HW 3

Due: Monday, June 11, 6:00 p.m.

Print your full LAST name: ________________________________________________

Print your full first name: _________________________________________________

Print your full OSU student ID#: __________________________________________

Turn this assignment in to box #15 (located outside of Wngr 234)

OR

e-mail a pdf document of the complete file,

prepared as directed on the next page.

“I affirm and attest that this HW assignment is my own work.
All the reasoning and results here are my own doing.”

Sign your name (full signature): ____________________________________________

Print today’s date: ________________________________________________________
**HW 3**

*Directions:*

Solve these four problems fully, just as you would if they were exam problems. Then turn in your entire solutions set (all these pages) to Box 15; OR email a .pdf file to coffinc@physics.oregonstate.edu with a subject line as follows:

**HW3_LastName_FirstName**

One of your four solutions will be chosen and scored for HW3 credit (35 points). Full solutions to all four problems will be posted soon after the due date/time.

*Note:* You’ll do much better with these problems if you work through the Prep sets 7-8 and 9-10 and also the SMT3 first, because these problems are all variations on selected Prep and SMT3 problems.

*Note:* The real MT3 (that’s the actual final exam this term) may also include variations on selected Prep and SMT3 problems.
1. Let the positive x-axis be north and the positive y-axis be up.

Experiment (i): At point $P_1$, an electron is moving vertically downward as it enters a rectangular region (shaded here) where there is a uniform, horizontal magnetic field $B$. As the electron exits the field at point $P_2$, it is moving directly south at $335276 \text{ m/s}$. The straight-line distance from $P_1$ to $P_2$ is $4.56 \text{ cm}$.

Experiment (ii): A long stream of alpha particles (those are helium nuclei: two protons and two neutrons each) enters the same field by moving north through point $P_2$. That stream then exits the field moving south. The stream contains $9.87 \times 10^{10}$ particles per mm (uniformly distributed). Ignore any effects the particles have on one another.

Assuming that the stream has completely exited the field from Experiment (ii), suppose its midpoint is now passing through the origin. Find the maximum magnetic field it could be causing at the point (0 mm, 2 mm, 4 mm). Specify this field in rectangular form, $(B_x, B_y, B_z)$.

This is a case of a charged particle moving in a perpendicular B-field. (The electron’s entry velocity is vertical, and the field is horizontal.) The particle moves in a circular arc at all times while within the field; and the radius of that arc is given by $r_e = m \nu_e/(qB)$. (The particle’s speed doesn’t change in the field; a magnetic force does no work on it. So $v_{e,exit} = v_{e,enter} = v_e$.) If the electron were turning to its left, it would complete a semi-circle and exit the field upward (at a point somewhere north of its entry point). It doesn’t do that. So it must be completing a quarter-circle by turning to its right while in the field, as shown here:

The geometry: $d_{1/2} = (\sqrt{2})r_e = (\sqrt{2})m \nu_e/(qB) \quad 1/2 \text{ pt.}$

Solve for $B$: $B = (\sqrt{2})m \nu_e/(q d_{1/2}) = (\sqrt{2})(9.11 \times 10^{-19})(335276)/((1.60 \times 10^{-19})(0.0456)) = 5.9204 \times 10^{-5} \text{ T} \quad 1 \text{ pt.}$

(And by RHR 1 (right-turn force on a negative charge), the direction of $B$ is into the page, which is west.)

The alpha particles entering the field at $P_2$ are each positive charges, so they would circle to the left—and in order to exit back to the south, they would need to travel a full semi-circle within the field. At what radius? The stream will later form a straight current whose field must be maximized, so the charge must move as fast as possible. Since $r_{\alpha} = m \nu_{\alpha}/(qB)$, the fastest $\nu_{\alpha}$ implies the greatest $r_{\alpha}$. So the stream exits the field at exactly its upper corner:

The geometry: $r_{\alpha} = r_e/2 = d_{1/2}/(2\sqrt{2}) = m \nu_e/(qB) \quad 1/2 \text{ pt.}$

Solve for $\nu_{\alpha}$: $\nu_{\alpha} = q_B d_{1/2}/(2m \nu_e/\sqrt{2}) = (3.20 \times 10^{-19})(5.9204 \times 10^{-5})(0.0456)/[2(6.64 \times 10^{-27})(\sqrt{2})] = 45.999 \text{ m/s} \quad 1 \text{ pt.}$

Now, probably the easiest way to find the B-field at (0 mm north, 2 mm up, 4 mm east)—as caused by the straight south-bound current—is to change the coordinate system so that current is directed out of the page. With this viewpoint, the field is easy to draw and calculate:

We know: $\vert B \vert = \mu_0 I/(2 \pi d)$

Find $d$: $d = [0.004^2 + 0.002^2]^{1/2} = 0.00447216 \text{ m}$

Find $I$: $I = [9.87 \times 10^{10} \text{ particles/mm}][1000 \text{ mm/m}][(45.999) \text{ m/s}][(3.20 \times 10^{-19}) \text{ C/particle}]$

$= 1.45285 \times 10^{-3} \text{ C/s} = 1.45285 \text{ mA}$

Therefore: $\vert B \vert = (4\pi \times 10^{-7})(1.45285 \times 10^{-3})/[(2\pi)(0.00447216)] = 64.9734 \text{ nT}$

Now refer to this drawing to determine the field components.

First: $\theta = \tan^{-1}(2/4) = 26.565^\circ$

And: $B_{north} = 0$
Then: \[ B_{up} = B \cos \theta = (64.9734 \times 10^{-9}) \cos 26.565^\circ = 58.114 \text{ nT} \]

And: \[ B_{east} = -B \cos \theta = (64.9734 \times 10^{-9}) \sin 26.565^\circ = -29.057 \text{ nT} \]

Now express these results in the coordinate system of the problem, where \( x = \text{north}, \ y = \text{up} \) and \( z = \text{east} \):

\[ B = [0, 58.1, -29.1] \text{ nT} \]
2. A steady, uniform magnetic field $\mathbf{B}$ with unknown magnitude and direction exists throughout the shaded rectangular region shown here. This region is planar—entirely in the $x$-$y$ plane ($+x$ is east and $+y$ is north). The width of the region (from west edge to east edge) is a known distance $D$. Consider the following experiments, some performed with this field.

**Experiment (i):** A single circular loop of wire of diameter $D$ is given a net charge of $+Q$. This charge is distributed uniformly along the wire. The loop is then made to spin around an east-west axis through its center, at a known steady rate $\omega_{\text{rpm}}$ (given in rpm) with its tangential velocity vectors as shown here. With the loop’s center located in the field $\mathbf{B}$, the total magnetic field at the loop’s center is zero.

**Experiment (ii):** The loop’s spinning is halted, and the loop is discharged; it’s now a neutral wire. Then the wire is cut and re-shaped into a single straight length, and fixed in place within the field (so that the entire length of wire is in the $x$-$y$ plane and completely within the field). A steady current $I$ is then sent through it. Under these conditions, the maximum possible magnetic force magnitude that can be exerted on this wire is measured to be $F_{\text{mag,max}}$.

**Experiment (iii):** Now the B-field is removed, and the wire is rotated so that its current is flowing directly south. Then a second identical length of wire is fixed in place parallel to the first wire, but at a distance $D/100$ to the east of the first wire. This second wire carries twice as much current as the first wire, but its current flows north.

a. Find an expression for the force (magnitude and direction) exerted by the second wire on the first wire.

b. Find an expression for the magnetic field (magnitude and direction) at a point midway between the two wires.

Your answers should be expressions that include only known values, and for full credit, you must show that the units of your solutions are also correct. These values are known: $D$, $Q$, $\omega_{\text{rpm}}$, $F_{\text{mag,max}}$, $\mu_0$

From experiment (i): The spinning loop of charged wire constitutes a current, $I$ (after all, it’s a stream moving charge). We could use any units here, but we choose SI….

Find an expression for $I$: $I = \left[\omega_{\text{rpm}} \text{ rev/min}\right][1 \text{ min}/60\text{s}][2\pi \text{ rad/rev}][D/2 \text{ m/rad}][Q/(\pi D) \text{ C/m}]$  2 pts.

$= Q\omega_{\text{rpm}}/60 \text{ C/s} = Q\omega_{\text{rpm}}/60 \text{ A}$  1 pt.

Therefore: $B_{\text{loop.center}} = \mu_0 I/(2R) = \mu_0 I/D = \mu_0 Q\omega_{\text{rpm}}/(60D) \text{ west}$ (by RHR 2)  1 pt.

But $B_{\text{total.center}} = 0$, so: $B = -B_{\text{loop.center}} = \mu_0 Q\omega_{\text{rpm}}/(60D) \text{ east}$  1 pt.

From experiment (ii): The maximum $F_{\text{mag}}$ occurs when the current is perpendicular to the field, so that would require the current I here to run north-south (either way, same magnitude), so choose, say, north, for example….

We know $F_{\text{mag,max}}$, and: $F_{\text{mag,max}} = I L B \sin 90^\circ = I L B$

where: $L = \pi D$

and: $B = \mu_0 Q\omega_{\text{rpm}}/(60D)$

Solve for $I$: $I = F_{\text{mag,max}}/(L B) = F_{\text{mag,max}}/[\pi D \mu_0 Q\omega_{\text{rpm}}/(60D)] = 60 F_{\text{mag,max}}/(\pi \mu_0 Q\omega_{\text{rpm}})$

Now in experiment (iii), here’s the picture—at far right (not to scale):

a. First, find $|F_{\text{mag,2}}|$: $|F_{\text{mag,2}}| = I L_{\text{min}} B_2 \sin 90^\circ = I(\pi D)[\mu_0 2 I/(2\pi d)] = I^2 D \mu_0 / d$

$= 100 I^2 \mu_0 = 100(60 F_{\text{mag,max}}/(\pi \mu_0 Q\omega_{\text{rpm}}))^2 \mu_0$

Thus: $F_{\text{mag,2}} = (360,000/\mu_0)(F_{\text{mag,max}}/(\pi Q\omega_{\text{rpm}}))^2 \text{ west}$ (anti-parallel currents repel)

**Units check:** $F_{\text{mag,max}}/(\mu_0 Q^2 \omega_{\text{rpm}}^2)$ must be unitless: $(C \cdot m^2/s)/(T \cdot m^2/C)/(C^2/s^2) = (C^2/s^2)/(C^2/s^2)$  OK
b. At the midpoint between the two currents, their fields would reinforce—add together (by RHR #2). And both fields are directed out of the page (that’s \textbf{vertically upward out of the earth}).

Combined magnitudes:  
\[
B_{\text{mag, total}} = [\mu_0 J_1/(2\pi x)] + [\mu_0 2J_1/(2\pi x)]
\]

where:  
\[
x = D/200
\]

and:  
\[
I_1 = [60F_{\text{mag, max}}/(\pi \mu_0 Q\omega_{rpm})]
\]

Thus:  
\[
B_{\text{mag, total}} = [200\mu_0 J_1/(2\pi D)] + [400\mu_0 J_1/(2\pi D)] = 300\mu_0 J_1/(\pi D)
\]

\[
= [300\mu_0/(\pi D)][60F_{\text{mag, max}}/(\pi \mu_0 Q\omega_{rpm})] = 18000F_{\text{mag, max}}/(\pi^2 D Q\omega_{rpm})
\]

\textbf{Units check:} \quad T = (C\cdot m^2/T)/(m^2/C) = T \quad \text{\textit{OK}}
3. A uniform magnetic field $B$ with unknown magnitude, directed into the page, exists throughout the shaded region shown here. The field’s magnitude can be adjusted or made time-dependent, as desired. Now consider the following experiments.

**Experiment (i):** For this experiment, the field’s magnitude is held steady. A single circular loop of wire is initially placed at rest in the field. The wire’s diameter is $d$, and the loop’s diameter is $D$. The wire has a known resistivity, $\rho$. Then, during a time interval $\Delta t$, the wire is re-shaped into a square. As a result, a total charge of $Q$ flows steadily (at a constant rate) past point $P$ in the loop.

**Experiment (ii):** The wire loop (now a square after Experiment i) is removed from the field entirely but placed at rest at the field’s edge, as shown here. Then, at time $t = 0$, the loop is pushed to the right, into the field, at constant velocity. Also starting at time $t = 0$, the field’s magnitude begins to decrease (starting at its value from Experiment i) according to this time function: $B(t) = B_0 e^{-2kt}$, where $k$ is known.

At the moment when the loop is halfway into the field, no current flows in the loop.

**Experiment (iii):** The field is reset to its steady magnitude from Experiment i, and the loop is again placed at rest, this time fully within the field, as shown here. At time $t = 0$, the loop is rotated around the axis shown at a steady rate.

a. Find an expression for the required speed of the loop in Experiment ii.

b. Find an expression for the period of the rotation in Experiment iii that will induce a maximum voltage difference $\Delta V_{\text{max}}$ in the rotating loop.

Your answers should be expressions that include only known values, and for full credit, you must show that the units of your solutions are also correct. These values are known: $d, D, \rho, Q, k, \Delta V_{\text{max}}$

**a.** In experiment (i), the induced effect is constant, so we can use Faraday’s Law in non-derivative form to find $B$…

Like this:

$$Q/\Delta t = |I_{\text{ind,avg}}|/R = \left|\Delta V_{\text{ind,avg}}\right|/R = |\Delta \Phi_{\text{mag}}|/(R \Delta t)$$

Simplified:

$$QR = \left|\Delta \Phi_{\text{mag}}\right|$$

In more detail:

$$Q \rho L/\text{wire} = B |A_{\text{loop,f}} - A_{\text{loop,i}}|$$

$$(\cos \phi = 1; \text{loop's normal and B-field always align})$$

Expanded fully:

$$Q \rho \pi D (t D^2/4) = B(\pi D^2/4) - (\pi D^2/4)$$

(side $S$ of square loop is $\pi D/4$)

Simplified:

$$4Q \rho /d^2 = B(\pi D/16)(4 - \pi)$$

Solve for $B$:

$$B = 64Q \rho /[(\pi D^2/4)(4 - \pi)]$$

In experiment (ii), we are looking for an instantaneous value (the situation at one moment in time).

So we must use Faraday’s Law in full derivative form to find $v$…

Like this:

$$|I_{\text{ind}}(t)| = \left|\Delta V_{\text{ind}}\right|/R = \left|\Delta \Phi_{\text{mag}}\right|/(R \Delta t) = (1/R)\left|\{d[B(t)A(t)\cos \phi(t)]/dt\}\right| = 0$$

Simplified:

$$d[B(t)A(t)]/dt = 0$$

(Product rule: $A(dB/dt) + B(dA/dt) = 0$)

where:

$$dB/dt = (-2k/3)B_0 e^{-2kt}$$

($B_0$ here is the $B$ value found via experiment i)

and:

$$A(t) = Sx(t)$$

and so:

$$dA/dt = S(dx/dt) = Sv$$

Substitute:

$$Sx((-2k/3)B_0 e^{-2kt}) + [B_0 e^{-2kt}]Sv = 0$$

Simplify:

$$v = 2kx/3 = (2k/3)(S/2) = Sk/3 = \pi Dk/12$$

Units check:

$k$ must be $s^{-1}$; exponent of $B$’s time function is unitless. So: $Dk$ is $m\cdot s^{-1}$, which is $v$. 1 pt.
b. In experiment (iii), we are again looking for an instantaneous value (the maximum induced $\Delta V$).
So, again, we must use Faraday’s Law in full derivative form…

Like this:

$$|\Delta V_{ind}| = |d\Phi_{mag}/dt| = |\{d[B(t)A(t)\cos(\phi(t))/dt]\}$$

Simplified:

$$|\Delta V_{ind}| = |BA[d(\cos\phi)/dt]| \quad (B \text{ and } A \text{ never vary; only } \phi, \text{ the angle between them; and again, } B \text{ here is the } B \text{ value found via experiment i.})$$

But we know:

$$\phi(t) = \omega t$$

And so:

$$|\Delta V_{ind}| = |BA[d(\cos\omega t)/dt]| = |BA\omega \sin\omega t|$$

Therefore:

$$\Delta V_{max} = BA\omega = BA(2\pi/T) \quad (\text{amplitude of a sinusoid is its maximum magnitude})$$

Solve for $T$:

$$T = \frac{2\pi BA}{\Delta V_{max}} = 2\pi\{64\rho p/[(4\pi Dd^2)(4 - \pi)]\}pD/(4\Delta V_{max})$$

$$= \frac{[8\pi^2(4 - \pi)]pD/(d^2\Delta V_{max})}{pD/(d^2\Delta V_{max})}$$

Units check:

$$Q\rho D/(d^2\Delta V_{max}) \text{ must have units of s:}$$

$$(C)(\Omega \cdot m)/(m^2) \cdot V = (C)((V/A)/V) = C/A = \text{ s. OK}.$$
4. You have the following equipment:

1 non-ideal battery (with internal resistance \( r = 0.190 \Omega \)), plus 2 switches and plenty of wire.
1 parallel-plate capacitor, initially uncharged.
3 identical ohmic resistors, each with resistance \( R = 4.00 \Omega \).
2 solenoid inductors, A and B, of equal length, with inductance values \( L_A \) and \( L_B \), respectively.
Inductor A has a diameter of 10.0 cm; inductor B has a diameter of 11.0 cm.
1 laser (which can be battery-powered) that produces a single-wavelength light beam with a diameter of 1.00 mm.
The laser behaves as an ohmic resistor that converts 40.0% of the power it uses into light (the rest is waste heat).
Two sheets of Polaroid film, plus a sheet of paper to use as a target for the laser beam.

a. **Which of Maxwell’s equations explains how inductors work?**
   Be specific; write the full equation and explain in words what it’s saying.

Now consider the following experiments.

Experiment (i): You build the circuit shown here (switch initially open), then close the switch at \( t = 0 \). **Result:** The capacitor has 75.0% of its full charge at \( t = 11.09 \text{ ms} \). Then you leave the switch closed for a total of 36.68 s, then open it and dismantle the circuit, setting the capacitor aside for later. It is now charged with 148.92 mC.

Experiment (ii): You build the circuit shown here (with both switches initially open). The angle between the two film sheets’ planes of polarization is 27.4°. Then you close both switches at the same moment and leave them closed for a long time. **Results:** The amplitude of the magnetic field in the beam that arrives at the paper is 1.03311 mT; the energy stored in inductor B is 3.5142 J; and the current from the battery is 59.542 A.

Experiment (iii): Continuing from experiment (ii), you now open switch A at \( t = 0 \).
**Result:** At \( t = 0.250 \text{ ms} \), the total power being produced by the resistors in series with \( L_A \) is 818.01 W.

b. If you were to connect inductor A and the charged capacitor as shown here, then close the switch at \( t = 0 \), what percentage of the total energy stored in the circuit will be in the electric field at \( t = 6.86 \text{ ms} \)?

c. If you were to use the two inductors \( L_1 \) and \( L_2 \) to build a simple transformer, and you then connect it across a 120V AC power source, what voltage value(s) could you achieve across the secondary coil?

a. **Faraday’s Law:**
   \[ \oint E \cdot ds = -(d\Phi_{mag}/dt) \]
   An inductor is a device in which an electric field around each coil is induced in opposition to the change in magnetic flux presently occurring in that coil.

   The \( \oint E \cdot ds \) of Faraday’s law is the voltage difference (electric field times path length) that is induced around the loop; the \( d\Phi_{mag}/dt \) is the rate of change of the magnetic flux.

b. From experiment (i), we can calculate the value of \( C \) via the partial-charging data, and then the \( \Delta V_{\text{battery}} \) from the full charge data:
   A charging RC circuit:
   \[ Q(t) = Q_{\text{max}}(1 - e^{-t/RC}) \]
   From the data:
   \[ 0.75Q_{\text{max}} = Q_{\text{max}}(1 - e^{-t/RC}) \]
   Solve for \( C \):
   \[ \ln(0.25) = -t/(RC) \]
   \[ C = -t/[R\ln(0.25)] = -(0.01109)/[(4.19)\ln(0.25)] = 1.90925 \text{ mF} \]

   At full charge:
   \[ C = \frac{Q_{\text{max}}}{\Delta V_{\text{battery}}} \]
   Thus:
   \[ \Delta V_{\text{battery}} = \frac{Q_{\text{max}}}{C} = (148.92 \times 10^{-3})/(1.90925 \times 10^{-3}) = 78.00 \text{ V} \]
**Experiment (ii)** allows us to solve for the current in each branch of the circuit—and since those currents have been flowing for a long time, they are no longer changing, so the inductors are irrelevant; they are like simple wires. So the initial situation is simply a non-ideal battery connected to 4 parallel resistors. Just use Ohm’s Law and the known information to start at the battery (assigning 0 volts at the battery’s negative terminal) and work around the circuit...

Like this:
\[ \Delta V_r = I_{total} r = 59.542(0.19) = 11.313 \]
\[ V_{top} = V_r - \Delta V_r = 78 - 11.313 = 66.878 \]

Like this:
\[ I_g = \Delta V/g/R = (66.878 - 0)/4 = 16.672 \text{ A} \]

And now **Experiment (iii)** can reveal the value of \( L_A \). When switch A is opened, the current decays as an L-R loop with two series resistors….

The current function:
\[ I_{LA}(t) = I_{LA0} e^{-t/(R/LA)} \]

where:
\[ R_{total} = 2R \]

and:
\[ I_{LA0} = I_R \]

Substituting:
\[ I_{LA}(t) = I_R e^{-t/(2R/LA)} = I_R e^{-2t/(LA)} \]

Resistors’ power:
\[ P_{totalR}(t) = [I_{LA}(t)]^2 R_{total} = 2RI_R^2 e^{-4t/(LA)} \]

Solve for \( L_A^* \):
\[ -4tR/L_A = \ln[P_{totalR}(t)/(2RI_R^2)] \]

Solve for \( L_A^* \):
\[ L_A^* = -4tR/\ln(2RI_R^2) = -0.00025(4)/\ln(818.01/(2·4·16.672)) = 4.000 \text{ mH} \]

Now to the question of the LC circuit….

The charge function:
\[ Q(t) = Q_0 cos(\omega t) \quad (\omega \text{ is in radians/sec here}) \]

where
\[ \omega = [L_A r C]^{-1/2} \]

The \( U_C \) function:
\[ U_C(t) = Q(t)²/(2C) = Q_0^2 cos²(\omega t)/(2C) \]

At \( t = 0 \), all of the circuit’s energy is stored in the electric field of the capacitor (i.e. as \( U_C \)). So the portion stored in that form at time \( t \) is quite simple:

It’s this ratio:
\[ \%U_C = 100[U_C(t)/U_C(0)] = 100[[Q_0^2cos²(\omega t)/(2C)]/[Q_0^2/(2C)]] = 100cos²(\omega t) = 100cos²[t(L_A r C)^{-1/2}] = 100cos²((6.86 x 10^{-2}((4.000 x 10^{-3})(1.90925 x 10^{-3})^{-1/2}) = 62.5\% \]

**c.** To build a transformer using \( L_A \) and \( L_B \), we must first find the value of \( L_B \), so we look again to Experiment ii….

We know:
\[ I_{total} = 3I_R + I_{laser} \]

Solve for \( I_{laser} \):
\[ I_{laser} = I_{total} - 3V_R = 59.542 - 3(16.672) = 9.5267 \text{ A} \]

But \( I_{laser} = I_{LB} \):
\[ U_{LB} = (1/2)L_{LB} I_{LB}^2 \]

Solve for \( L_B \):
\[ L_B = 2U_{LB}/I_{LB}^2 = 2((3.5142)/(9.5267)^2) = 77.441 \text{ mH} \]

The transformer:
\[ \Delta V_p/\Delta V_S = N_B/N_A \quad \text{is either} \quad N_p/N_B \text{ or } N_p/N_A \quad 2 \text{ pts.} \]

Thus:
\[ \Delta V_S = \text{ either } \Delta V_p(N_B/N_A) \text{ or } \Delta V_p(N_A/N_B) \quad 1 \text{ pt.} \]

Any solenoid:
\[ L = \mu_0 N^2 A/l = \mu_0 N^2 \pi D^2/(4l) \quad 2 \text{ pts.} \]

Therefore:
\[ L_B/L_A = [\mu_0 N_B^2 \pi D_B^2/(4l_B)]/[\mu_0 N_A^2 \pi D_A^2/(4l_A)] = [N_B^2 D_B^2/(N_A^2 D_A^2)] \quad (\text{lengths are the same}) \quad 2 \text{ pts.} \]

Solve for \( N_B/N_A \):
\[ N_B/N_A = [L_B D_A^2/(L_A D_B^2)]^{1/2} = (77.441 x 10^{-3}(0.103))/(4.000 x 10^{-3}(0.11))^2 = 4.00 \]

Thus:
\[ \Delta V_S = \text{ either } 120(4) = 480 \text{ V} \quad 1 \text{ pt.} \]

or
\[ 120/(4) = 30.0 \text{ V} \quad 1 \text{ pt.} \]
Note here about this problem. As it turns out, knowing both the battery voltage and its total current made it unnecessary to analyze the laser and its average power and intensity in order to answer the questions asked. Here’s how you would use those clues at least to find the power of the laser (you would have needed more data anyway to determine the current through the laser or its resistance).

Emitting from the laser: \[ I_0 \]  

(all intensity values are average values here)

Transmitting through the first film: \[ I_1 = (1/2)I_0 \]

Transmitting through the second film: \[ I_2 = (\cos^2 \theta_{12})I_1 = (\cos^2 \theta_{12})(1/2)I_0 \]

But we know: \[ I_2 = (1/2)ce_oE_{2,\text{max}}^2 = (1/2)ce_o(cB_{2,\text{max}})^2 = (1/2)c^3e_oB_{2,\text{max}}^2 \]

Substituting: \[ (\cos^2 \theta_{12})(1/2)I_0 = (1/2)c^3e_oB_{2,\text{max}}^2 \]

Solving for \( I_0 \): \[ I_0 = \left[ c^3e_oB_{2,\text{max}}^2 \right]/(\cos^2 \theta_{12}) \]

And then \( P_{\text{beam}} = (I_0)(A_{\text{beam}}) \):

\[ P_{\text{beam}} = \left\{ \left[ c^3e_oB_{2,\text{max}}^2 \right]/(\cos^2 \theta_{12}) \right\}[\pi d_{\text{beam}}^2/4] \]

But \( P_{\text{beam}} = 0.40P_{\text{laser}} \):

\[ P_{\text{laser}} = \left\{ \left[ c^3e_oB_{2,\text{max}}^2 \right]/(\cos^2 \theta_{12}) \right\}[\pi d_{\text{beam}}^2/1.6] \]

\[ = \left\{ [(3.00 \times 10^8)(8.85 \times 10^{-12})(1.03311 \times 10^{-3})^2]/(\cos^2 27.4^\circ) \right\}[\pi(0.001)^2/1.6] = 635.31 \text{ W} \]

And then: Knowing also that \( I_{\text{laser}} = 9.5267 \text{ A} \), you can calculate that \( R_{\text{laser}} = 7.00 \Omega \). (This is also the value you get if you analyze all the resistance in the circuit.)