Physics 208, Spring 2016 – Exam #3

A

Name (Last, First): ________________________________

ID #: __________________

Section #: _________________

- You have 75 minutes to complete the exam.
- Formulae are provided on an attached sheet. You may NOT use any other formula sheet.
- You may use only a simple calculator: one without memory, or with a memory demonstrated to be cleared.
- When calculating numerical values, be sure to keep track of units. Results must include proper units.
- Be alert to the number of significant figures in the information given. Results must have the correct number of significant figures.
- If you are unable to solve a problem whose solution is needed in another problem, then assign a symbol for the solution of the first problem and use that symbol in solving the second problem.
- If you need additional space to answer a problem, use the back of the sheet it is written on.
- Show your work. Without supporting work, the answer alone is worth nothing.
- Mark your answers clearly by drawing boxes around them.
- Please write clearly. You may gain marks for a partially correct calculation if your work can be deciphered.

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208 Mid-Term 3 POINTS TABLE	
Multiple Choice (out of 20)	
Problem 1 (out of 20)	
Problem 2 (out of 20)	
Problem 3 (out of 20)	
Problem 4 (out of 20)	
TOTAL SCORE (out of 100)	

MC1. (5 marks) An electron moving in the direction of the +x-axis enters a magnetic field. If the electron experiences a magnetic deflection in the -y direction, the direction of the magnetic field in this region points in the direction of the

A) +y-axis.

B) -y-axis.

C) -x-axis.

D) +z-axis.

E) -z-axis.

MC2. (5 marks) The figure shows three long, parallel, current-carrying wires. The current directions are indicated for currents I_1 and I_3. The arrow labeled F represents the net magnetic force acting on current I_3. The three currents have equal magnitudes. What is the direction of the current I_2?

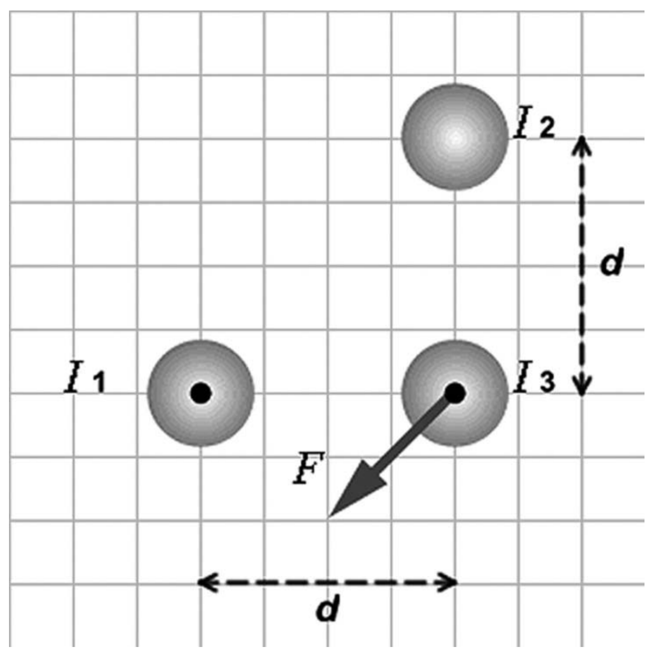
A) out of the picture (in the same direction as I_1 and I_3)

B) vertically downward

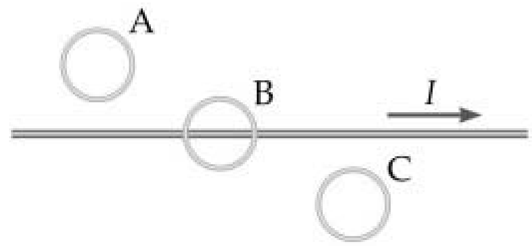
C) vertically upward

D) horizontally to the right

E) into the picture (in the direction opposite to that of I_1 and I_3)



MC3. (5 marks) The long straight wire in the figure carries a current I that is decreasing with time at a constant rate. The circular loops A, B, and C all lie in a plane containing the wire. The induced emf in each of the loops A, B, and C is such that



A) a counterclockwise emf is induced in all the loops.

B) loop A has a clockwise emf, loop B has no induced emf, and loop C has a counterclockwise emf.

C) loop A has a counter-clockwise emf, loop B has no induced emf, and loop C has a clockwise emf.

D) loop A has a counter-clockwise emf, loops B and C have clockwise emfs.

E) no emf is induced in any of the loops.

MC4. (5 marks) A resistor and an ideal inductor are connected in series to an ideal battery having a constant terminal voltage V_0. At the moment contact is made with the battery,

A) the voltage across the resistor is zero and the voltage across the inductor is zero.

B) the voltage across the resistor is V_0 and the voltage across the inductor is V_0.

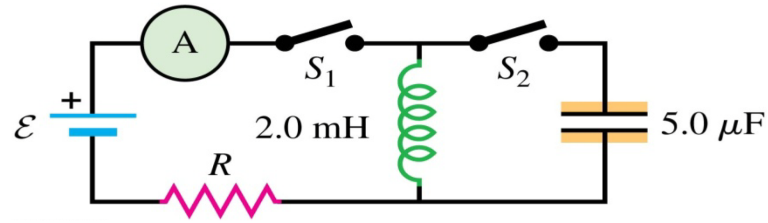
C) the voltage across the resistor is V_0 and the voltage across the inductor is zero.

D) the voltage across the resistor is zero and the voltage across the inductor is V_0.

1. **(20 marks)** In the circuit shown, switch S_1 has been closed for a long enough time so that the current reads a steady 5.50 A. Suddenly, switch S_2 is closed and S_1 is opened at the same instant.

   a) What is the maximum charge that the capacitor will receive?

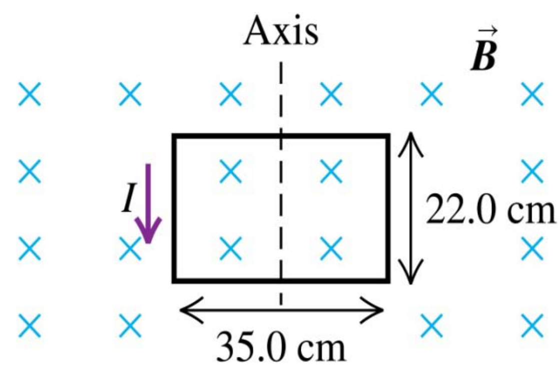
   b) What is the current in the inductor at this time?



2. (20 marks) A rectangular coil of wire, 22.0 cm by 35.0 cm and carrying a current of 1.95 A, is oriented with the plane of its loop perpendicular to a uniform 3.50-T magnetic field.

a) Calculate the net force and torque (magnitude and direction) that the magnetic field exerts on the coil.

b) The coil is rotated about a 25.0° angle about the axis shown, with the left side coming out of the plane of the figure and the right side going into the plane. Calculate the net force and torque (magnitude and direction) that the magnetic field now exerts on the coil. (*Hint:* To visualize this three-dimensional problem, make a careful drawing of the coil as viewed along the rotation axis.)



3. (20 marks) A very long, straight wire with a circular cross section of radius $\boldsymbol{R}$ carries current $\boldsymbol{I}$. Assume that the current density is not constant across the cross section of the wire, but rather varies as $\boldsymbol{J} = \boldsymbol{\beta r}$, where $\boldsymbol{\beta}$ is a constant.

a) By the requirement that $\boldsymbol{J}$ integrated over the cross section of the wire gives the total current $\boldsymbol{I}$, calculate the constant $\boldsymbol{\beta}$ in terms of $\boldsymbol{I}$ and $\boldsymbol{R}$.

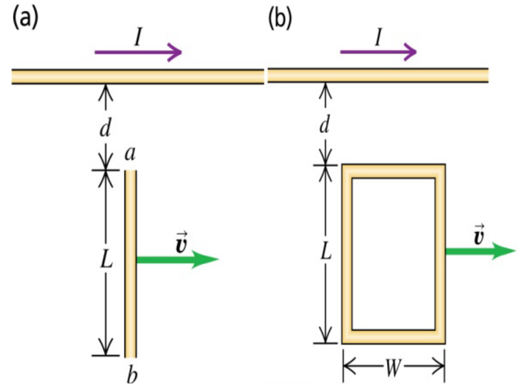
b) Use Ampere's Law to calculate the magnetic field $\boldsymbol{B(r)}$ for (i) $\boldsymbol{r \leq R}$ and (ii) $\boldsymbol{r \geq R}$. Express your answers in terms of $\boldsymbol{I}$.

4. (20 marks) A very long, straight wire shown in Figure (a) carries constant current $\boldsymbol{I}$. A metal bar with length $\boldsymbol{L}$ is moving with constant velocity $\vec{v}$, as shown in the figure. Point $\boldsymbol{a}$ is a distance $\boldsymbol{d}$ from the wire.

a) Calculate the emf induced in the bar (in figure (a)).

b) Which point, $\boldsymbol{a}$ or $\boldsymbol{b}$, is at a higher potential?

c) If the bar is replaced by a rectangular loop of resistance $\boldsymbol{R}$ (figure (b)), what is the magnitude of the current induced in the loop?



PHYSICS 208 EXAM 3/Final Spring 2016
Formula/Information Sheet

- Basic constants

Gravitational acceleration	g	$=$	9.8 m/sec^2
Permittivity of free space	ϵ_0	$=$	8.8542×10^{-12} C^2/N·m^2 [$k = 1/4\pi\epsilon_0 = 8.9875 \times 10^9$ N·m^2/C^2]
Permeability of free space	μ_0	$=$	$4\pi \times 10^{-7}$ T·m/A [$k_m = \mu_0/4\pi = 10^{-7}$ Wb/A·m]
Elementary charge	e	$=$	1.60×10^{-19} C
Unit of energyelectron volt	1 eV	$=$	1.60×10^{-19} J
Unit of energykilowatt-hour	1 kWh	$=$	3.6×10^6 J
Planck's Constant	h	$=$	6.626×10^{-34} J sec
Speed of light	c	$=$	3.00×10^8 m/sec

- Properties of some particles

Particle	Mass [kg]	Charge [C]
Proton	1.67×10^{-27}	$+1.60 \times 10^{-19}$
Electron	9.11×10^{-31}	-1.60×10^{-19}
Neutron	1.67×10^{-27}	0

- Some indefinite integrals

$$\int \frac{dx}{x} = \ln x \qquad \int x^n dx = \frac{x^{n+1}}{n+1} \quad (n \neq -1)$$
$$\int \frac{dx}{(x^2+a^2)^{3/2}} = \frac{x}{a^2\sqrt{x^2+a^2}} \qquad \int \frac{x\ dx}{(x^2+a^2)^{3/2}} = -\frac{1}{\sqrt{x^2+a^2}}$$
$$\int \cos ax\ dx = \frac{1}{a}\sin ax \qquad \int \frac{dx}{(a+x)^2} = -\frac{1}{a+x}$$

- Basic equations for Electromagnetism

Maxwell equations
$$\oint \vec{E} \cdot d\vec{l} = -\frac{d\phi_B}{dt}$$
$$\oint \vec{B} \cdot d\vec{l} = \mu_0\ (i + \epsilon_0 \frac{d\phi_E}{dt})$$
$$\oint \vec{E} \cdot d\vec{A} = \frac{Q_{enclosed}}{\epsilon_0}$$
$$\oint \vec{B} \cdot d\vec{A} = 0$$

- Basic Equations for Geometric Optics, Waves, Interference and Diffraction

Law of Reflection	$\theta_{incident}$	$=$	$\theta_{reflected}$
Snell's Law	$n_1 \sin(\theta_1)$	$=$	$n_2 \sin(\theta_2)$
Refraction at spherical surface	$\frac{n_a}{d_o} + \frac{n_b}{d_i}$	$=$	$\frac{n_b - n_a}{R}$
Magnification by spherical surface	m	$=$	$-\frac{n_a d_i}{n_b d_o}$
Lens Equation	$\frac{1}{f}$	$=$	$\frac{1}{d_o} + \frac{1}{d_i}$
Lens Maker's Equation	$\frac{1}{f}$	$=$	$(n-1)(\frac{1}{R_1} - \frac{1}{R_2})$
Magnification	m	$=$	$\frac{h_i}{h_o} = \frac{-d_i}{d_o}$
Wave Equation	$\frac{\partial^2 f(x,t)}{\partial x^2}$	$=$	$\frac{1}{v^2}\frac{\partial^2 f(x,t)}{\partial t^2}$
Plane EM wave traveling in the $+x$ direction	$E(x,t)$	$=$	$E_0 \sin(kx - \omega t)$
	$B(x,t)$	$=$	$B_0 \sin(kx - \omega t)$
Speed of an EM wave [m/s]	c	$=$	$\frac{1}{\sqrt{\mu_0\epsilon_0}} = \frac{E_0}{B_0} = \frac{E(x,t)}{B(x,t)}$
Wave length of an EM wave [m]	λ	$=$	$\frac{c}{f}$
Wave number of an EM wave	k	$=$	$\frac{2\pi}{\lambda}$
Poynting vector [J/s·m^2]	$\vec{S}$	$=$	$\frac{1}{\mu_0}\vec{E} \times \vec{B}$
Time-averaged S [J/s·m^2]	S_{ave}	$=$	$\frac{E_0 B_0}{2\mu_0}$
Intensity of an EM wave [J/s·m^2]	I	$=$	S_{ave}
Total energy of an EM wave [J]	U	$=$	$I\ A\ t$
Total momentum of an EM wave	$\lvert\vec{p}\rvert$	$=$	$\frac{U}{c}$
Double Slit Const. Int.	$d \sin(\theta)$	$=$	$m\lambda$
Double Slit Dest. Int.	$d \sin(\theta)$	$=$	$(m + \frac{1}{2})\lambda$

- Basic equations for Magnetism and Induction

Faraday's Law		$\mathcal{E}$	$=$	$-\frac{d\,\Phi_m}{d\,t}$
Self Inductance [H]	(definition)	L	$=$	$\frac{N\Phi_m}{I}$
Self Induced electromotive force [V]		$\mathcal{E}$	$=$	$-L\frac{d\,I}{d\,t}$
Mutual Inductance [H]	(definition)	M_{21}	$=$	$N_2\frac{\Phi_{21}}{I_1}$
Electromotive force induced by mutual induction [V]		$\mathcal{E}_2$	$=$	$-M_{21}\frac{d\,I_1}{d\,t}$
Magnetic field energy density		$u_{magnetic}$	$=$	$\frac{1}{2\,\mu_o}B^2$
Magnetic energy stored in L [J]		$U_B(t)$	$=$	$\frac{1}{2}LI(t)^2$
Time constant in RL circuits [s]		τ_{RL}	$=$	$\frac{L}{R}$
Current in RL circuit		$i(t)$	$\propto$	$e^{-t/\tau}$or $(1-e^{-t/\tau})$
Angular frequency of LC circuit [rad/sec]		ω	$=$	$\sqrt{\frac{1}{LC}}$

Magnetic force [N]	on charge q	$\vec{F}$	$=$	$q\,\vec{v}\times\vec{B}$
	on current-carrying conductor	$\vec{F}$	$=$	$\int I d\vec{l}\times\vec{B}$
Magnetic moment [A·m^2 or J/T]		$\vec{\mu}$	$=$	$I\vec{A}$
Torque [N·m]	on a current loop	$\vec{\tau}$	$=$	$\vec{\mu}\times\vec{B}$
Potential energy [J]	of a current loop	U	$=$	$-\vec{\mu}\cdot\vec{B}$

Ampere's law		$\oint\vec{B}\cdot d\vec{l}$	$=$	$\mu_0\,I$
Biot-Savart law		$d\vec{B}$	$=$	$k_m\,\frac{I\,d\vec{l}\times\hat{r}}{r^2}$
Magnetic field [T]	moving point charge q	$\vec{B}$	$=$	$k_m\,\frac{q\,\vec{v}\times\hat{r}}{r^2}$
	a long straight wire	$\lvert\vec{B}\rvert$	$=$	$\mu_0 I/(2\pi a)$
	inside a toroid	$\lvert\vec{B}\rvert$	$=$	$\mu_0 NI/(2\pi r)$
	inside a solenoid	$\lvert\vec{B}\rvert$	$=$	$\mu_0 NI/\ell$
	a straight wire segment	$\lvert\vec{B}\rvert$	$=$	$k_m I(\cos\theta_1-\cos\theta_2)/a$
	a circular arc (radius R)	$\lvert\vec{B}\rvert$	$=$	$k_m I\theta/R$
Displacement current [A]	(definition)	I_d	$\equiv$	$\epsilon_0\frac{d\Phi_E}{dt}$
Ampere-Maxwell law		$\oint\vec{B}\cdot d\vec{l}$	$=$	$\mu_0\,(I+I_d)$

- Basic equations for Electric Fields

Coulomb's law		$\lvert\vec{F}\rvert$	$=$	$k\,\frac{\lvert q_1\rvert\lvert q_2\rvert}{r^2}$
Electric field [N/C = V/m]	(point charge q)	$\vec{E}(r)$	$=$	$k\,\frac{q}{r^2}\,\hat{r}$
		($\hat{r}$ = unit vector radially from q)		
	(group of charges)	$\vec{E}$	$=$	$\sum\vec{E}_i\;=\;k\sum\frac{q_i}{r_i^2}\,\hat{r}_i$
	(continuous charge distribution)	$\vec{E}$	$=$	$k\int\frac{dq}{r^2}\,\hat{r}$
		($\hat{r}$ = unit vector radially from dq)		
Electric force [N]	(on q in $\vec{E}$)	$\vec{F}$	$=$	$q\,\vec{E}$
Torque [N·m]		$\vec{\tau}$	$=$	$\vec{r}\times\vec{F}$

Electric flux	(through a small area ΔA_i)	$\Delta\Phi_i$	$=$	$\vec{E}_i \cdot \Delta\vec{A}_i = E_i\ \Delta A_i\ \cos\theta_i$
	(through an entire surface area)	$\Phi_{surface}$	$=$	$\lim_{\Delta A \to 0} \sum \Delta\Phi_i = \int \vec{E} \cdot d\vec{A}$
Gauss' law	(through a closed surface area)	Φ_{closed}	$\equiv$	$\oint \vec{E} \cdot d\vec{A} = \frac{Q_{in}}{\epsilon_0}$

Electric potential [V = J/C]	(definition)	$V_A - V_B$	$=$	$\int_A^B \vec{E} \cdot d\vec{s}$
	(point charge q)	$V(r)$	$=$	$k\,\frac{q}{r}$ (with $V(\infty) = 0$)
	(group of charges)	$V(\vec{r})$	$=$	$\sum V_i(\lvert\vec{r}_i - \vec{r}\rvert) = k \sum \frac{q_i}{\lvert\vec{r}_i - \vec{r}\rvert}$ ($V_i(\infty) = 0$)
	(continuous charge distribution)	$V(\vec{r})$	$=$	$k \int \frac{dq}{\lvert\vec{r}\,' - \vec{r}\rvert}$ ($V(\infty) = 0$)
Electric potential energy [J]	(definition)	$U_A - U_B$	$=$	$q_0 \int_A^B \vec{E} \cdot d\vec{s}$
			$=$	$q_0\ (V_A - V_B)$
$\vec{E}$ from V		$\vec{E}$	$=$	$-\vec{\nabla}V$ ($\vec{\nabla}$ = gradient operator)
Electric potential energy of two-charge system		U_{12}	$=$	$k\,\frac{q_1 q_2}{r_{12}}$

Capacitance [F]	(definition)	C	$\equiv$	$\frac{Q}{\lvert\Delta V\rvert}$
	(parallel-plate capacitance)	C	$=$	$\kappa \frac{\epsilon_0 A}{d}$
Capacitors in series		$\frac{1}{C_{eq}}$	$=$	$\frac{1}{C_1} + \frac{1}{C_2} + \frac{1}{C_3} + ...$
Capacitors in parallel		C_{eq}	$=$	$C_1 + C_2 + C_3 + ...$
Electric field energy density		$u_{electric}$	$=$	$\frac{1}{2}\epsilon_0 E^2$
Electrostatic potential energy [J] stored in capacitance		$U_E(t)$	$=$	$\frac{1}{2}\,\frac{Q(t)^2}{C}$
Electric dipole moment ($2a$ = separation between two charges)		$\lvert\vec{p}\rvert$	$=$	$2aq$
Torque on electric dipole moment		$\vec{\tau}$	$=$	$\vec{p} \times \vec{E}$
Potential energy of an electric dipole moment		U	$=$	$-\vec{p} \cdot \vec{E}$

Current [A]	(definition)	I	$\equiv$	$\frac{d\,Q(t)}{d\,t}$
	with motion of charges	I	$=$	$nqv_d A$
Current density [A/m^2]		J	$=$	$\frac{I}{A}$ (where $I = \int \vec{J} \cdot \vec{n}\ dA$)
Resistivity [Ω·m]		ρ	$=$	$\frac{\lvert\vec{E}\rvert}{\lvert\vec{J}\rvert}$
Resistance [Ω]	(definition)	R	$\equiv$	$\frac{V}{I}$
	for uniform cross-sectional area A	R	$=$	$\rho\frac{\ell}{A}$
Resistors in series		R_{eq}	$=$	$R_1 + R_2 + R_3 + ...$
Resistors in parallel		$\frac{1}{R_{eq}}$	$=$	$\frac{1}{R_1} + \frac{1}{R_2} + \frac{1}{R_3} + ...$
Energy loss rate on R [J/s]		P	$=$	$I^2\ R = V^2/R = IV$
Time constant in RC circuit [s]		τ_{RC}	$=$	RC
Charge in RC circuit		$Q(t)$	$\propto$	$e^{-t/\tau}$ or $(1 - e^{-t/\tau})$