19F-PHYSICS1C-4 Midterm

RYAN RIAHI

TOTAL POINTS

91 / 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 **7 / 10**

2.2 Part b **10 / 10**

QUESTION 3

Problem 3 20 pts

3.1 Part a **10 / 10**

3.2 Part b **9 / 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 **10 / 15**

+ 10 Point adjustment

Math error. 800,000/100 = 8000 and you can take a nice cube root of that. You didn't show much work to show how you got tau. It looks like you just did this based on dimensional analysis. That's partly okay but there could be a factor of 2 or pi off. Partial credit.

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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

Ryan Riahi

1) Short answers:

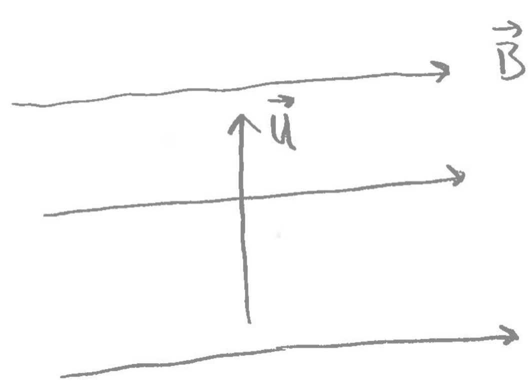
a) (5 pts) In class we performed a demonstration where a student pedaled a bicycle connected to a generator to power light bulbs in parallel. The reason he had to pedal harder as more bulbs were added was:

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.



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.]

$\lambda = 2\ m$ $\qquad E_0 = 300$

$k = \frac{2\pi}{\lambda} = \frac{2\pi}{2} = \pi\ \frac{1}{m}$

$E(x,t) = \hat{j}\, E_0 \cos(kx - \omega t)$

$c = \lambda f \qquad f = \frac{c}{\lambda} = 1.5 \times 10^8\ Hz$

$E_0 = cB_0$

$\omega = 2\pi f = 9.4 \times 10^8\ \frac{rad}{s}$

$B_0 = \frac{E_0}{c} = \frac{300}{3 \times 10^8} = 1 \times 10^{-6}\ T$

$$B(x,t) = -(1 \times 10^{-6}\ T)\, \hat{k} \cos\left((3.14\ \tfrac{rad}{m})x - (9.4 \times 10^8\ \tfrac{rad}{s})t \right)$$

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.]

$$A = 4m^2$$

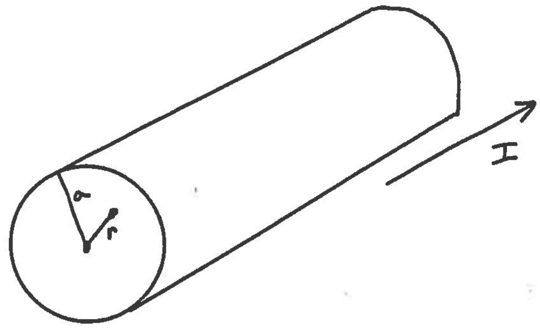
$$I = \frac{E^2}{2\mu_0 c} = \frac{(300)^2}{(8\pi \times 10^{-7})(3\times 10^8)} = \frac{90000}{240\pi \times 10} = 119.4 \frac{W}{m^2}$$

$$P_{rad} = \frac{I}{c} = \frac{119.4}{3\times 10^8} = \frac{F}{A}$$

$$F = \frac{4(119.4)}{3\times 10^8} = 1.59\times 10^{-6} \text{ N}$$

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]

$$I = \int \vec{J} \cdot d\vec{A} \qquad dA = 2\pi r\, dr$$

$$I_0 = \int J(r)\, 2\pi r\, dr = \int J_0\left(\frac{r^3}{a^3}\right) 2\pi r\, dr = \frac{J_0 2\pi}{a^3}\int_0^a r^4\, dr$$

$$I_0 = \frac{2\pi J_0}{a^3}\left[\frac{1}{5} r^5\right]_0^a = \frac{2\pi J_0}{a^3}\left(\frac{a^5}{5}\right) = \frac{2\pi J_0 a^2}{5}$$

$$3.14 = \frac{2\pi J_0 (5)^2}{5} \qquad J_0 = \frac{3.14}{10\pi} = .1\,\frac{A}{m^2}$$

[extra space]

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.]

$$\oint \vec{B}\cdot d\vec{l} = \mu_0 I_{enc}$$

$$I_{enc} = \int \vec{J}\cdot d\vec{A} = \int_0^2 10 \cdot 2\pi r\, dr = 20\pi\left[\frac{1}{2}r^2\right]_0^2 = 40\pi \text{ A}$$

$$B(2\pi(2)) = (4\pi\times 10^{-7})(40\pi)$$

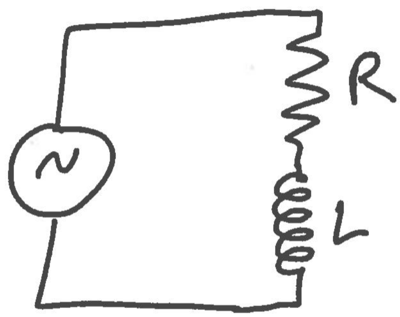
$$B = 4\pi\times 10^{-7}(10) = 1.26\times 10^{-5}\text{ T}$$

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?

$V_0 = V_{rms}\sqrt{2} = (240)(\sqrt{2}) = 339\text{ V}$

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]

$V_L = I X_L$

$X_L = \omega L$

$\omega = 2\pi f = 2\pi(50) = 100\pi$

$X_L = (100\pi)(100\times10^{-3}) = 31.4$

$V_{rms} = I_{rms} Z$

$240 = I_{rms} Z$

$Z = \sqrt{R^2 + X_L^2} = \sqrt{(62.8)^2 + (31.4)^2} = 70.2$

$I_{rms} = \frac{240}{70.2} = 3.42\text{ A}$

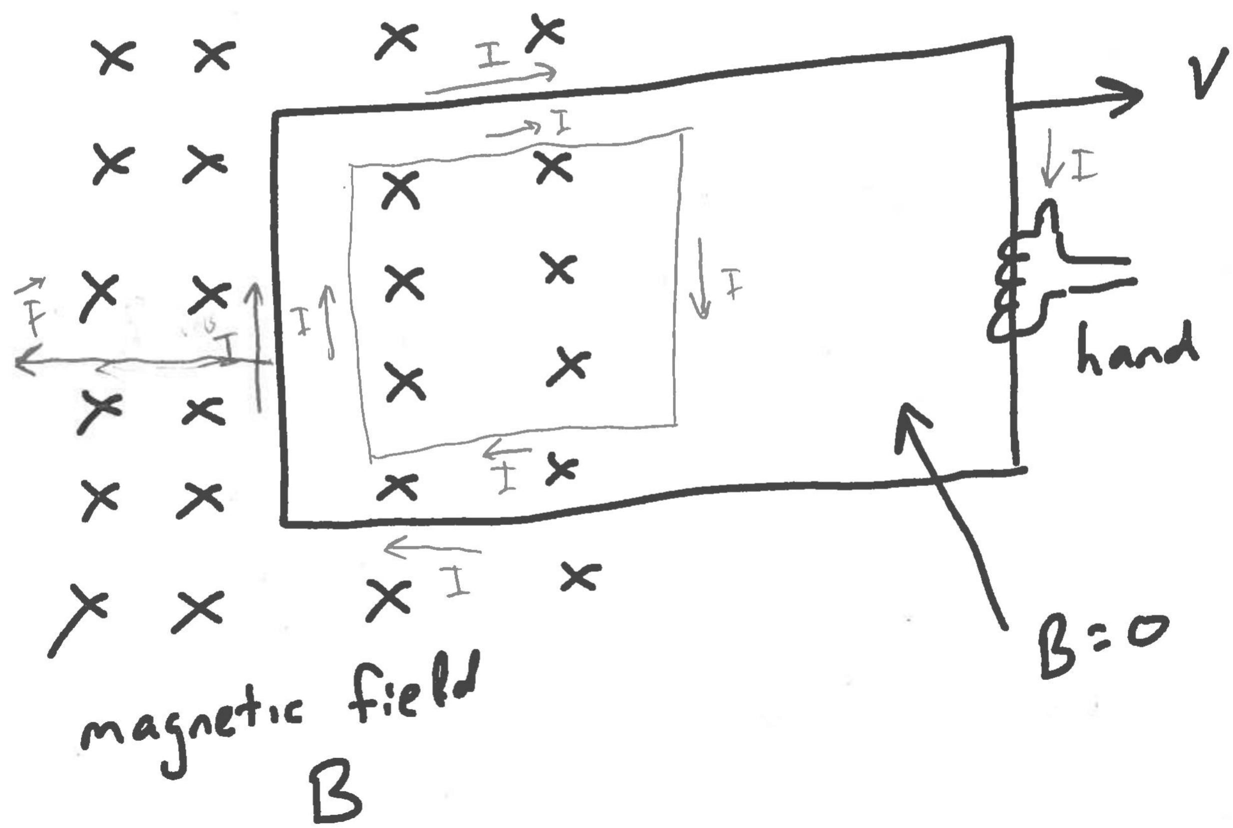
$V_L = (3.42)(31.4) = 107\text{ V}$

[extra space]

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

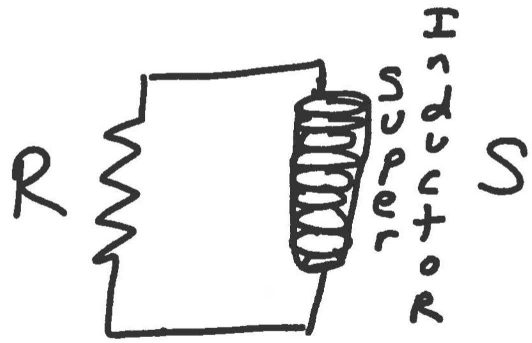


Current [near hand] experiences no force since not in magnetic field

Current on top and bottom experience equal & opposite forces, so they cancel

net force is related to force on left most side of the plate

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* Ω and the initial current at time t=*0* is I_0.



$\mathcal{E} = -L\frac{dI}{dt}$ $L: \frac{V\cdot s}{A}$

$V = S\frac{d^3I}{dt^3}$ $\frac{L}{R}: \frac{V\cdot s}{\Omega\cdot A} : s$

$V = S\left(\frac{A}{s^3}\right)$

$\tau = \frac{L}{R}$; units seconds

At what time does the current become $(1/e)I_0$?
[extra page follows if needed]

$I(t) = I_0 e^{-t/\tau}$ $\tau = \cancel{S/R = 8{,}000}$

$I(t) = \frac{1}{e} I_0$! $V = S\frac{d^3I}{dt^3}$ S: units: $\frac{V\cdot s^3}{A} = R\cdot s^3$

$\frac{1}{e} I_0 = I_0 e^{-t/\tau}$ S/R: units $\frac{V\cdot s^3}{R\cdot A} : s^3$

$e^{-1} = e^{-t/\tau}$ $\tau = \sqrt[3]{S/R} = \sqrt[3]{80{,}000} = 43$

$-1 = -t/\tau$

when $t = \tau$

$t = 43$ seconds

[extra page]