19F-PHYSICS1C-4 Midterm

KYLE OSBORN

TOTAL POINTS

90 / 100

QUESTION 1

Problem 1 15 pts

1.1 Part a **5 / 5**

1.2 Part b **5 / 5**

1.3 Part c **5 / 5**

QUESTION 2

Problem 2 20 pts

2.1 Part a **10 / 10**

2.2 Part b **10 / 10**

QUESTION 3

Problem 3 20 pts

3.1 Part a **10 / 10**

3.2 Part b **10 / 10**

QUESTION 4

Problem 4 15 pts

4.1 Part a **5 / 5**

4.2 Part b **10 / 10**

QUESTION 5

Problem 5 15 pts

5.1 Part a **10 / 10**

5.2 Part b **5 / 5**

QUESTION 6

6 Problem 6 **5 / 15**

gradescope

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MIDTERM
Version C
Physics 1C, Prof. David Saltzberg
November 7, 2019

Time: 90 minutes. Closed Notes. Closed Book. One 3"x5" sheet of notes allowed. Calculators (even graphing) are allowed. Show your work. *Please write your name on every page just in case.*

If a problem is confusing or ambiguous, notify the professor. Clarifications will be written on the blackboard. Check the board.

Problem	Points
1	/15
2	/20
3	/20
4	/15
5	/15
6	/15
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TOTAL	/100

Kyle Osborn

1) Short answers:

a) (5 pts) In class we performed a demonstration where a student pedaled a bicycle connected to a generator to power light bulbs in parallel. The reason he had to pedal harder as more bulbs were added was:

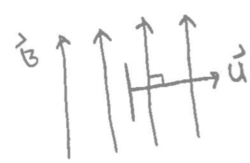
1) due to increasing back-EMF (or "counter-EMF") of the generator
2) due to increasing back-torque (or "counter-torque") of the generator
3) due to the presence of the Maxwell term $+\mu_0\varepsilon_0(d\Phi_E/dt)$ in the Ampère-Maxwell Law
4) due to the presence of the conduction current term $\mu_0 I_C$ in the Ampère-Maxwell Law
5) because aluminum is diamagnetic and like-poles (e.g., N and N) repel.

b) (5 pts) A block of material is placed near a bar magnet and is weakly attracted to it. When the bar magnet is removed, the block of material is found not to be magnetized. This is an example of:

1) diamagnetism
2) ~~ferromagnetism~~
3) paramagnetism
4) animal magnetism
5) a magnetic monopole

c) (5 pts) A magnetic dipole **μ** is placed in a uniform magnetic field, **B**. Draw a configuration where the magnitude of the torque on the dipole is maximal.

$\tau = \vec{u} \times \vec{B} = |u||B|\sin\theta$ max when $\theta = \frac{\pi}{2}$



Kyle Oba

2) A sinusoidal electromagnetic wave with wavelength 2.0 m travels in vacuum in the +x direction with its electric field having an amplitude of 300 V/m that points along the y-axis. At *x*=0, *t*=0 the electric field is zero and decreasing in value (i.e., becoming more negative).

a) (10 pts) Write the equation for the magnetic field in terms of its amplitude, wavenumber *k*, and angular frequency ω. [Hint: your answer should be a vector. It should have numerical values with units for *k*, ω, and the field amplitude.]

$E = -300\hat{j}\sin(kx - wt)$

$\lambda = 2$

$k = \frac{2\pi}{\lambda}$ $\quad w = 2\pi f$

$B_A = \frac{E_A}{c} = \frac{300}{3\times10^8} = 1\times10^{-6} = 1\,\mu T$

$\hat{i} = \hat{j}\times\hat{k}$ θ dir

$k = \frac{2\pi}{2} = \pi \approx 3.14$ $\quad f = \frac{c}{\lambda}$

$w = kc \approx 9.42\times10^8 \frac{rad}{s}$

$\boxed{B = -(1\,\mu T)\hat{k}\sin\left(\left(3.14\,\frac{rad}{m}\right)x - \left(9.42\times10^8\,\frac{rad}{s}\right)t\right)\ T}$

units in Tesla

micro Tesla $= \mu T$

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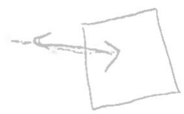
b) (10 pts) Suppose this wave is perfectly absorbed uniformly over an entire square-shaped sail with dimensions 2.0m × 2.0m. The Poynting vector of the wave is parallel to the area vector of the sail. What is the force on the sail in Newtons? [Hint: this one may need your calculator.]



$$I = \frac{E_{max}B_{max}}{2\mu_0} = \frac{(300)(1\times10^{-6})}{2(4\pi\times10^{-7})} = 119.366\ \frac{W}{m^2}$$

absorbed: $p_{rad} = \frac{I}{c} = 3.9789\times10^{-7}\ \frac{N}{m^2}$

$$F = p_{rad}(A) = 3.9789\times10^{-7}(4) = \boxed{1.592\times10^{-6}\ N}$$

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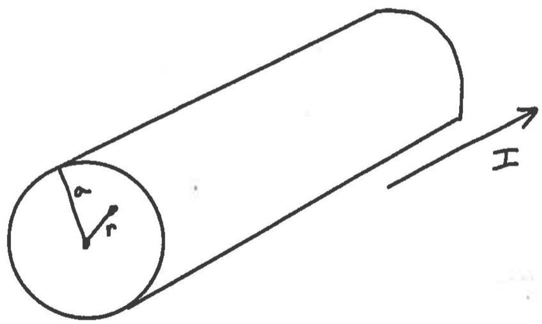
3) A long cylindrical wire of radius, a, carries a current density $J(r)$ along its axis that is proportional to the cube of the radius, r, that is:

$$J(r) = J_0(r/a)^3, r < a,$$
$$J(r) = 0, \text{ elsewhere}$$



a) (10 pts) Suppose a=5.0 m and the total current carried in the wire is I_0=3.14 A. What is J_0? [Answer is a numerical value with units]
[extra space on next page if needed]

$$3.14 = \int J \cdot d\vec{A} = 2\pi \int_0^a J_0\left(\frac{r}{a}\right)^3 r\,dr$$

$$= 2\pi \int_0^a J_0 \frac{r^4}{a^3} dr = 2\pi J_0 \int_0^a \frac{r^4}{a^3} dr = 2\pi J_0 \left(\frac{r^5}{5a^3}\Big|_0^5\right)$$

$$= 2\pi J_0\left(\frac{r^5}{625}\Big|_0^5\right) = 2\pi J_0(5-0) = 10\pi J_0 = 3.14$$

$$10 J_0 = 1$$

$$\boxed{J_0 = 0.1 \frac{A}{m^2}}$$

[extra space]

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b) (10 pts) Suppose the current is changed so that J_0=10 A/m^2. [Hint: this part does not depend on your answer for part a]. What is the value **B** at r=2.0m? [This is a numerical value with units.]

$$\oint \vec{B} \cdot d\vec{l} = U_0 I_{enc}$$

$$B(2\pi r) = U_0 \, 2\pi(10) \int_0^r \frac{r'^4}{a^3} \, dr'$$

$$B = \frac{U_0 20\pi}{4\pi} \left(\frac{r'^5}{5a^3} \Big|_0^2 \right) = 5U_0(0.0512 - 0)$$

$$\boxed{B = 3.217 \times 10^{-7} \, T}$$

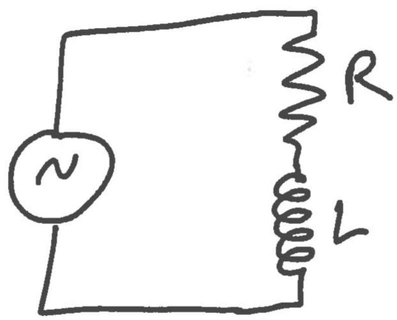
Kyle Osban

4) An AC wall socket in Europe provides a voltage that is sinusoidal in time with a frequency of 50 Hz and root-mean-square (R.M.S.) voltage of 240 V between its two conductors.

a) (5 pts) What is the amplitude of the voltage?

$V_{RMS} = \frac{V}{\sqrt{2}}$ $\quad V = \sqrt{2}(240) = \boxed{339.411\ V}$

b) (10 pts) Now you connect an inductor and resistor in series to this European AC wall socket, as shown below:



Where R=62.8 Ω and L= 100 mH. The current is at its maximum positive value at *t=0*. What is the RMS voltage across the inductor? [Hint: you may need your calculator a little.]
[extra space on next page]

$V_L = I_{RMS} X_L$ $\quad I_{RMS} = \frac{V_{RMS}}{Z}$

$X_L = \omega L = (2\pi(50))(100\times10^{-3}) = 31.416$

$Z_{tot} = \sqrt{X_L^2 + R^2}$
$= \sqrt{31.416^2 + 62.8^2}$
$= 70.220\ \Omega$

$I_{RMS} = \frac{240}{70.22} = 3.418\ A$

$V_{L_{RMS}} = 3.418(31.416) = \boxed{107.375\ V}$

[extra space]

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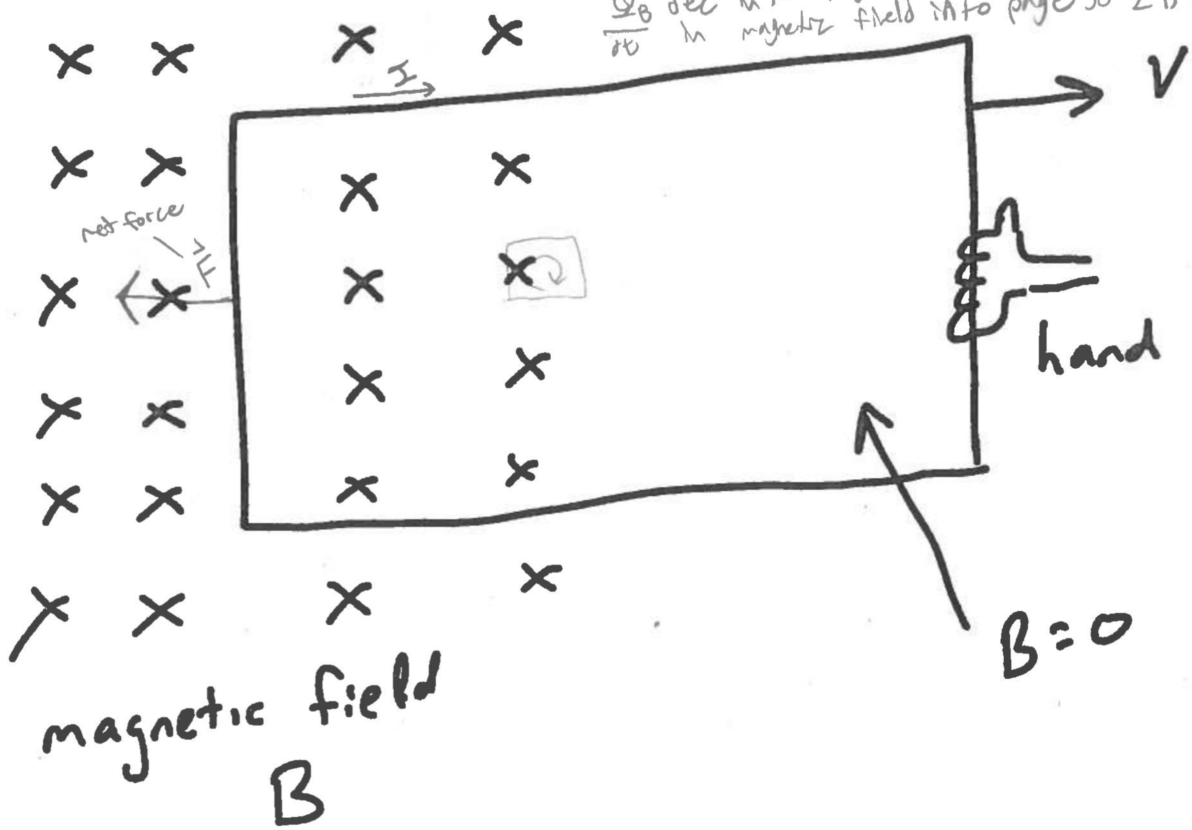
5) You are pulling a rectangular plate of copper out of a region with uniform magnetic field B with a constant speed v.
a) (10 pts) On the figure below draw one of the eddy current loops with non-zero current. Show the direction of current flow.
b) (5 pts) Also indicate the direction of the net force on the copper due to eddy currents

$\frac{\Phi_B}{dt}$ dec into page so induced $\mathcal{E}$ results in magnetic field into page so I is clockwise



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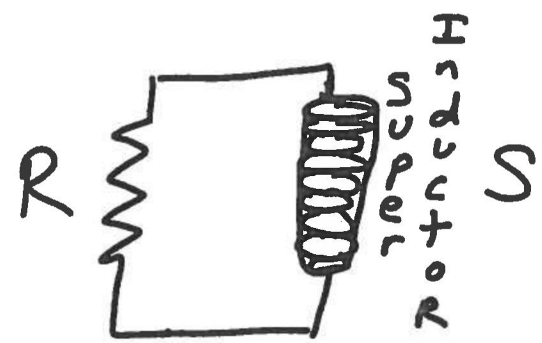
6) (15 pts) Scientists at a top-secret government laboratory recently invented a *super-inductor*. The voltage drop across a super-inductor is given by $V(t) = S\frac{d^3}{dt^3}I(t)$, where S is a constant known as the *super-inductance*, and $I(t)$ and $V(t)$ are the current and voltage. In the circuit below, a super-inductor with super-inductance $S=800{,}000$ (in the appropriate S.I. units) is in series with a resistor with resistance $R=100\ \Omega$ and the initial current at time $t=0$ is I_0.



At what time does the current become $(1/e)I_0$?

[extra page follows if needed]

$I(t) = I_0 e^{-t/\tau}$

$I_0 e^{-t/\tau} = (1/e) I_0$

$\tau = \frac{S}{R} = \frac{800{,}000}{100} = 8000$

$e^{-t/8000} = 1/e$

$-t/8000 = -1$

$\boxed{t = 8{,}000 \text{ sec}}$

[extra page]