Name ____**Student ID** ___________________ **Score**__________

last *first*

Constants you may find useful

$G = 6.67 \times 10^{-11}$ Nm^2/kg^2

$M_{Earth} = 5.97 \times 10^{24}$ kg

$M_{Sun} = 1.99 \times 10^{30}$ kg

$r_{Earth} = 6.38 \times 10^{3}$ km

$r_{Sun} = 6.96 \times 10^{5}$ km

$d_{Sun-Earth} = 149.6 \times 10^{6}$ km

$g = 9.8 m/s^2$

$\varepsilon_0 = 8.85 \times 10^{-12}$ $C^2/(Nm^2)$

$\mu_0 = 4\pi \times 10^{-7}$ Tm/A

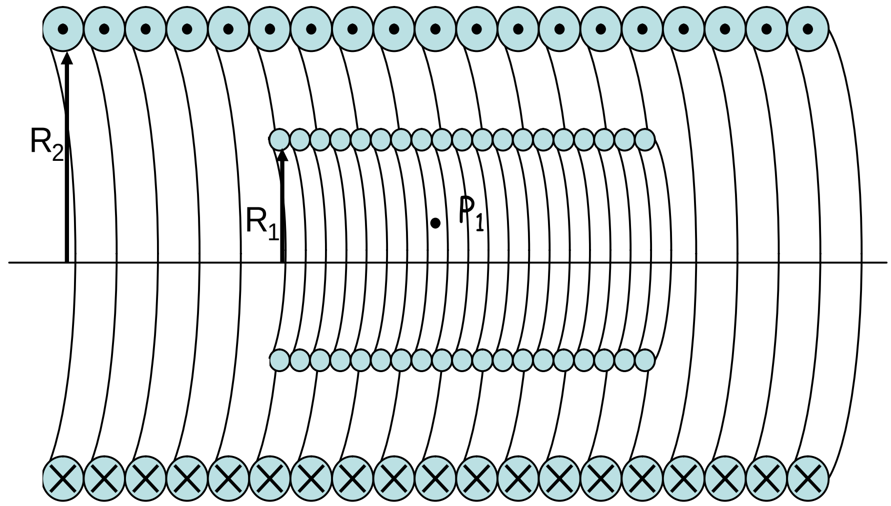
$m_e = 9.11 \times 10^{-31}$ kg

$q_e = 1.6 \times 10^{-19}$ C

Name ____**Student ID** ___________________ **Score**__________

last *first*

Part I. [xx points] Consider the solenoid within a solenoid, show at right. The outer solenoid is hooked to a current source, which can supply a current, $\boldsymbol{I_{outer}}$. The current flows out of the page at the top of the solenoid and into the page at the bottom, as indicated. The outer solenoid has 200 windings, and the inner one 150 windings. The outer coil is 2 m long; the inner coil is 1 m long. The ends of the inner coil are joined by a resistor of 20 Ω. The outer coil has a radius of $\boldsymbol{R_2}$ = 10 cm, the inner coil a radius of $\boldsymbol{R_1}$ = 5 cm.



1. [xx points] A constant current $\boldsymbol{I_{outer}}$ = 2 A has been flowing in the outer coil for a long time. What is the magnitude of the magnetic field at radius $\boldsymbol{r}$ = 2 cm due to the outer coil (point $\boldsymbol{P_1}$)?

   A. 0 T
   B. 1.3 x 10-4 T
   C. 2.5 x 10-4 T
   D. 5.0 x 10-4 T
   E. 1.3 x 10^{-2} T

   B is const $B = \mu_0 n I$

   $= (4\pi \times 10^{-7})\left(\frac{200}{2}\right) 2 = 2.51 \times 10^{-4}$ T

2. [xx points] What is the induced current in the inner coil, $\boldsymbol{I_{inner}}$?

   A. 0.0 mA
   B. 0.014 mA
   C. 0.020 mA
   D. 0.030 mA
   E. 0.059 mA

   $\frac{dI}{dt} = 0$!! so nothing is induced

3. [xx points] At time $\boldsymbol{t_0}$ = 0 sec, $\boldsymbol{I_{outer}}$ starts *decreasing* at the constant rate of 1 A/s. After 1 second has passed, what is the magnitude of the magnetic field in the inner coil?

   A. 0 T
   B. 1.26 x 10-4 T
   C. 2.51 x 10-4 T
   D. 5.03 x 10-4 T
   E. 1.26 x 10^{-2} T

   I after started @ 2A, now 1 amp.

   $\Rightarrow \frac{2.51 \times 10^{-4}}{2}$ T $= 1.26 \times 10^{-4}$

Name ____ **Student ID** ___________________ **Score**__________

last *first*

4. [xx points] What is the induced current in the inner coil, $\boldsymbol{I_{inner}}$, at t = 1 sec?

   A. 1.48×10^{-4} mA
   B. 7.4×10^{-3} mA
   C. 9.87×10^{-3} mA
   D. 1.48×10^{-2} mA
   E. 2.96×10^{-2} mA

   area of inner loop

   $\mathcal{E} = N\frac{d\Phi}{dt} = NA\frac{dB}{dt} = NA\mu_0 n\frac{dI}{dt}$

   $= (150)\pi(.05)^2(4\pi\times10^{-7})(\frac{200}{2})(1)$

   $= 1.48\times10^{-4}$ V

   $\Delta V = IR \rightarrow I = 7.4\times10^{-6}$ A

5. [xx points] Which statement best describes the direction current flows in the inner coil at t = 1 sec?

   A. Same direction as the outer coil
   B. Opposite direction as the outer coil
   C. It doesn't flow
   D. Not enough information to tell

   opposes increase!

6. [xx points] Which of the following is a true statement about $\boldsymbol{I_{inner}}$ just as $\boldsymbol{I_{outer}}$ reaches zero?

   A. I_{inner} is 0 mA.
   B. I_{inner} is the same as in problem 4.
   C. I_{inner} is less than it was in problem 4 (but not the same magnitude).
   D. I_{inner} is greater than it was in problem 4.
   E. I_{inner} is the same magnitude, but is moving in the opposite direction.

   — who cares about "0" - $\frac{dI}{dt}$ is what matters.

7. [xx points] The current in the outer loop, $\boldsymbol{I_{outer}}$, is returned to the full 2 A and left there for a long time. At some time later, $\boldsymbol{t_1}$, the current source is switched off, and the current output drops to zero instantly. During a short time after $\boldsymbol{t_1}$ does the current $\boldsymbol{I_{outer}}$

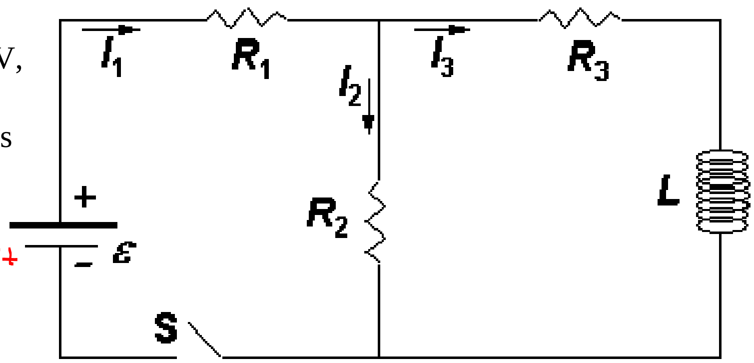
   A. Fall to zero instantly.
   B. Continue to flow for some amount of time in the same direction.
   C. Continue to flow for some amount of time in the opposite direction.
   D. Not enough information to tell.

   opposes the change.

Name ____**Student ID** ___________________ **Score**__________

last *first*

Part II. [xx Points] The elements in the circuit shown above have the following values: $\mathcal{E}$ = 104 V, L = 2.2 H, R_1 = 16 Ω, R_2 = 20 Ω, and R_3 = 33 Ω. After the switch has been open for a long time, it is closed at t = 0.



8. [xx points] Calculate the current through R_2 at t = 0+.

A. 1.5 A
B. 2.9 A
C. 3.2 A
D. 5.2 A
E. 6.5 A

$I_3 = 0$ @ $t = 0+$; $I = \frac{V}{R_1 + R_2} = \frac{104}{36} = 2.88A$

9. [xx points] Calculate the potential drop across the inductor at t = 0+.

A. 0.0 V
B. 21 V
C. 54 V
D. 58 V
E. 80 V

Same as drop accross R_2! $V = (2.88A)(20) = 57.7V$

10. [xx points] At what rate is the current through the inductor increasing at t = 0+?

A. 0 A/s
B. 9.5 A/s
C. 24 A/s
D. 26 A/s
E. 36 A/s

$\mathcal{E} = L\frac{dI}{dt}$; $\frac{dI}{dt} = \frac{57.7}{2.2} = 26.26$

11. [xx points] After a long time, what is the current through R_2?

A. 0.0 A
B. 1.4 A
C. 1.6 A
D. 2.3 A
E. 3.7 A

Now L is a conductor. $R_T = R_1 + \left(\frac{1}{R_2} + \frac{1}{R_3}\right)^{-1} = 28.45\Omega$; $I = \frac{V}{R} = \frac{104}{28.45} = 3.65A$; $\Delta V_1 = (3.65A)(16\Omega) = 58.48V$; $\Delta V_2 = 104 - 58.48 = 45.5$; $I = \frac{V_2}{R_2} = \frac{45.5}{20} = 2.27A$

12. [xx points] After being closed for a long time, the switch is opened at time T. What is the magnitude of the current through R_2 immediately afterward?

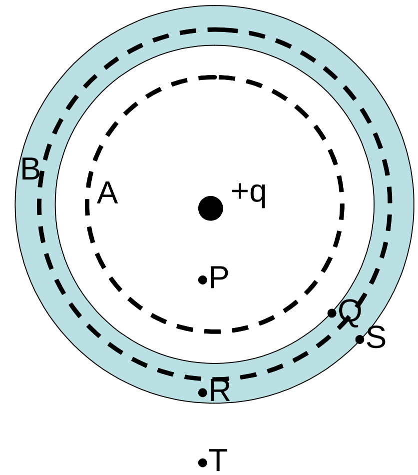
A. 0.0 A
B. 1.4 A
C. 2.0 A
D. 2.3 A
E. 3.7 A

What ever the current through L is at that moment. $I_3 = I_L = 3.65 - 2.27A = 1.37A$

Name ____**Student ID** ___________________ **Score**__________

last *first*

Part III. [xx Points] A small charge of +9 mC is placed at the center of an uncharged metal sphere, as shown at the right. The sphere's inner radius is 7 cm, and the outer radius is 9 cm. Two Gaussian surfaces with spherical symmetry are shown at A and B. The points P, Q, R, S, and T are 3.5 cm, 7cm, 8.5 cm, 9 cm, and 12 cm from the positive test charge, respectively.



13. [xx points] What is charge enclosed for the Gaussian Surface A?

A. 0 μC
B. 4.5 μC
C. 9 μC — all that is in there!
D. 13.5 μC
E. 18 μC

14. [xx points] What is charge enclosed for the Gaussian Surface B?

A. 0 μC — E in metal is zero
B. 4.5 μC
C. 9 μC
D. 13.5 μC
E. 18 μC

15. [xx points] What is the magnitude of the electric field at point P?

A. 0.0 N/C
B. 2.3 x 10^6 N/C
C. 3.3 x 10^7 N/C
D. 6.6 x 10^7 N/C
E. 9.9 x 10^7 N/C

$E = \frac{1}{4\pi\varepsilon_0}\frac{q}{r^2} = \frac{1}{4\pi 8.85\times10^{-12}}\frac{9\times10^{-6}C}{(.035)^2}$

$= 6.61\times10^7$ N/C

16. [xx points] What is the magnitude of the electric field at point R?

A. 0.0 N/C — in metal!!
B. 9.5 x 10^5 N/C
C. 5.6 x 10^6 N/C
D. 1.7 x 10^7 N/C
E. 2.2 x 10^7 N/C

17. [xx points] What is the magnitude of the electric field at point T?

A. 0.0 N/C
B. 6.7 x 10^5 N/C
C. 2.8 x 10^6 N/C
D. 8.4 x 10^6 N/C
E. 1.1 x 10^7 N/C

fix!

$E = \frac{1}{4\pi\varepsilon_0}\frac{q}{r^2} = \frac{1}{4\pi 8.85\times10^{-12}}\frac{9\times10^{-6}C}{(0.12)^2}$

↑ By G's Law!

$= 5.6\times10^6$ N/C

Name ____ **Student ID** ___________________ **Score**__________

last *first*

18. [xx points] What is the magnitude of the potential difference (|ΔV|) between points Q and S?

- **A.** 0.0 kV — in metal, eq pot surface.
- **B.** 260 kV
- **C.** 900 kV
- **D.** 1200 kV
- **E.** 6500 kV

19. [xx points] What is the magnitude of the potential difference (|ΔV|) between points P and T?

- **A.** 0.0 kV
- **B.** 670 kV
- **C.** 1400 kV
- **D.** 1600 kV
- **E.** 54000 kV

$$\Delta V = \int_P^T E \cdot dl$$

zero between Q and S.

$$= \int_P^Q E \cdot dl + \int_S^T E \cdot dl$$

$$= \frac{1}{4\pi\varepsilon_0} q \left[\frac{1}{r_Q} - \frac{1}{r_P} + \frac{1}{r_T} - \frac{1}{r_S} \right]$$

$$= \frac{1}{4\pi \, 8.85\times10^{-12}} \, 9\times10^{-6}\,C \left[\frac{1}{0.02} - \frac{1}{0.035} + \frac{1}{0.12} - \frac{1}{0.09} \right]$$

$$= 1380\,kV$$

Name ___________________________________Student ID _____________ Score______
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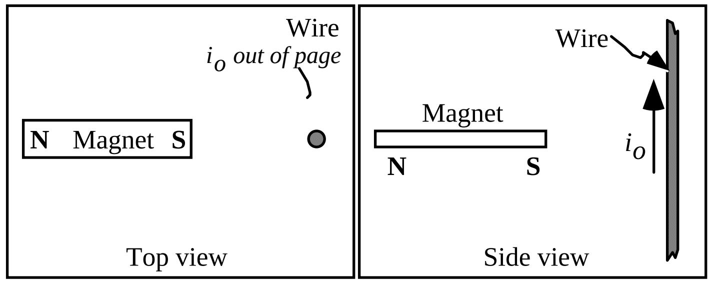
IV. [25 pts]



A bar magnet is held near a long current-carrying wire as shown in the top and side views at right. The magnet is free to rotate about its center.

17. [5 pts] What is the direction of the torque on the magnet?

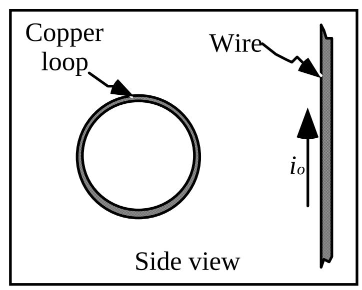
A. out of the page, (top view)

With the right hand rule, it is found the wire creates a magnetic field directed downward near the magnet. Trying to align itself with the field (think of the magnet as a compass needle), the magnet rotates counter-clockwise, so torque is directed out of the page.

18. [5 pts] At which of the labeled points is it possible that the net magnetic field is zero at the instant shown?

C. Point S

Point S is the only point at which the magnetic field from the magnet and wire can add to zero for the arrangement shown.



The magnet is replaced by a neutral copper loop oriented as shown. There is a current i_o toward the top of the page in the wire.

19. [5 pts] Suppose the loop is moved at a constant velocity toward the top of the page (*i.e.*, parallel to the wire). In that case, which one of the following is true:

D. There is no induced current in the loop

As it moves upward, the loop stays the same distance from the wire, so the magnetic flux through the loop does not change. Since there is no change in magnetic flux, by Faraday's Law there is no induced current.

20. [5 pts] The loop is now moved directly toward the wire. While the loop is moving, how does the absolute value of the magnetic flux through the loop change?

A. Increases

Magnetic field strength increases as one nears a current carrying wire, so as the loop nears the wire the magnetic flux through the loop increases.

21. [5 pts] As the loop is moving toward the wire, which one of the following correctly describes the net magnetic force on the wire?

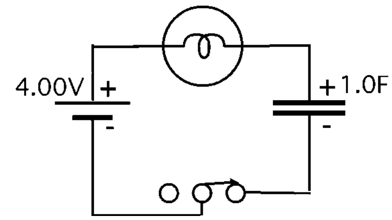
C. Away from the loop

By Lenz's Law, a clockwise current is induced in the loop to oppose the change in external flux. The section of the loop nearer to the wire repels from the wire while the section further *away attracts the wire. Overall, since the magnitude of the force from the nearer section is greater, the net force on the wire is away from the loop.*

Name ____**Student ID** _______________ **Score**_________

last *first*

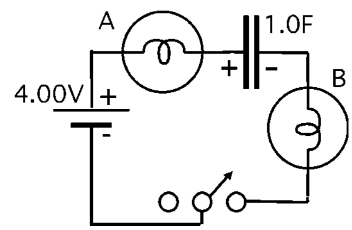
V. [25 pts. Total] Consider the circuit made up of a 4.00 volt battery, a light bulb, a switch and a 1.0 Farad capacitor. This circuit can be used to investigate the time-varying or transient behavior of current. Assume that the capacitor is initially uncharged and at $t = 0$, the switch is closed.



1. [5pts] Is the brightness of the bulb *greater* than, *equal* to, or *less* than the brightness of an identical bulb placed directly across the battery at $t = 0$. **Explain** your answer.

__Same brightness.__ The reason is that the potential drop across the capacitor is zero at t = 0 since there is no charge in the top or bottom plates at that time. Thus, effectively, the bulb is already across the battery.

2. [5 pts] The above circuit is changed by adding an identical bulb B as shown. Is the brightness of bulb A *greater* than, *equal* to, or *less* than the brightness of bulb B when the switch is closed at $t = 0$. **Explain** your answer in terms of charge flow to the left and right capacitor plates.

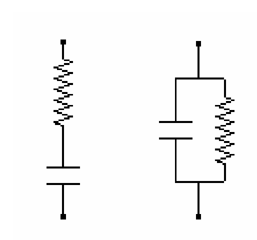


Bulb-B has the __same brightness__ as bulb-A since the $\Delta Q/\Delta t$ *leaving the right plate is the same as the* $\Delta Q/\Delta t$ *flowing to the left plate.*

3. [5 pts] What is the final (*not net*) charge on the capacitor in part 2 (above) a very long time after the switch has been closed. **Explain** your answer.

$Q = CV$ *where* $V = 4$ *volts* $\Rightarrow$ $Q = 4$ *coulombs. This occurs when the capacitor becomes fully charged and the current flow goes to zero. Thus, the entire voltage of the battery appears across the capacitor at that time*

4. [5 pts] Assume the capacitor in the above circuit has become leaky with age, such that, when isolated from the circuit (at $t = 0$), it begins losing its charge. The equivalent circuit for this *isolated* capacitor can be modeled by an ideal capacitor and a (linear) resistor R_L. Which equivalent circuit (shown to the right) properly describes this leaky capacitor and **explain** why it should.



A series resistor would not allow charges on the high-potential plate to move back to the low potential plate (or vice versa). The parallel resistor does allow this to occur (making a complete circuit).

5. [5 pts] Assuming that it takes exactly $t = 8$ days for the leaky capacitor to lose 37% of its original charge, at what time t' (relative to $t = 0$) does it have only 5% of its original charge?

First of all, if 37% of the charge is lost, then there is 63% of the charge remaining. Use the following: $Q = Q_0 e^{-t/\tau}$ *which yields* $-t/\tau = \ln(Q/Q_0)$, *evaluated at 8 days and the unknown time* t'. *Thus, 8 days =* $-\tau \ln(0.63)$ *and* $t' = -\tau \ln(0.05)$ *combine to yield* t' *= (8 days)*$\ln(0.05)/\ln(0.63)$ *= 52 days.*

Name (please print): ______________________________ Points ________
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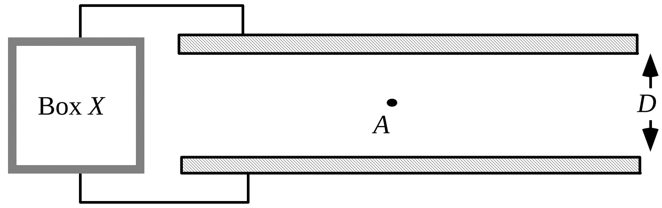
VI. [25 pts] Two large conducting plates are placed parallel to one another a distance D apart. The plates are connected by wires to Box X as shown. The potential difference between the plates is V_o.

1. [5 pts] A positive charge q_o with mass m_o is released from rest at the top positively charged plate. Write an expression in terms of the given variables for the speed of the particle when it reaches the negatively charged plate. Show your work.



using $\Delta V = -W_{elec}/q$ and $W_{net+} = \Delta KE = \frac{1}{2}m(v_f^2 - v_i^2)$:

$|V_o| = \frac{1}{2} m_o(v_f^2 - 0^2)/q_o$ $\longrightarrow$ $\mathbf{v_f = \sqrt{2V_o q_o/m_o}}$ *

or

using $\Delta V = Ed$; $F = qE = ma$; and $v_f^2 - v_i^2 = 2a\Delta x$:

$v_f^2 - 0^2 = 2aD = 2(q_oE/m_o)D = 2(q_oV_o/Dm_o)D$

$\mathbf{v_f = \sqrt{2V_o q_o/m_o}}$ *

* Can also express V_o in terms of σ: $E = \sigma/\varepsilon_o$, $V_o = \sigma D/\varepsilon_o$ $\longrightarrow$ $\mathbf{v_f = \sqrt{2\sigma D q_o/m_o\varepsilon_o}}$

2. [5 pts] A negative charge starts at a point not shown (point B) with a speed v_o. When it reaches point A, halfway between the plates, it is going faster than v_o. Is the potential difference, $\Delta V_{AB} = V_A - V_B$, *positive, negative,* or *zero?* Explain your reasoning.

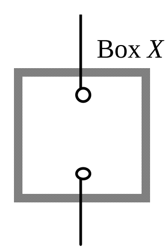
If the negatively charged particle is speeding up as it moves from B to A, then the net work on it must be positive. Based on the definition of electric potential difference: $\Delta V_{AB} = -W_{elec}/q = -(+W)/(-q) > 0$. In this case the negative sign in the definition cancels with the negative sign of the charge leaving a positive potential difference between points A and B.

It is observed that when the top plate is moved closer to the bottom plate, the electric field between the plates increases. (At all times the plates are close enough together that fringing effects can be ignored.)

3. [5 pts] When the top plate is moved closer to the bottom plate, does the absolute value of the charge density on the top plate *increase, decrease,* or *remain the same?* Explain your reasoning.

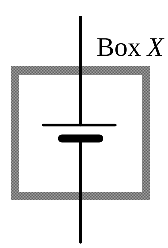
The electric field between the plates is directly proportional to the charge density of the plates. Since the electric field increases, the charge density of the plates must increase.

4. [5 pts] On the basis of this observation, is it possible that Box X contains an open circuit as shown at right? Explain your reasoning.



No. If Box X contained an open circuit, then there would be no way for any charge to be transferred to or from the plates, and so the charge density would be constant. Since the electric field between the plates is directly proportional to the charge density on the plates, the electric field would not change when the plates were moved closer together. Since the electric field increases, it is not possible that Box X

5. [5 pts] On the basis of this same observation, is it possible that Box X contains a battery as shown at right? Explain your reasoning.



Yes. If Box X contained a battery, then the electric potential difference between the plates of the battery would not change when the plates were brought closer together. By definition, the electric potential difference between the plates equals the work done by an external agent in moving a charge from one plate to the other (with no change in kinetic energy) divided by the charge. So the work done by an external agent in moving a test charge from one plate to the other plate would remain constant even though the distance between the plates is reduced. This can only happen if the force the external agent applies is increased. While moving at a constant velocity between the plates, the only forces on the test charge are the force exerted by the external agent and the force exerted by the electric field; these forces must have equal magnitudes. Since the force exerted by the external agent has increased, the electric field must increase. Thus the increase in the electric field when the two plates is brought closer together is consistent with Box X containing a battery as shown.