Name ______________________________________ Student ID Number ____________
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Part I. Lecture Multiple Choice (43 points total)

1. (5 pts.) The voltage between the cathode and the screen of a television set is 22 kV. If we assume a speed of zero for an electron as it leaves the cathode, what is its speed just before it hits the screen? (m_e= 9.1 x 10^{-31} kg; q_e= 1.6 x 10^{-19} C)

A. 8.8×10^7 m/s
B. 2.8×10^6 m/s
C. 6.2×10^7 m/s
D. 7.7×10^{15} m/s
E. 5.3×10^7 m/s

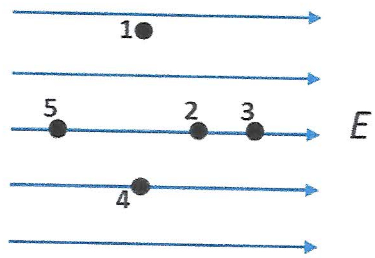
$22 \times 10^3 \times 1.6 \times 10^{-19} = \frac{1}{2} 9.1 \times 10^{-31} v^2$

$V q = \frac{1}{2} m v^2$

$\Rightarrow v = \sqrt{\ } = 8.8 \times 10^7$

2. (3 pts.) Which points in the diagram are at the same potential?

A. 2 and 5
B. 2, 3, and 5
C. 2 and 4
D. 1 and 5
E. 1 and 4



3. (5 pts.) You assemble the system of point charges q_1 = 1 μC, q_2 = 2 μC, and q_3 = 3 μC at the corners of an equilateral triangle whose side s = 30 cm. What is the electrostatic potential energy of the system? (assume U = 0 at infinity)

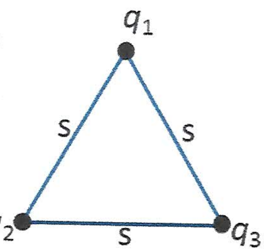
A. 1.10 J
B. 0.990 J
C. 0.631 J
D. 0.330 J
E. 0.123 J

$U = k\left[\frac{q_1 q_2}{s} + \frac{q_1 q_3}{s} + \frac{q_2 q_3}{s}\right]$

$= \frac{k}{s}(q_1 q_2 + q_1 q_3 + q_2 q_3)$

$= \frac{9 \times 10^9}{0.3} \cdot 10^{-12}(2+3+6) = 3 \times 10^{-2} \times 11$

$= 33 \times 10^{-2}$



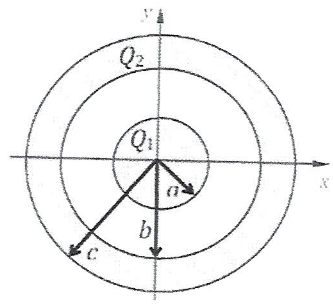
4. (4 pts.) A parallel plate capacitor filled with air is connected to a battery. When a dielectric is inserted between the plates of the capacitor

A. only the capacitance changes.
B. only the voltage across the capacitor changes.
C. only the charge on the capacitor changes.
D. both the capacitance and the voltage change.
E. both the capacitance and the charge change.

Name ______________________________ **Student ID Number** ____________
last *first*

Diagram pertains to the next two questions:

A solid conducting sphere of radius a is centered on the origin, and carries a total charge Q_1. Concentric with this sphere is a conducting spherical shell of inner radius b and outer radius c, which carries a total charge Q_2. The value of parameters are given in the figure.



$Q_1 = -4\ \mu C$
$Q_2 = +5\ \mu C$
$a = 2$ cm
$b = 6$ cm

5. (5 pts.) Calculate the magnitude of the electric potential difference between the radius **r = b** (the inner surface of the conducting shell) and the origin.

A. $|V_b - V_0| = 1.50 \times 10^5$ V
B. $|V_b - V_0| = 4.50 \times 10^5$ V
C. $|V_b - V_0| = 6.00 \times 10^5$ V
D. $|V_b - V_0| = 12.0 \times 10^5$ V
E. $|V_b - V_0| = 18.0 \times 10^5$ V

$\Delta V = V(b) - V(a) = -kQ_1\left[\frac{1}{a} - \frac{1}{b}\right] = +9\,10^9 \times 4\,10^{-6}\left[\frac{1}{0.02} - \frac{1}{0.0\ldots}\right]$

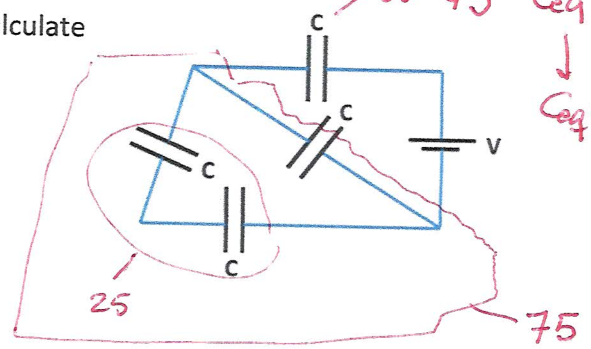
$\Delta V = 1.2 \times 10^6$ V

6. (3 pts.) If the inner conducting sphere were replaced with an insulating sphere having the same total charge Q_1 distributed uniformly throughout its volume, the magnitude of the potential difference $|V_b - V_0|$ would

A. increase
B. decrease
C. stay the same

7. (5 pts.) All four capacitors have equal values of 50 μF. Calculate the equivalent capacitance of this network of capacitors.

A. 50 μF
B. 30 μF
C. 75 μF
D. 100 μF
E. 83 μF

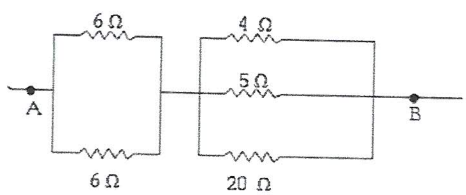


$\frac{1}{50} + \frac{1}{75} = \frac{1}{C_{eq}}$ → $C_{eq} = 30$

8. (5 pts.) A current of 1.2 A flows from A to B. Therefore, the magnitude of the potential difference between points A and B is approximately

A. 1.0 V
B. 4.2 V
C. 4.6 V
D. 6.0 V
E. 20 V

$5 \times 1.2 = 6$



3Ω 2Ω

Name ______________________________ **Student ID Number** ____________

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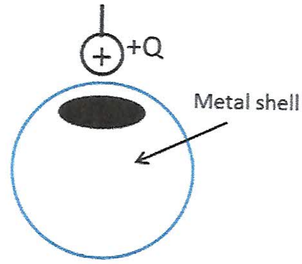


9. (4 pts) A metal ball of charge +Q is lowered into an uncharged metal shell and allowed to rest on the bottom of the shell. When the charges reach equilibrium,

A. the outside of the shell has a charge of –Q and the ball has a charge of +Q. ✗
B. the outside of the shell has a charge of +Q and the ball has a charge of +Q. ✗
✗ C. the outside of the shell has a charge of zero and the ball has a charge of +Q.
D. the outside of the shell has a charge of +Q and the ball has zero charge.
E. the ouside of the shell has a charge of +Q and the ball has a charge of –Q. ✗

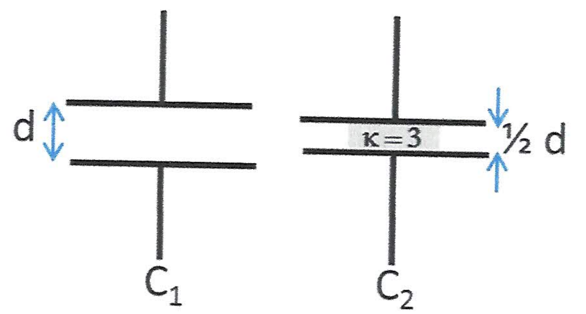
$Q_{MS} + Q_{MB} = +Q$

charge repels itself

D is correct.

10. (4 pts) Parallel plate capacitor C_1 has plate area A and separation distance d. Capacitor C_2 is made by starting with C_1 and first reducing the plate separation to d/2. Next, a dielectric with κ=3 and plate area A/2 is inserted into the middle, as shown. What is C_2 in terms of C_1?

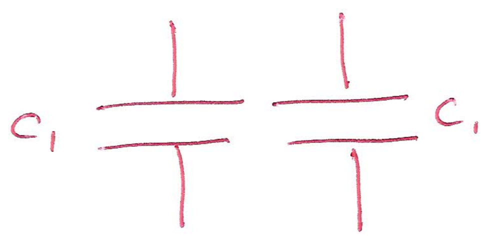
A. $C_2 = C_1 / 4$
B. $C_2 = C_1$
C. $C_2 = 2\ C_1$
D. $C_2 = 3\ C_1$
E. $C_2 = 4\ C_1$



$C = \frac{\epsilon_0 A}{d}$

$d \rightarrow d/2 \Rightarrow C = 2C_1$

consider as two in parallel



one gets filled

C_1 $C_1 K$

$\rightarrow$ $C_2 = C_1 (1 + K)$

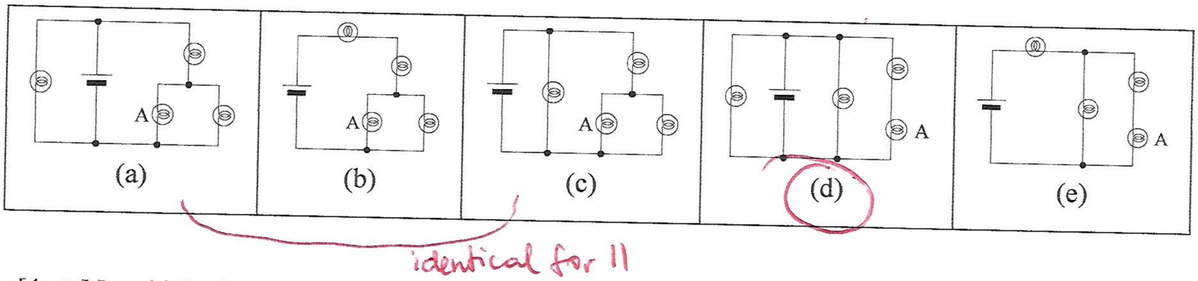
Name ______________________________ **Student ID** ______________ **Score** ______

last *first*

II. Lab questions [12 pts]

For problems 10–12, assume that the battery and ammeter are ideal and that all bulbs are identical.

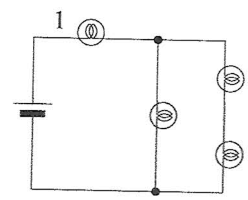
11. [4 pts] In which circuit below is bulb A **brightest**?

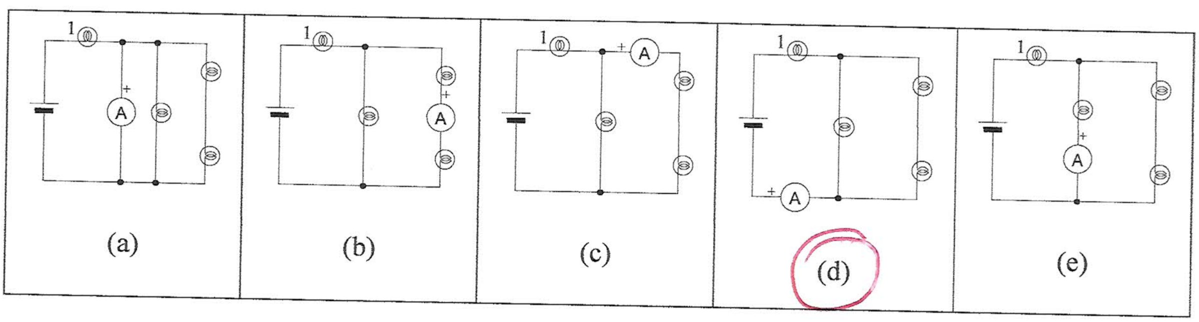


12. [4 pts] In which circuit **above** is the **power delivered by the battery** the **lowest**?

b

13. [4 pts] An ammeter is to be **added to the circuit at right** in order to measure the current through the bulb labeled 1. Which placement of the ammeter will **correctly** measure the current through bulb 1?





Name ______________________________ Student ID Number __________
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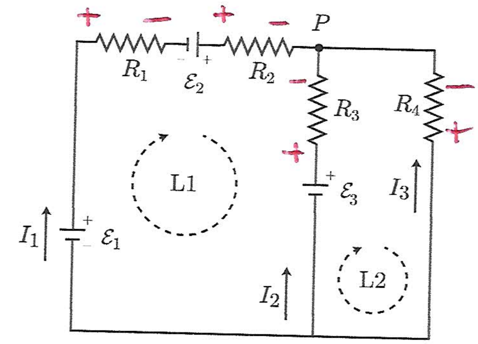
The next four problems are related.

Kirchhoff Laws. Study the circuit and answer the following questions.



X. (3 pts) Use the Kirchhoff Current Law to relate the three currents at point P.

P: $I_1 + I_2 + I_3 = 0$

X. (6 pts) Use the Kirchhoff Voltage Law to write equations for the sum of the voltage drops around loops L1 and L2. Express all equations in terms of the parameters defined in the figure above.

L1: $I_1 R_1 - \mathcal{E}_2 + I_1 R_2 - I_2 R_3 + \mathcal{E}_3 - \mathcal{E}_1 = 0$

L2: $I_2 R_3 - I_3 R_4 - \mathcal{E}_3 = 0$

X. (9 pts) Assume that all emf sources supply 5 V and all resistors have a resistance of 100 Ohms. I_1 is found to be 0.03 A. What are the remaining currents?

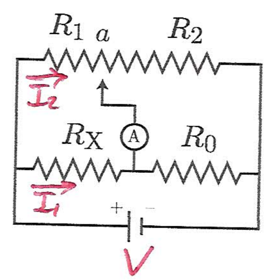
L_1: $I_1 \, 2R - I_2 R = \mathcal{E}_1 + \mathcal{E}_2 - \mathcal{E}_3 = 5 \Rightarrow 2I_1 - I_2 = \frac{5}{100}$ (1)

L_2: $I_2 R - I_3 R = 5$, with $-I_3 = I_2 + I_1$: $I_2 2R + I_1 R = 5 \Rightarrow I_1 + 2I_2 = \frac{5}{100}$ (2)

$2 \times (1) + (2) \Rightarrow 5I_1 = \frac{15}{100}$ $I_1 = 0.03$ ✓ $I_2 = \frac{5/100 - 3/100}{2} = \frac{1}{100}$

$I_2 = \frac{1}{100}$ $I_3 = -I_2 - I_1 = -4/100$

X. (7 pts) Wheatstone Bridge: Measuring the resistance. The variable resistor is adjusted by moving the contact position a. a is the position relative to the total length of the resistor such that the resistance from the LHS of the resistor to the contact point is $R_1 = a R_{Tot}$ and resistance from the contact point to the RHS of the resistor is $R_2 = (1-a) R_{Tot}$.



The contact position a is varied until there is no current flowing through the ammeter (A). What is the resistance of R_X as a function of R_0, a, and R_{Tot}?

$I_1 = \frac{V}{R_x + R_0}$ $I_2 = \frac{V}{R}$

$(1-a)R\left(\frac{V}{R}\right) = R_0 \frac{V}{R_x + R_0} \Rightarrow \frac{R_x}{R_0} + 1 = \frac{1}{1-a} \Rightarrow$

$\boxed{\frac{R_x}{R_0} = \frac{1}{1-a} - 1}$

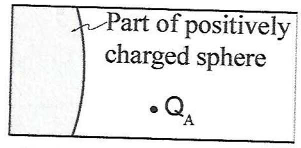
Name ________________________________ Student ID ______________ Score________
last first

V. [20 points total] Two experiments are conducted with two identical positively charged spheres and two different test charges. $Q_A = -1.5$ nC, $Q_B = +3$ nC.

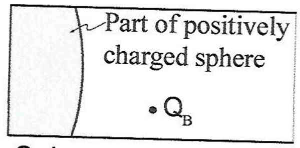
Experiment A: Q_A is released from rest at point P, and moves toward the sphere. When it reaches the surface of the sphere it has 8 J of kinetic energy.

Experiment B: A hand moves Q_B from rest at point P to rest at the surface of the sphere.

In each experiment, consider the system of the sphere and test charge.



Q_A is released at point P.



Q_B is moved from point P to the sphere.

A. [4 pts] In Experiment A, does the potential energy of the system increase, decrease, or remain the same as Q_A moves toward the sphere? Explain.

$\Delta U + \Delta K = 0$ $\Delta K > 0 \Rightarrow \boxed{\Delta U < 0}$

B. Let ΔU_A and ΔU_B represent the changes in electric potential energy in Experiments A and B, respectively.

i. [3 pts] Is the magnitude of ΔU_A greater than, less than, or equal to the magnitude of ΔU_B? Explain.

Assume charges fixed on sphere

$\Delta U_A = Q_A \Delta V$
$\Delta U_B = Q_B \Delta V$ $\Rightarrow \frac{|\Delta U_A|}{|\Delta U_B|} = \frac{|Q_A|}{|Q_B|} = \frac{1}{2} \Rightarrow \boxed{\Delta U_A < \Delta U_B}$

ii. [3 pts] Is the sign of ΔU_A the same as or different from the sign of ΔU_B? Explain.

$\frac{\Delta U_A}{\Delta U_B} = \frac{Q_A}{Q_B} = -\frac{1}{2}$

C. [4 pts] If the reference point for the electric potential is at the surface of the sphere, is the electric potential at point P in Experiment A positive, negative, or zero? Explain.

$U(A) > U(B)$ assume $U(B) = 0 \Rightarrow U(A) > 0$ but $Q_A < 0$
$\Rightarrow \boxed{V(A) < 0}$

D. Let ΔV_A and ΔV_B represent the electric potential differences from point P to the surface of the sphere in Experiments A and B, respectively.

i. [3 pts] Is the magnitude of ΔV_A greater than, less than, or equal to the magnitude of ΔV_B? Explain.

ii. [3 pts] Is the sign of ΔV_A the same as or different from the sign of ΔV_B? Explain.