SOLUTIONS

UCLA Department of Electrical Engineering
EE101A – Engineering Electromagnetics
Winter 2015
Midterm, February 9 2015, (1:45 minutes)

Name ______________________________ Student number ______________________________

This is a closed book exam – you are allowed 1 page of notes (front+back).

Check to make sure your test booklet has all of its pages – both when you receive it and when you turn it in.

Remember – there are several questions, with varying levels of difficulty, be careful not to spend too much time on any one question to the exclusion of all others.

Exam grading: When grading, we focusing on evaluating your level of understanding, based on what you have written out for each problem. For that reason, you should make your work clear, and provide any necessary explanation. In many cases, a correct numerical answer with no explanation will not receive full credit, and a clearly explained solution with an incorrect numerical answer will receive close to full credit. CIRCLE YOUR FINAL ANSWER.

If an answer to a question depends on a result from a previous section that you are unsure of, be sure to write out as much of the solution as you can using symbols before plugging in any numbers, that way at you will still receive the majority of credit for the problem, even if your previous answer was numerically incorrect.

Please be neat – we cannot grade what we cannot decipher.

	Topic	Max Points	Your points
Problem 1	Capacitor	50	
Problem 2	Electrostatics	10	
Problem 3	Inductor	40	
Total		100	

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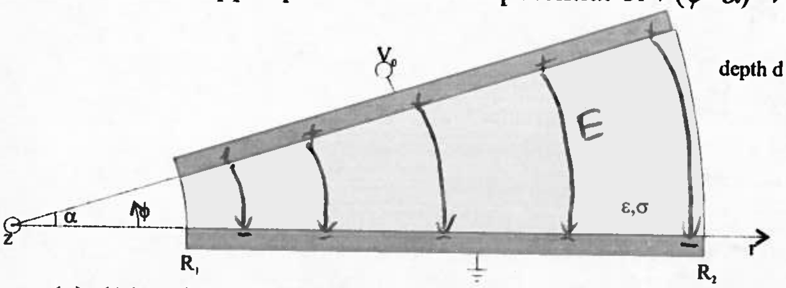
1. Angled Capacitor (50 points)

Consider the capacitor formed by two metal plates (perfect conductors) angled with each other with angle α. The capacitor is filled with a dielectric medium of permittivity ε, and conductivity σ. The capacitor is drawn on a cylindrical axis, and has depth d (out of the page). There is no free charge in the dielectric. The upper plate is held at a potential of $V(\phi=\alpha)=V_0$ and the lower plate is held at $V(\phi=0)=0$.



(a) (10 points) The scalar potential has the functional form $V(\phi)=A\phi+B$. What values of the coefficients A and B satisfy the boundary conditions?

Must satisfy boundary conditions $V(0)=0 \Rightarrow \boxed{B=0}$

$V(\alpha)=V_0 \Rightarrow A\alpha=V_0$

$\boxed{A=V_0/\alpha}$

$$V(\phi)=\frac{V_0}{\alpha}\phi$$

(b) (10 points) What is the electric field inside the capacitor as a function of r and ϕ? (Don't forget the vector direction.)

$\vec{E}=-\nabla V$ use cylindrical coords.

Since $\partial/\partial r=0$, $\frac{\partial}{\partial z}=0$

$$\boxed{\vec{E}=-\hat{\phi}\frac{1}{r}\frac{\partial V}{\partial \phi}=-\hat{\phi}\frac{V_0}{\alpha r}}$$

(c) (10 points) What is the surface charge density held on the upper and lower plates?

$\rho_s = \varepsilon \hat{n} \cdot \vec{E}$

On upper plate : $\hat{n} = -\hat{\phi}$

$$\boxed{\rho_{s,upper} = \varepsilon \frac{V_0}{\alpha r}}$$

lower $\hat{n} = \hat{\phi}$

$$\boxed{\rho_{s,lower} = -\varepsilon V_0 / \alpha r}$$

(d) (10 points) What is the capacitance? You may neglect fringing fields.

$C = \frac{Q}{V}$

$$Q = \int_S \rho_{s,upper}\, dS$$

$$= \int_{R_1}^{R_2} dr \int_0^d dz \; \frac{\varepsilon V_0}{\alpha r}$$

$$Q = \frac{\varepsilon V_0 d}{\alpha} \left[\ln(R_2) - \ln(R_1) \right]$$

$$\boxed{C = \frac{\varepsilon d}{\alpha} \ln\left(\frac{R_2}{R_1}\right)}$$

(e) (10 points) What is the resistance between the upper and lower plates?

Since ε + σ are uniform, + we can neglect fringing fields

$$RC = \frac{\varepsilon}{\sigma}$$

$$R = \frac{\varepsilon}{\sigma}\frac{1}{C} = \frac{\varepsilon}{\sigma}\frac{\alpha}{\varepsilon d}\frac{1}{\ln(R_2/R_1)}$$

$$\boxed{R = \frac{\alpha}{\sigma d}\frac{1}{\ln(R_2/R_1)}}$$

0n

-1

2. Electrostatics (10 points)

One of these is an impossible electrostatic field. Which one? You must explain why for credit.

(A): $\mathbf{E} = 4\left[xy\hat{x} + 2yz\hat{y} + 3xz\hat{z}\right]$

(B): $\mathbf{E} = 2\left[y^2\hat{x} + (2xy + z^2)\hat{y} + (2yz)\hat{z}\right]$

An electrostatic field must have $\nabla \times E = 0$

For (A)

$$\nabla \times E = \hat{x}(0-2y) + \hat{y}(0-3z) + \hat{z}(-x)$$

← (A) is not electrostatic

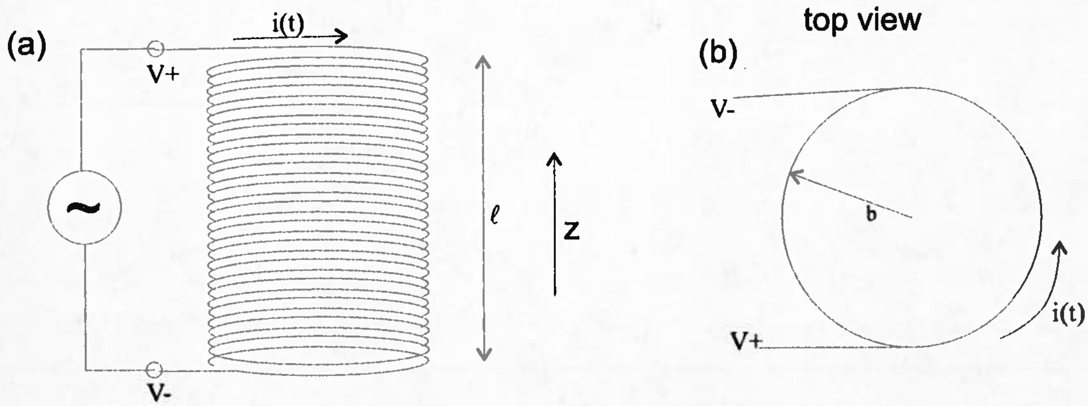
For (B)

$$\nabla \times E = \hat{x}(2z-2z) + \hat{y}(0-0) + \hat{z}(2y-2y) = 0$$

(B) is electrostatic

3. Inductance (40 points)

Consider a solenoid of length l with N turns or radius b driven to produce a magnetic field with current $i(t) = I_0 \cos(\omega t)$ (I_0 is real). As shown in the figure, we use the convention that a positive current is associated with current in the ϕ direction. You may consider $l \gg b$ (i.e. the long solenoid approximation).



(a) (10 points) What is the self-inductance of a long solenoid, in terms of fundamental constants, and the parameters mentioned above (i.e. l, b, N, ϵ, μ). ?

$$L = \frac{\mu_0 N^2 (\pi b^2)}{l}$$

Field inside solenoid is $B \approx \hat{z} \frac{\mu_0 I N}{l}$

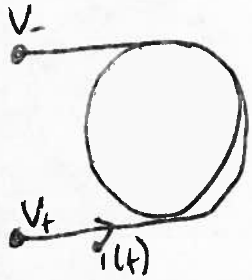
Flux through one loop: $\Phi = \pi b^2 B = \frac{\mu_0 \pi b^2 I N}{l}$

$$L = \frac{N\Phi}{I} = \frac{\mu_0 N^2 (\pi b^2)}{l}$$

(b) (10 points) If a current $i(t) = I_0 \cos(\omega t)$ is flowing through the solenoid, write the H-field inside the solenoid as a function of time. Make sure to give vector direction.

Inside the solenoid $\vec{H}(t) = \dfrac{\hat{z}\, i(t) N}{l} = \hat{z} \dfrac{N}{l} I_0 \cos(\omega t)$

(c) (10 points) What is the voltage difference $v(t)=V_+ - V_-$ at the terminals as a function of time? Pay careful attention to the sign of your answer.



$$V_{emf} = -L\frac{di}{dt}$$

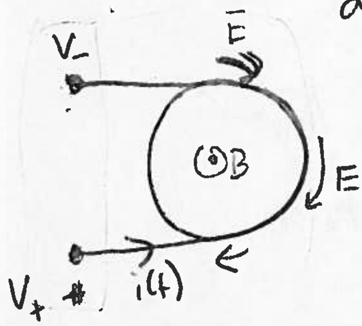
$$v(t) = V_+ - V_- = -V_{emf} = L\frac{di}{dt}$$

$$= -L I_0 \omega \sin(\omega t)$$

$$\boxed{v(t) = -\frac{\mu_0 N^2 (\pi b^2)}{\ell} I_0 \omega \sin(\omega t)}$$

How do we check sign?

Assume $\frac{di}{dt}$ is constant and positive.

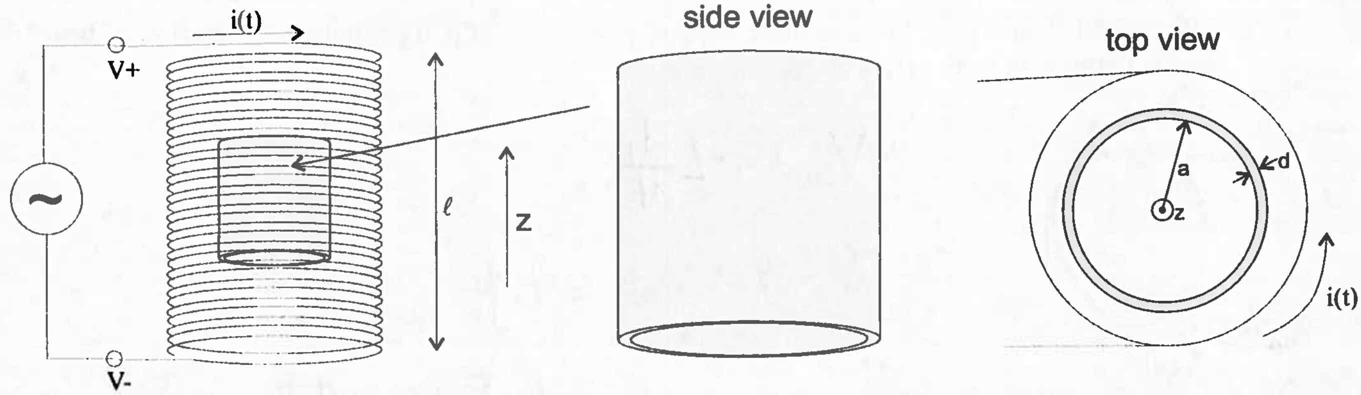


This creates a solenoidal E-field in clockwise direction, which pushes positive charge to V_+ terminal and negative charge to V_- terminal.

So for positive $\frac{di}{dt}$, $V_+ - V_-$ is positive

so $V_+ - V_- = L\frac{di}{dt}$.

$j\omega L$



Now imagine a piece of superconducting pipe that is a perfect electrical conductor with radius $a = b/2$, and thickness d is inserted into the center of the solenoid, as shown in part (b) of the figure. You may assume d
$\ll a$

(d) (10 points) Will the addition of the perfectly conducting ($\sigma = \infty$) pipe increase, decrease, or leave unchanged the apparent self-inductance L of the solenoid? Give a qualitative explanation why.

A perfectly conducting conductor will perfectly cancel the B-field inside. Therefore, the total flux $\Phi = \int_S \vec{B} \cdot d\vec{S}$ will be lower for a given current I, which results in a lower inductance : $L = \frac{\Phi}{I}$.