Print your name and section clearly above. If you do not know your section number, write your TA’s name.

Your final answer must be placed in the box provided. **You must show all your work to receive full credit.** If you only provide your final answer (in the box), and do not show your work, you will receive very few points.

Problems will be graded on reasoning and intermediate steps as well as on the final answer. Be sure to include units, and also the direction of vectors.

You are allowed one 8½ x 11” sheet of notes and no other references. The exam lasts exactly 90 minutes.

### Problems

- **Problem 1:** _______ / 20
- **Problem 2:** _______ / 20
- **Problem 3:** _______ / 20
- **Problem 4:** _______ / 25
- **Problem 5:** _______ / 20

**TOTAL:** _______ / 105
1) [20 pts, 4 pts each] Multiple choice/short answer.

i) A negatively charged particle is moving at speed v to the right in a magnetic field directed into the page. The direction of the force on the particle is

a) up
b) down
c) left
d) right
e) into page
f) out of page
g) none of these

ii) Current flows through all parts of the infinitely long wire as shown. What is the magnetic field strength at the center of the loop of radius $R$?

a) $B = \mu_0 I / 4R$
b) $B = \mu_0 I / 4R + \mu_0 I / 2\pi R$
c) $B = \mu_0 I / 4R + 2\mu_0 I / 2\pi R$
d) $B = -\mu_0 I / 4R + 2\mu_0 I / 2\pi R$
e) $B = \mu_0 I / 2R$
f) none of these

iv) Water (index of refraction=1.33) is inside a glass fishtank (index of refraction=1.5). A flashlight held underwater is pointed at the glass. The critical angle for total internal reflection $\theta_c$ satisfies

a) $0^\circ < \theta_c \leq 30^\circ$
b) $30^\circ < \theta_c \leq 45^\circ$
c) $45^\circ < \theta_c \leq 60^\circ$
d) $60^\circ < \theta_c < 90^\circ$
e) none of the above

v) At right is an infinitely long coaxial cable. The inner and outer conductors uniformly carry equal currents in opposite directions as shown. The magnitude of the magnetic field outside the outer conductor and between the two conductors compare as

a) $B_{\text{outside}} = B_{\text{between}}$
b) $B_{\text{outside}} < B_{\text{between}}$
c) $B_{\text{outside}} > B_{\text{between}}$
d) none of these true for all points
2) [20 pts, 5 pts each] Your Badger radio network (WIBA) is 1310 kHz on the AM dial (this is the frequency in kHz).

a) What is the wavelength of this wave when it propagates in air (n=1.0)?

\[ \lambda = \boxed{\text{Value}} \text{ Units} \]

b) You take your radio under water in a swimming pool to listen for a while. Calculate how fast the radio wave travels under the water (water index of refraction=1.33).

\[ v = \boxed{\text{Value}} \text{ Units} \]

c) Find the frequency and wavelength under water.

\[ f = \boxed{\text{Value}} \text{ Units} \]
\[ \lambda = \boxed{\text{Value}} \text{ Units} \]

d) The WIBA transmission tower is south of the beltline on Fish Hatchery road, about 5 km from campus, and broadcasts 5 kW (5000 Watts) of EM radiation. Calculate the amplitude of the electric field on campus (no water!), assuming no absorption or reflection by buildings, trees, etc.

\[ E = \boxed{\text{Value}} \text{ Units} \]
3) [20 pts, 5 pts each] A loop of wire with dimensions as shown is oriented with plane of the loop parallel to a uniform magnetic field of strength \( B = 1 \) T in the \( z \)-direction. A current \( I = 1 \) A is flowing clockwise in the loop.

\( L = 2 \) m, \( W = 1 \) m, \( B = 0.2 \) T, \( I = 1 \) A.

a) Calculate the net force on the loop. Explain.

\[
\begin{array}{|c|c|}
\hline
\text{Value} & \text{Units} \\
\hline
\text{F} & \\
\hline
\end{array}
\]

b) Calculate the magnetic dipole moment of the loop.

\[
\mu =
\]

\[
\begin{array}{|c|c|c|}
\hline
\text{Magnitude} & \text{Units} & \text{Direction} \\
\hline
\text{\mu} & & \\
\hline
\end{array}
\]

c) Calculate the torque on the loop.

\[
\tau =
\]

\[
\begin{array}{|c|c|c|}
\hline
\text{Magnitude} & \text{Units} & \text{Direction} \\
\hline
\text{\tau} & & \\
\hline
\end{array}
\]

d) Calculate the amount of work you must do to rotate the top of the loop 90° into the page so that the plane of the loop is perpendicular with the magnetic field.

\[
W =
\]

\[
\begin{array}{|c|c|}
\hline
\text{Value} & \text{Units} \\
\hline
\text{W} & \\
\hline
\end{array}
\]
4) [25 pts, 5 pts each] Three linear polarizers are arranged as shown, with transmission axes indicated by the heavy line. The unpolarized incoming light is propagating in the \( z \)-direction.

a) Write down the space- and time-dependent electric field \textbf{vector} of the light after the first polarizer (region I), assuming its amplitude is \( E_0 \).

b) What is the amplitude of the electric field vector of the EM wave after it passes through the second polarizer (region II in the diagram).
c) Write down the space- and time-dependent electric field vector in region II as a sum of vector components in the $x$ and $y$ directions.

d) Write down an expression for space- and time-dependent electric field vector in region III. Explain your reasoning.

e) Find an expression for the intensity of the light in region III (after passing through the third polarizer) in terms of $E_o$ and fundamental constants.
5) **[20 pts, 5 pts each]** A square loop lying flat on a table is pushed across a current-carrying wire at constant speed as shown. The field is largest closest to the wire, and is of opposite sign on either side of wire.

You don’t need to calculate any integrals for this problem! Just use physical reasoning and explanations in words, diagrams, or simple equations.

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**a)** As the loop approaches the wire from the left, does the induced loop current flow clockwise or counterclockwise? **Explain your reasoning.**

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**b)** What direction is the net force on the loop from the magnetic field as the loop approaches the wire from the left (as in part a)? **Explain your reasoning.**
c) Now suppose the loop has moved past the wire, and is moving at the same constant speed to the right of the wire. does the induced loop current flow clockwise or counterclockwise? **Explain your reasoning.**

d) What direction is the net force on the loop from the magnetic field now that it has moved past the wire? **Explain your reasoning.**