) The current in the loop is counterclockwise (as viewed in the diagram).

b) Does the field exert a force on the loop while it is decreasing? Explain your answer.

right side view

$B_i \rightarrow$

$\rightarrow \vec{B}_f$

$\leftarrow \Delta\vec{B}$

$\rightarrow \vec{B}_{ind}$

$\rightarrow$ Clockwise

Yes on vertical section. So $\vec{F} = I\vec{L} \times \vec{B}$ (+1)

and $\vec{L}$ is $\uparrow$

$\otimes \uparrow I$

$\vec{B}$ is $\otimes$

So force is $\leftarrow$

(+2)

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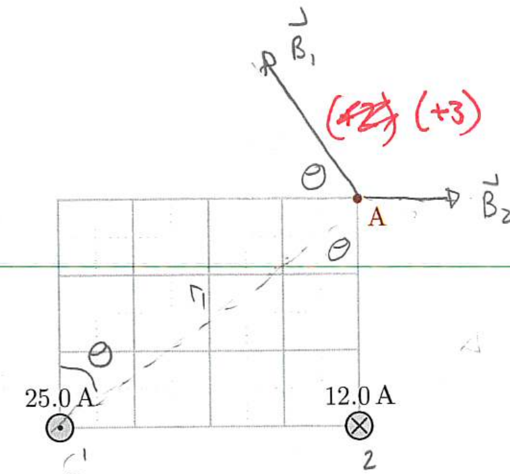
Question 4

Two infinitely long wires point perpendicular to the page and carry the indicated currents. The grid blocks have units 1.00 cm.



a) Determine the net magnetic field at the point A.

$\vec{B} = \vec{B}_1 + \vec{B}_2$

$B_1 = \frac{\mu_0 I_1}{2\pi r_1} = \frac{4\pi\times10^{-7}\,Tm/A \times 25.0\,A}{2\pi\times 0.0500\,m} = 1.00\times10^{-4}\,T$ (+1) (+2)

$r_1 = \sqrt{(0.04\,m)^2 + (0.03\,m)^2} = 0.05\,m$ (+1)

$B_2 = \frac{\mu_0 I_2}{2\pi r_2} = \frac{4\pi\times10^{-7}\,Tm/A\times 12.0\,A}{2\pi\times 0.0300\,m} = 0.80\times10^{-4}\,T$

$\theta = \arctan\frac{4}{3} = 53.1^\circ$ (+2)

Components

$B_{1x} = -B_1\cos\theta = -1.00\times10^{-4}\,T\cos 53.1^\circ = -6.0\times10^{-5}\,T$

$B_{1y} = +B_1\sin\theta = +1.00\times10^{-4}\,T\sin 53.1^\circ = +8.0\times10^{-5}\,T$ (+3)

So

actual adding (+2)

$\vec{B} = 2.0\times10^{-5}\,T\,\hat{i} + 8.0\times10^{-5}\,T\,\hat{j}$

	x	y
$\vec{B}_1$	$-0.60\times10^{-4}\,T$	$+8.0\times10^{-5}\,T$
$\vec{B}_2$	$0.80\times10^{-4}\,T$	0

b) A proton moves past location A with velocity 4.00×10^6 m/s to the left. Determine the net force exerted by the magnetic field as the proton passes A.

$\vec{v} = -4.00\times10^6\,m/s\,\hat{i}$

$\vec{F} = q\vec{v}\times\vec{B} = 1.6\times10^{-19}\,C\left(-4\times10^6\,m/s\,\hat{i}\times\left[2.0\times10^{-5}\,T\,\hat{i} + 8.0\times10^{-5}\,T\,\hat{j}\right]\right)$ (+3)

(+1)

$= -5.13\times10^{-17}\,N\,\hat{k}$

(+1)

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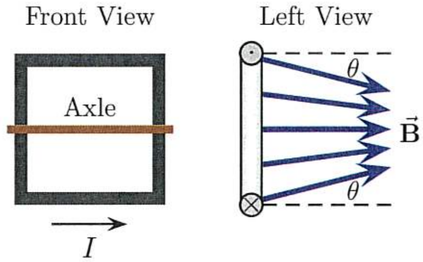
Question 7

A square loop carries current I and is placed in a non-uniform magnetic field with magnitude B. Viewed from the left side the current in the upper end of the loop is out of the page and in the lower end of the loop it is into the page. Viewed from the left side the magnetic field lies in the plane of the page and is angled as illustrated; the field does not varying horizontally across the face of the loop.



Need to draw forces (+2)

a) Is the force exerted by the magnetic field on the loop (at the illustrated moment) zero or not? Explain your answer. Non-zero

The currents on the vertical sections are opposite $\Rightarrow$ forces cancel

On top $\vec{F} = I\vec{L} \times \vec{B}$ +1 on bottom . The forces are $\vec{F}_{top}$ $\vec{F}_{bottom}$ $\rightsquigarrow$ $\vec{F}_{net}$

$\vec{L}$ $\vec{F}$ $\vec{B}$ $\vec{B}$ $\vec{L}$ $\vec{F}$ non-zero

b) Is the torque exerted by the magnetic field on the loop (at the illustrated moment) zero or not? Explain your answer.

Zero. The two forces produce equal + opposite torques.

These cancel

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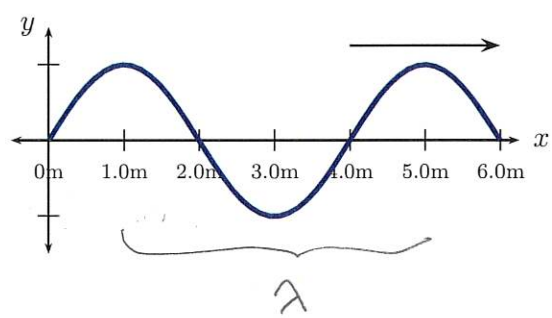
Question 8

At one instant a snapshot of a wave is as illustrated. The wave travels right with speed 240 m/s.



a) Determine the wavelength and frequency of the wave.

From snapshot $\lambda = 4.0\,m$ +1

$v = \lambda f \Rightarrow f = \frac{v}{\lambda} = \frac{240\,m/s}{4\,m} = 60\,Hz$ +3

Question 8 continued . . .

b) Determine how many crests pass the $x = 5\,\mathrm{m}$ mark every minute. +2

The frequency is the number of crests in one second $\Rightarrow 60/s$

In one minute $= 60s$ there will be $60 \times 60 = 3600$ crests

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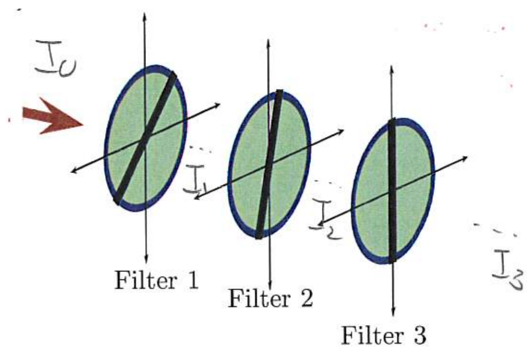
Question 9

Linearly polarized light, whose direction of polarization is horizontal, is incident on a succession of three polarizing filters. The transmission axis of the first filter is 45° above the horizontal. The transmission axis of the second filter is 75° above the horizontal (and 30° from the first) and the transmission axis of the third filter is vertical. Let I_0 be the intensity of the light before the first filter. Determine an expression for the intensity of the light transmitted by the third filter, expressing your answer in terms of I_0.



$I_{tran} = I_{inc} \cos^2 \theta$

$I_1 = I_0 \cos^2 45°$

$I_2 = I_1 \cos^2 (75° - 45°) = I_1 \cos^2 30°$

$I_3 = I_2 \cos^2 (15°)$

$\Rightarrow \quad I_3 = I_1 \cos^2(30°) \cos^2(15°)$

$= I_0 \cos^2 45° \cos^2 30° \cos^2 15°$

$I_3 = 0.350\, I_0$

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