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

163fa22 Exam 3A – 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 | $k = 8.99 \times 10^{9}\ \frac{\mathrm{N\cdot m^2}}{\mathrm{C^2}}$ | $c = 3.00 \times 10^{8}\ \frac{\mathrm{m}}{\mathrm{s}}$ | $\varepsilon_0 = 8.85 \times 10^{-12}\ \frac{\mathrm{C^2}}{\mathrm{N\cdot m^2}}$

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

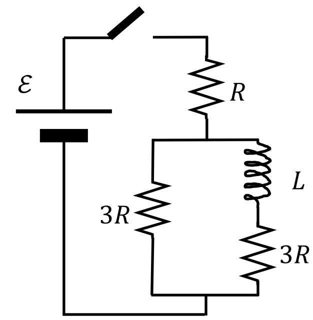
Material	Resistivity at 20° C (in SI units)	Temp. Coefficient (in SI units)
Silver	1.62×10^{-8}	4.1×10^{-3}
Copper	1.69×10^{-8}	4.3×10^{-3}
Aluminum	2.75×10^{-8}	4.4×10^{-3}
Nichrome	1.00×10^{-6}	0.4×10^{-3}
Carbon	3.5×10^{-5}	-0.5×10^{-3}
Germanium	0.46	-48×10^{-3}

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

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

WRITE YOUR NAME AT THE TOP OF THIS PAGE!

A circuit is connected to a battery and switch as shown in the figure. The battery has negligible internal resistance and potential difference $\mathcal{E}$. Initially the switch is in the *open* position for a long time. The switch is *closed* and, after a long time, the circuit reaches steady state.



1a) Determine the current that flows through the bottom right resistor at time *just after the switch is closed*.

1b) Determine the current that flows through the bottom right resistor in steady state?

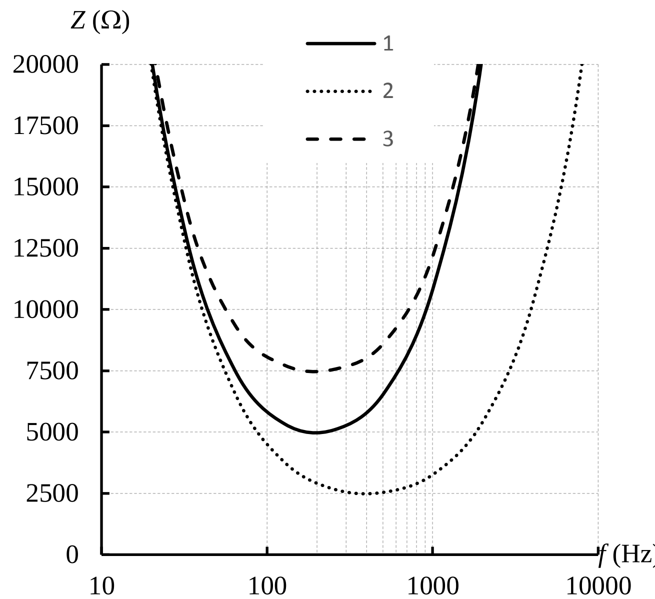
1c) While in steady state, an evil Jorstad *re-opens* the switch. The instant after the switch is *re-opened*, determine the current through the bottom right resistor.

1d) What is the time constant of the circuit after it is reopened?

**1e) Write an equation for the voltage across the bottom right resistor as a function of time *after the switch is re-opened*. Assume $t = 0$ corresponds to the moment the evil Jorstad *re-opens* the switch.

1a	
1b	
1c	
1d	
1e	

Three different RLC-series circuits are designed and tested. The impedance versus frequency is shown for all three circuits in the plot at right. All circuits use identical capacitance.



2a) In any RLC circuit, which circuit element (R, L, or C) causes the impendence to trend towards ∞ at low frequencies?

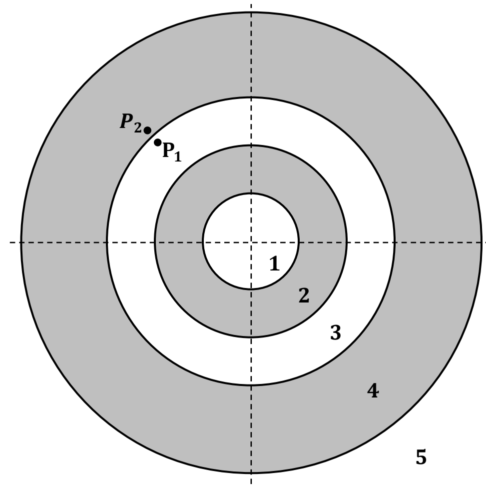
2b) Which circuit has (or circuits have) the lowest resonance frequency? If it is impossible to rank them without more information, explain what information is needed.

2c) Rank the inductances in each circuit from smallest to largest (clearly indicating any ties). If it is impossible to rank them without more information, explain what information is needed.

2d) Estimate the resistance (in kΩ) of the resistor in each circuit.

R_1 (kΩ)	R_2 (kΩ)	R_3 (kΩ)

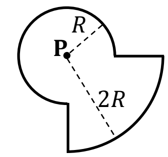
A coaxial cable is made from two cylindrical shells. The inner shell has inner radius R and outer radius $2R$. The outer shell has inner radius $3R$ and outer radius $5R$ (figure not to scale). The inner shell has non-uniform current density $J = \frac{\alpha}{r^3}$. The density constant is unknown, but we do know the total current in the inner shell is I directed into the page. The current in the outer shell is distributed uniformly. **There is no magnetic field in region 5**.



3a) Determine an expression for the density constant α in terms of I & R.
3b) Determine the current density in the outer shell in terms of I & R.
3c) Determine an expression for the magnetic field (magnitude) in region **1**.
3d) Determine an expression for the magnetic field (magnitude) in region **2**.
3e) Determine an expression for the magnetic field (magnitude) in region **3**.
3f) Determine an expression for the magnetic field (magnitude) in region **4**.

3a	
3b	
3c	
3d	
3e	
3f	

Two wires are formed as shown at right. Assume the wires are actually *very* far away from each other (so they do not affect each other). The magnetic field at point **P** is B directed *out of the page*. The magnetic field at **P'** is also directed out of the page. Figures *approximately* to scale.

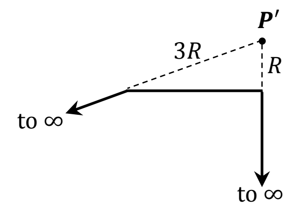


4a) What direction is current in the upper coil? Circle the best answer.

Clockwise	Counter-clockwise	Impossible to determine without more info

4b) What direction is current in the horizontal segment of wire 2? Circle the best answer.

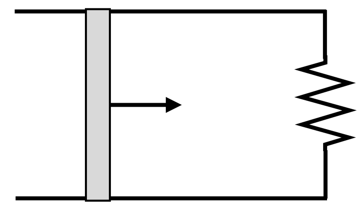
To the left	To the right	Impossible to determine without more info



***4c) Determine current required in the upper coil in terms of B & R.
**4d) Suppose both wires are running the same current.
Determine the ratio of magnetic field magnitude at **P** to the field magnitude at **P'**.
I am expecting a decimal number with 3 sig figs.

4c	
4d	

A rod on rails is pulled to the right with constant force magnitude F (starting from rest).
The rails are parallel to the ground and level (top view shown at right).
The rod has length L and mass m.
The rails and rod have negligible resistance compared to resistance R connecting the two rails.
A uniform external magnetic field with magnitude B is directed *out of the page*.



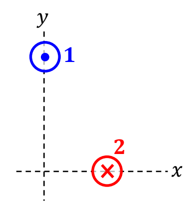
5a) What is the direction of induced current in the rod? Circle the best answer.

Downwards	Upwards	Impossible to determine without more info

*****5b) Determine an expression for induced current in the rod as a function of time. You must show work for this question. Writing down a memorized result receives zero credit.

5b	

Two infinitely long wires carrying equal current are shown in the figure at right (figure to scale). The wires are infinitely long running into and out of the page.



6a) Which best describes the *horizontal* component of the net magnetic field produced at the origin?

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

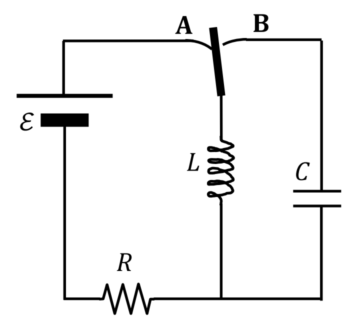
6b) Which best describes the *vertical* component of the net magnetic field produced at the origin?

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

6c) Which best describes the relationship between B_x & B_y? Phrased another way, which component is bigger?

$\lvert B_x\rvert > \lvert B_y\rvert$	$\lvert B_x\rvert = \lvert B_y\rvert$	$\lvert B_x\rvert < \lvert B_y\rvert$	Impossible to determine without more info

The circuit shown at right is built using a 3.00 mH inductor, a 222 nF capacitor, and a $470\ \Omega$ resistor. The switch is left in position **A** for a long time, and the inductor stores energy 675 µJ. 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 DC power supply (drawn as battery) during the switching.



7a) What is the period of current oscillations after $t = 0$?
7b) Which plate of the capacitor (top or bottom) first becomes positively charged?
7c) What is the maximum charge on the capacitor?
**7d) What is the potential difference across the DC power supply?

7a	
7b	
7c	
7d	

An LCR series circuit is built using a 3.00 mH inductor, a variable capacitor set to 222 nF, and a 470 Ω resistor. The function generator used to drive the circuit produces a sine wave with voltage amplitude 12.00 V. Phase angle when using these parameters is $-56.7°$. For the following, circle the best answer or answers (all which apply).

8a) Which circuit element is dominating this circuit?

Resistor	Inductor	Capacitor	Impossible to determine without more info

8b) Which best describes the relationship between current and source voltage as functions of time?

Current leads source voltage	Source voltage leads current	Impossible to determine without more info

8c) Which of the following actions will increase current amplitude?

Increase capacitance	Decrease capacitance	Increase function generator frequency	Decrease function generator frequency	None of the listed actions increases current amplitude

****8d) Determine a numerical value of the frequency of operation (in units of Hz).

TIP 1: First get ω then determine f…it saves a lot of pain dealing with 2π's.

TIP 2: For this problem, keep 7 sig figs on intermediate values.

Alternatively, used stored values in your calculator.

One version of the test involves subtracting two similar numbers which causes a loss of sig figs.

8d	

Extra Credit: Reconsider problem 2 (plots of Z versus ω).
Is it possible to determine a numerical value for inductance in circuit 1?
If this is *not* possible, explain why.
If it *is* possible, determine the numerical value.

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