AFTER I GIVE THE SIGNAL TO BEGIN YOU CAN REMOVE THIS SHEET. DO NOT TURN IT IN!

163fa23t3b – Once the exam has officially started, remove the top sheet. The remaining sheets comprise your exam. It is each student's individual responsibility to ensure the instructor has received her or his completed exam. Any exams not received by the instructor earn zero points. Smart watches, phones, or other devices (except scientific calculators) are not permitted during the exam.

$e = 1.602 \times 10^{-19}$ C $\quad k = 8.99 \times 10^9 \frac{\text{N·m}^2}{\text{C}^2}$ $\quad c = 3.00 \times 10^8 \frac{\text{m}}{\text{s}}$ $\quad \varepsilon_0 = 8.85 \times 10^{-12} \frac{\text{C}^2}{\text{N·m}^2}$

$h = 6.626 \times 10^{-34}$ J · s $\quad hc \approx 1240$ eV · nm $\quad \mu_0 = 4\pi \times 10^{-7} \frac{\text{T·m}}{\text{A}}$ $\quad 1$ eV $= 1.602 \times 10^{-19}$ J

$m_p = 1.673 \times 10^{-27}$ kg $\quad m_e = 9.11 \times 10^{-31}$ kg

$\vec{F} = q\vec{E}$ $\quad k = \frac{1}{4\pi\varepsilon_0}$ $\quad \Delta x = v_{ix}t + \frac{1}{2}a_x t^2$ $\quad v_{fx}^2 = v_{ix}^2 + 2a_x\Delta x$

$\vec{F}_{1on2} = \frac{kq_1q_2}{r_{12}^2}\hat{r}_{1to2}$ $\quad \vec{E} = \frac{kq}{r^2}\hat{r}$ $\quad V = \frac{kq}{r}$ $\quad U_{12} = \frac{kq_1q_2}{r_{12}}$

$\oint \vec{E} \cdot d\vec{A} = \frac{q_{enc}}{\varepsilon_0}$ $\quad q_{enc} = \int \rho dV$ $\quad E_{\parallel\, plates} = \frac{|\Delta V|}{d} = \frac{\sigma}{\varepsilon_0}$ $\quad E_{plate} = \frac{\sigma}{2\varepsilon_0}$

$E_{ring} = \frac{kQz}{(R^2+z^2)^{3/2}}$ $\quad V_{ring} = \frac{kQ}{(R^2+z^2)^{1/2}}$ $\quad E_x = -\frac{dV}{dx}$ $\quad V_b - V_a = -\int_a^b \vec{E} \cdot d\vec{s}$

$\Delta U = q\Delta V$ $\quad U_C = \frac{1}{2}Q_C\Delta V_C$ $\quad Q_C = \Delta V_C C$ $\quad I_C = -C\frac{dV_C}{dt}$

$\frac{1}{C_{eq}} = \frac{1}{C_1} + \frac{1}{C_2} + \cdots$ $\quad C_{eq} = C_1 + C_2 + \cdots$ $\quad C_{plates} = \frac{\varepsilon_0 A}{d}$ $\quad C' = \kappa C$

$R_{eq} = R_1 + R_2 + \cdots$ $\quad \frac{1}{R_{eq}} = \frac{1}{R_1} + \frac{1}{R_2} + \cdots$ $\quad R = \frac{\rho L}{A}$ $\quad \rho = \rho_0(1 + \alpha\Delta T)$

$\Delta V_R = I_R R$ $\quad \mathcal{P}_R = I_R \Delta V_R$ $\quad X(t) = X_f + (X_i - X_f)e^{-t/\tau}$ where $\tau = RC$ or $\frac{L}{R}$

$\vec{F} = q\vec{v} \times \vec{B}_{ext}$ $\quad \vec{F} = I\int d\vec{s} \times \vec{B}_{ext}$ $\quad \vec{\tau} = \vec{\mu} \times \vec{B}_{ext}$ $\quad \vec{\mu} = NI\vec{A}$

$U = -\vec{\mu} \cdot \vec{B}_{ext}$ $\quad B_{sol} = \frac{\mu_0 NI}{L}$ $\quad B_{ring} = \frac{\mu_0 I r^2}{2(r^2+z^2)^{3/2}}$ $\quad B_{straight} = \frac{\mu_0 I}{2\pi a}$

$\oint \vec{B} \cdot d\vec{s} = \mu_0 I_{enc}$ $\quad I_{enc} = \int \vec{J} \cdot d\vec{A}$ $\quad \vec{B} = \frac{\mu_0 I}{4\pi}\int \frac{d\vec{s} \times \hat{r}}{r^2}$ $\quad \Phi_B = \int \vec{B} \cdot d\vec{A}$

$EMF = -N\frac{d}{dt}\Phi_B$ $\quad EMF = B_\perp Lv$ $\quad L = \frac{\Phi_B}{I}$ $\quad U_L = \frac{1}{2}LI^2$

$\frac{\Delta V_2}{\Delta V_1} = \frac{N_2}{N_1}$ $\quad \Delta V_L = -L\frac{dI_L}{dt}$ $\quad Z = \sqrt{R^2 + (X_L - X_C)^2}$ $\quad \tan\phi = \frac{X_L - X_C}{R}$

$X_L = \omega L$ $\quad X_C = \frac{1}{\omega C}$ $\quad V_{source} = V_0 \sin\omega t$ $\quad i = i_{max}\sin(\omega t - \phi)$

$\Delta V_{Rmax} = i_{max}R$ $\quad \Delta V_{Lmax} = i_{max}X_L$ $\quad \Delta V_{Cmax} = i_{max}X_C$ $\quad V_{source\ max} = i_{max}Z$

$\Delta V_{max} = \frac{\Delta V_{pk-pk}}{2}$ $\quad \Delta V_{rms} = \frac{\Delta V_{max}}{\sqrt{2}}$ $\quad \omega_0 = \frac{1}{\sqrt{LC}}$

$\mathcal{P}_{avg} = I_{rms}\Delta V_{rms}\cos\phi = I_{rms}^2 R$

$c = f\lambda$ $\quad k = \frac{2\pi}{\lambda}$ $\quad \omega = 2\pi f = \frac{2\pi}{\mathbb{T}}$

$\vec{S} = \frac{\vec{E} \times \vec{B}}{\mu_0}$ $\quad I_{avg} = S_{avg} = \frac{E_{max}B_{max}}{2\mu_0} = \left(\frac{1}{c}\right)\frac{E_{max}^2}{2\mu_0} = c\frac{B_{max}^2}{2\mu_0}$

$\frac{E_{max}}{B_{max}} = c$ $\quad E_\gamma = hf = \frac{hc}{\lambda}$

$Rad.Pressure = \frac{Force}{Area} = \frac{S_{avg}}{c}$ $\quad Photon\ momentum = p_\gamma = \frac{E_\gamma}{c}$

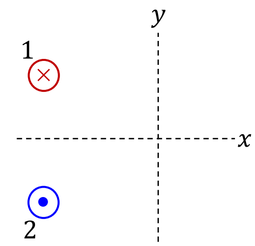
Material	**Resistivity** at 20° C (in SI units)	**Temp. Coefficient** (in SI units)
Silver	1.62×10^{-8}	4.1×10^{-3}
Copper	1.69×10^{-8}	4.3×10^{-3}
Aluminum	2.75×10^{-8}	4.4×10^{-3}
Nichrome	1.00×10^{-6}	0.4×10^{-3}
Carbon	3.5×10^{-5}	-0.5×10^{-3}
Germanium	0.46	-48×10^{-3}

$\int \frac{x\,dx}{(x^2+a^2)^{3/2}} = \frac{-1}{\sqrt{x^2+a^2}}$	$\int \frac{dx}{\sqrt{x^2 \pm a^2}} = \ln\left\|x + \sqrt{x^2 \pm a^2}\right\|$
$\int \frac{dx}{(x^2+a^2)^{3/2}} = \frac{x}{a^2\sqrt{x^2+a^2}} = \frac{1}{a^2}\sin\theta$	$\int \frac{x\,dx}{\sqrt{x^2 \pm a^2}} = \sqrt{x^2 \pm a^2}$
$\int \frac{dx}{x^2+a^2} = \frac{1}{a}\tan^{-1}\frac{x}{a}$	$\int \sqrt{x^2 \pm a^2}\,dx = \frac{1}{2}x\sqrt{x^2 \pm a^2} \pm \frac{a^2}{2}\ln\left\|x + \sqrt{x^2 \pm a^2}\right\|$
$\int \frac{x\,dx}{x^2+a^2} = \frac{1}{2}\ln\left\|x^2 + a^2\right\|$	**Binomial expansion:** $(1 \pm \delta)^n \approx 1 \pm n\delta + \cdots$

T = 10^{12}	G = 10^9	M = 10^6	k = 10^3	c = 10^{-2}	m = 10^{-3}	µ = 10^{-6}	n = 10^{-9}	p = 10^{-12}	f = 10^{-15}	a = 10^{-18}

Rip off eqt'n sheet & put name on this page. **NAME:____**

Wires 1 & 2 are infinitely long (both into & out of the page).
The wires carry equal current in the directions indicated.
The wires are 7.00 cm apart from each other, centered about the x-axis.
Each wire is 7.00 cm from the y-axis.
Net magnetic field created by the two wires at the origin has magnitude 22.2 mT.
Note: I used random numbers, reality check might be useless.



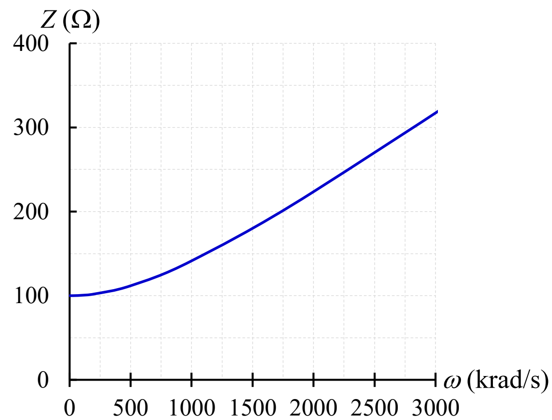
***1a) Which best describes the signs of field components at the origin? Circle the best answers.

$B_x > 0$	$B_x = 0$	$B_x < 0$	Impossible to determine without more info
$B_y > 0$	$B_y = 0$	$B_y < 0$	Impossible to determine without more info
$B_z > 0$	$B_z = 0$	$B_z < 0$	Impossible to determine without more info

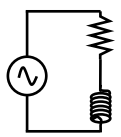
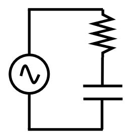
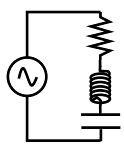
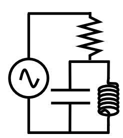
****1b) Determine current required to produce such a field.

1b	

A plot of impedance versus angular frequency is shown for a circuit with AC source. Impedance continues to increase past 3000 krad/s.



2a) Which of the circuits shown below is most likely to produce such a plot?

		None of the four circuits shown produces such a plot
		Impossible to determine without more info

2b) Estimate the resistance of the resistor used in the circuit.

$R \approx$

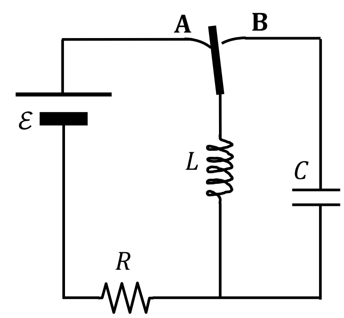
The circuit shown at right is built using a 6.00 V battery, a 2.00 mH inductor, a $30\underline{0}$ nF capacitor, and a 32.0 Ω resistor. The switch is left in position **A** for a long time. At time $t = 0$ the switch is changed to position **B**. A sliding switch ensures connection to **B** at the exact instant it disconnects from **A**. This prevents inductive sparking to position **A**. Furthermore, assume switching happens rapidly enough to ignore any charging of the capacitor by the battery during the switching.

Answer in engineering notation with appropriate prefix.

**3a) What is the max energy in the fully energized inductor?

**3b) How much time elapses before the capacitor first reaches full charge?

**3c) What is the max charge on the capacitor?

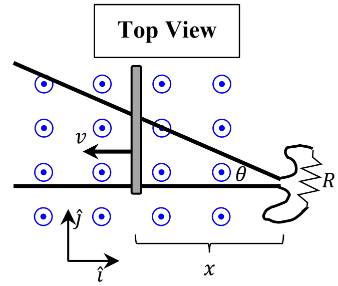


3a	
3b	
3c	

A set of conducting rails with negligible resistance are connected using a resistor of resistance R as shown at right. To be clear, the rails lie on a flat, level horizontal surface.

A conducting rod of negligible resistance is pulled to the left with constant speed v. To be clear, this rod is always in good electrical contact with both rails.

The figure at right shows a view from directly above the rails. Angle θ is known and you may assume the rails & rod essentially form a triangular loop. At one particular instant in time, the rod is distance x from the right end of the rails. At this same instant we known current in the rod is I.



4a) What direction is the induced current flowing in the rod? Circle the best answer.

Upwards	Downwards	Impossible to determine without more info

4b) What direction is the magnetic force on the rod? Circle the best answer.

$+\hat{\imath}$	$-\hat{\imath}$	$+\hat{\jmath}$	$-\hat{\jmath}$	$+\hat{k}$	$-\hat{k}$	Impossible to determine without more info

4c) As the rod continues moving left (at constant speed), what happens to the induced current in the rod?

Gets smaller	Stays the same	Gets larger	Impossible to determine without more info

*****4d) Determine the magnitude of the external magnetic field in terms of known parameters.

4d	

A series LRC circuit operates with a period of 55.5 μs. Source voltage amplitude is 22.2 V, resistance is 33.3 Ω, inductance is 888 μH, and capacitance 444 nF.

For this problem, write answers in engineering notation using the best choice of prefix.

5a) Determine resonance frequency (in Hz) for this circuit.

**5b) Determine impedance at the operating frequency.

5c) Determine phase angle **(in degrees) at the operating frequency.

***5d) Determine average power delivered to the resistor at the operating frequency?

5a	
5b	
5c	
5d	

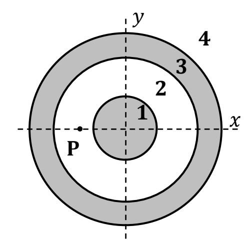
5e) Which best describes the relationship between source voltage and current at this operating frequency?

Current leads source voltage	Current lags source voltage	Current & source voltage in phase	Current & source voltage out of phase	Impossible to determine without more info

5f) Suppose the capacitor involved is a variable capacitor and we decide to slightly decrease capacitance. What should happen to the phase angle as capacitance is decreased slightly?

Becomes more positive	Stays the same	Becomes more negative	Impossible to determine without more info

A solid cylindrical wire of radius R is surrounded by a concentric conducting cylindrical shell. The solid wire carries non-uniform current density given by $J = kr^8$ where k is an UNKNOWN positive constant. Total current in the solid wire is I running *into the page*.



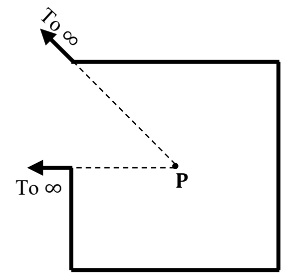
The outer shell has inner radius $3R$, outer radius $4R$, and carries the same total current directed *out of the page*. Figure not to scale.

Regions of space are indicated with numbers to speed up communication. One particular point in space (point **P**) is indicated in region **2** directly below the center of the solid wire.

6a) Determine the units for the constant k.
6b) Determine an expression for k in terms of I & R.
6c) Determine the direction of the field at the point **P**.
6d) Determine the magnetic field magnitude in region **1**.
6e) Determine the magnetic field magnitude in region **2**.
6f) Determine the magnetic field magnitude in region **3**.
6g) Determine the magnetic field magnitude in region **4**.

6a	
6b	
6c	
6d	
6e	
6f	
6g	

A wire is bent into the shape shown at right. The shape is essentially a square of side length 3.33 cm with half of one of the sides missing. A battery connects to the two diagonal segments far from the wire. You may assume the diagonal segments extend to infinity. The wire's current runs clockwise causing net magnetic field magnitude 222 μT at point **P** (center of the square).



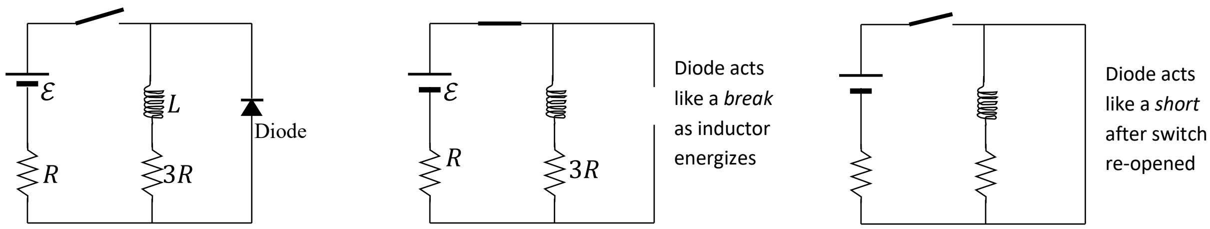
7a) What direction does the magnetic field direction point at the point **P**?

$+\hat{\imath}$	$-\hat{\imath}$	$+\hat{\jmath}$	$-\hat{\jmath}$	$+\hat{k}$	$-\hat{k}$	Impossible to determine without more info

*****7b) Determine current in the wire.

7b	

A circuit is designed as shown below. For the purposes of this question, we can model the diode as a one-way current valve. At time $t = 0$, as the inductor energizes, the diode acts like a break in the rightmost branch of the circuit. The circuit is allowed to reach steady state. After reaching steady state, the switch is re-opened. When the switch is *re*-opened, the diode acts like a short! A plot of voltage across $3R$ after reopening is shown below.



Answer the first three questions on this page algebraically in terms of $\mathcal{E}$, L, & R.

8a) What is voltage across the inductor just after the switch is first closed at time $t = 0$?

8b) What is steady state current through the inductor?

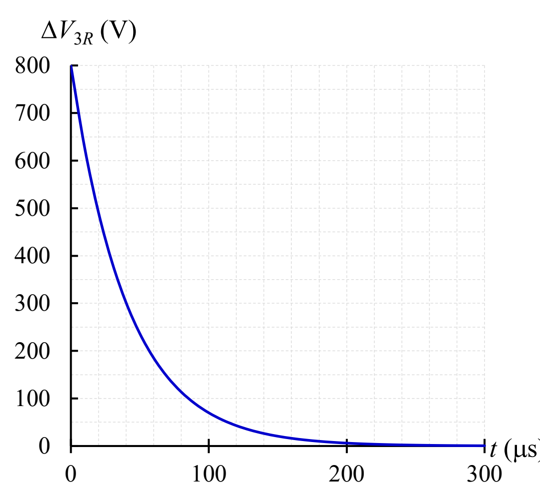
**8c) What is voltage across the inductor just after the switch is re-opened?

For the 4th & 5th questions I expect numerical results.

8d) What is potential difference across the battery?

***8e) Determine resistance R assuming $L = 1.23$ mH.

8a	
8b	
8c	
8d	
8e	



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