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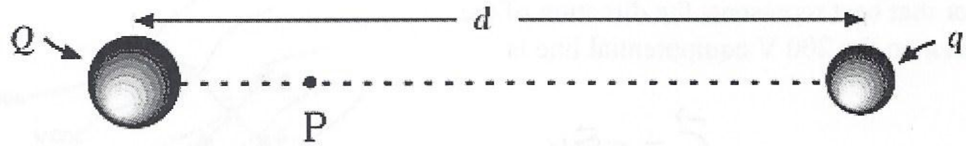


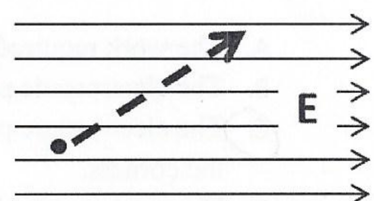
1. (4 pts.) Charges Q and q (Q > q), separated by a distance d, produce a potential $V_P = 0$ at point P. This means that

Take $V=0$ @ ∞

Then $\Delta U = q\Delta V = 0 = -W$

A) no force is acting on a test charge placed at point P.
B) Q and q must have the same sign.
C) the electric field must be zero at point P.
D) the net work in bringing Q to distance d from q is zero.
E) the net work needed to bring a charge from infinity to point P is zero.

2. (4 pts.) A charge of 5.0 μC is located in a uniform electric field of intensity 3.5×10^5 N/C. How much work is required to move this charge at constant speed 50 cm along a path making an angle of 33° with respect to the electric field direction?



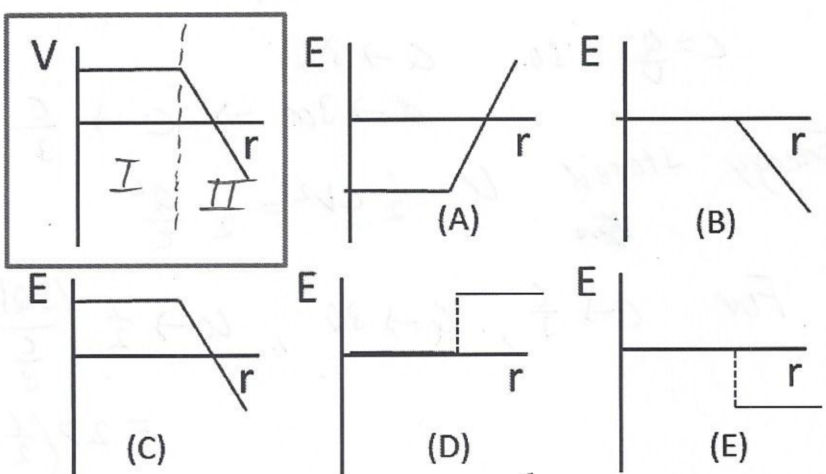
$W = \int \vec{F}\cdot d\vec{l}$ $\vec{F} = q\vec{E}$

$= q\int \vec{E}\cdot d\vec{l} = q\int E\cos\theta\, dl = qEl\cos\theta$ $\theta = 33°$

E uniform over path

A) 0.16 J
B) 0.27 J
C) 0.54 J
D) 0.73 J
E) 7.3 mJ

3. (4 pts.) Which graph below best shows the electric field E(r) corresponding to the potential V(r) shown in upper left graph?



$E(r) = \dfrac{-\partial V(r)}{\partial r}$

slope in region I = 0

slope in region II = −C

a constant

$E(r) = \begin{cases} 0 & \text{region I} \\ C & \text{region II} \end{cases}$

Choose: (A) (B) (C) (D) (E)

Don't forget negative sign before dirivative

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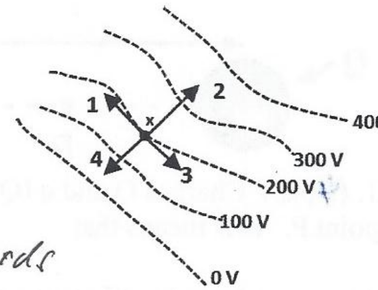
4. (3 pts.) The vector that best represents the direction of the electric field at point **x** on the 200 V equipotential line is

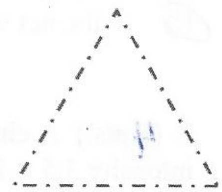


A) 1
B) 2
C) 3
D) 4
E) None of these is correct.

$\vec{E} = -\vec{\nabla} V$

$\vec{E}$ points towards decreasing potential

5. (3 pts.) Three charges are brought from infinity and placed at the corners of an equilateral triangle. Which of the following statements is <u>true</u>?



A. The work required to assemble the charges is always positive.
B. The electrostatic potential energy of the system is always positive.
C. The electrostatic potential energy does not depend on the order the charges are placed at the corners.
D. The work required to assemble the charges depends on which charge is placed at which corner.
E. The electrostatic potential energy depends on which charge is placed at which corner.

$\Delta u = \frac{k q_1 q_2}{r} = \frac{k q_2 q_1}{r}$ This is straight-forward

6. (4 pts.) If you increase the charge on a parallel-plate capacitor from 3 μC to 9 μC and increase the plate separation from 1 mm to 3 mm, the energy stored in the capacitor changes by a factor of

A) 27
B) 9
C) 8
D) 3
E) 1/3

$C = \frac{\epsilon_0 A}{d}$ for // plate cap

$C = \frac{Q}{V}$ so $Q \to 3Q$

$d \to 3d \Rightarrow C \to \frac{C}{3}$

Energy stored $u = \frac{1}{2} C V^2 = \frac{1}{2} \frac{Q^2}{C}$

For $C \to \frac{C}{3}$, $Q \to 3Q$, $u \to \frac{1}{2} \frac{(3Q)^2}{\frac{C}{3}}$

$= 27\left(\frac{1}{2}\frac{Q^2}{C}\right) = 27u$

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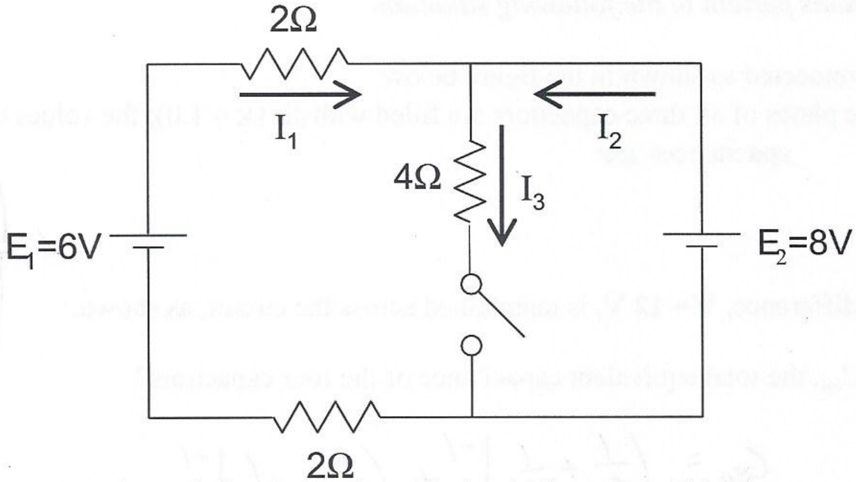
The next three questions pertain to the following circuit.



7. (4 pts.) With the switch open as shown, what is the current I_1?

(A) $I_1 = -7/2$ A
(B) $I_1 = -1/2$ A
(C) $I_1 = 1/2$ A
(D) $I_1 = 3/2$ A
(E) $I_1 = 7/2$ A

Kirchoff loop rule for outer loop:

$6 - 2I_1 - 8 - 2I_1 = 0 \Rightarrow -4I_1 = 2 \Rightarrow I_1 = -\frac{1}{2}$ V

For the next two questions the switch is closed.

8. (4 pts.) What is the voltage across the 4 ohm resistor?

(A) 2 V
(B) 6 V
(C) 7 V
(D) 8 V
(E) 14 V

Loop rule for right loop: $8 - 4I_3 = 0 \Rightarrow I_3 = 2$ A

Ohm's law: $V = 4I_3 = 8$ V

9. (3 pts.) Which of the currents have changed in magnitude after the switch is closed?

(A) Only I_3 has changed in magnitude.
(B) Only I_2 and I_3 have changed in magnitude.
(C) I_1, I_2, and I_3 have all changed in magnitude.
(D) No currents have changed in magnitude.

Before switch closed: $I_1 = -I_2$, $I_3 = 0$
After switch closed: $I_1 + I_2 = I_3$, $I_3 \neq 0$
Loop equation for outer loop (see above) remains the same
$\Rightarrow I_1$ does not change
$\Rightarrow I_2$ & I_3 change

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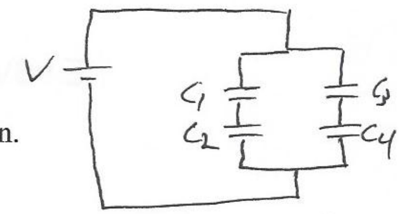
The next three questions pertain to the following situation.

Four capacitors are connected as shown in the figure below.
The gaps between the plates of all three capacitors are filled with air ($\kappa = 1.0$); the values of the c apacitances are:

$C_1 = 2\ \mu F$
$C_2 = 3\ \mu F$
$C_3 = 8\ \mu F$
$C_4 = 6\ \mu F$

A constant potential difference, $\boldsymbol{V} = \mathbf{12\ V}$, is maintained across the circuit, as shown.



10. (5 pts.) What is C_{tot}, the total equivalent capacitance of the four capacitors?

A) 0.89 μF
B) 3.68 μF
C) 4.63 μF
D) 4.75 μF
E) 19.0 μF

$$C_{eq} = \left(\frac{1}{C_1} + \frac{1}{C_2}\right)^{-1} + \left(\frac{1}{C_3} + \frac{1}{C_4}\right)^{-1}$$

11. (5 pts.) What is $V_b - V_a$, the potential difference between points b and a (*i.e.*, the voltage across capacitor C_4)? V is same in parallel branches; Q same for capacitors in series;

A) 5.14 V
B) 6.00 V
C) 6.86 V
D) 9.00 V
E) 16.00 V

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

$$Q = \left(\frac{1}{C_3} + \frac{1}{C_4}\right)^{-1} V$$

$$\rightarrow V_4 = \frac{V}{C_4}\left(\frac{1}{C_3} + \frac{1}{C_4}\right)^{-1}$$

12. (3 pts.) If capacitors C_1 and C_2 are removed from the circuit, how will the energy stored in C_4 change?

A) Increase
B) No change
C) Decrease

$E = \frac{1}{2}CV^2$, V_4 & C_4 do not depend on the C_1, C_2 branch.

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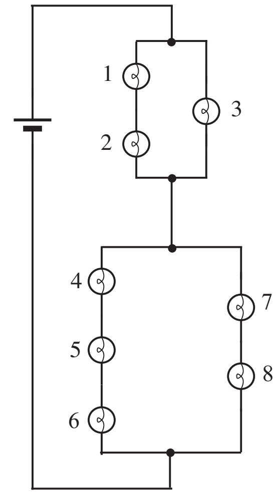
II. [10 pts total] The following questions are based on your experience in the lab. The questions are not related to each other. Please assume that all batteries are ideal and all bulbs are identical.

13. [3 pts.] Consider Circuit 1 at right.

The magnitude of the voltage across the upper network that contains bulbs 1 – 3 is __________ the magnitude of the voltage across the lower network that contains bulbs 4 – 8.

a. smaller than
b. the same as
c. greater than
d. not comparable to



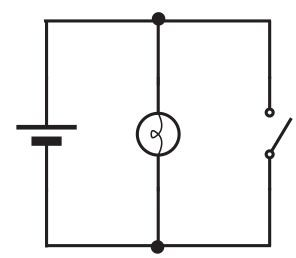
Circuit 1

The two networks are connected in series, therefore the same current runs through both networks. The lower network that contains bulbs 4 – 8 has higher resistance due to the configuration of bulbs when compared to the upper network that contains bulbs 1 – 3. From Ohm's law (V = IR), the voltage drop across each network is proportional to the resistance of the network. Because the upper network has lower resistance it should also have lower voltage drop across it. The answer is ***(a).***

14. [3 pts] Consider Circuit 2 at right.

When the switch is open, the voltage across the switch is:

a. 0 volts.
b. equal in magnitude to the voltage across the battery.
c. greater in magnitude than the voltage across the battery.
d. infinite magnitude voltage.

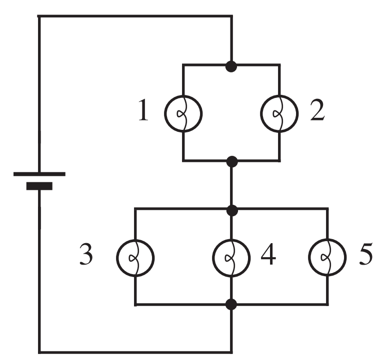

Circuit 2

If you applied Kirchhoff's law to the loop that includes the batter and the bulb, you can conclude that the voltage drop across the bulb and the voltage drop across the battery must have the same magnitude. If you drew a loop that includes the switch and the battery you can conclude that the voltage drop across battery and the voltage drop across the switch must have the same magnitude. The answer is ***(b).***

15. [4 pts] Consider Circuit 3 at right.

When bulb 5 is unscrewed and removed from the socket, bulb 1:

a. becomes dimmer.
b. remains at the same brightness as it was before bulb 5 was removed.
c. becomes brighter.
d. does not light because there is an open switch in the system.



Circuit 3

The more branches you have in a parallel network, the lower the resistance of the network, similarly, the fewer branches you have in a parallel network, the higher the resistance. Thus, when you remove bulb 5 from the circuit, the resistance of that network increases. By increasing the resistance of that particular network, the total current through the circuit must decrease (resistance is an obstacle to current). If the total current through the circuit decreases, then the current through each individual element also must decrease. If current through each element has decreased then the current through bulb one has decreased and bulb 1's brightness has become dimmer than it was originally. The answer is ***(a).***

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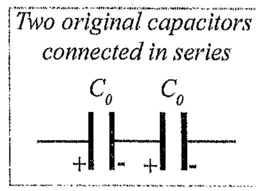
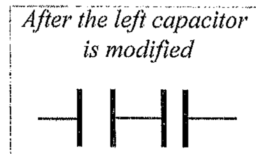
III. [25 pts] Parts A and B are independent.

A. A student charges two identical parallel-plate capacitors by connecting them one at a time across a 9-volt battery. Each capacitor is carefully disconnected from the battery so that it is not discharged. The student then connects the charged capacitors in series as shown at right. The capacitors are *not* connected to the battery.



Two original capacitors connected in series

Suppose now that the **left** capacitor is modified such that the distance between the plates is increased, as shown below right.


After the left capacitor is modified

1. [6 pts] After the ~~change, does~~ the charge on the **left** capacitor *increase, decrease,* ~~or~~ *remain the same?* Explain.

Because the leftmost & rightmost plates are not connected to anything, the charges on them remain the same, therefore the charges on the other plates remain the same as well

2. [6 pts] After the change, does the potential difference across the **left** capacitor *increase, decrease,* or *remain the same?* Explain.

$C = \frac{\epsilon_0 A}{d}$ implies C_{left} decreases because d increases

$V = Q/C$ with same Q & smaller C implies V_{left} increases

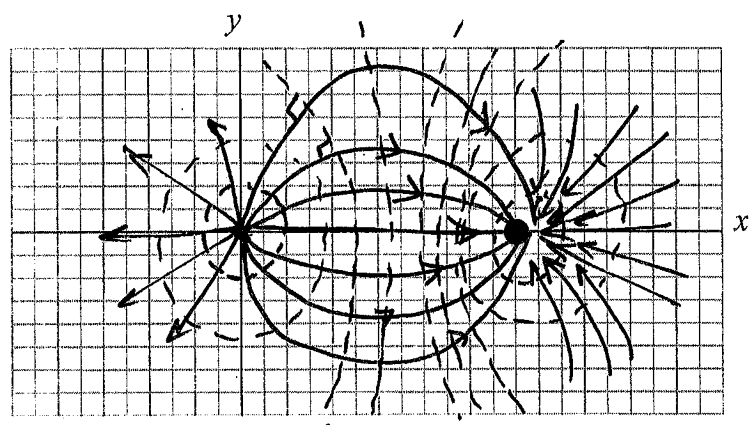
3. [7 pts] ~~After the~~ change, does the potential difference across the **right** capacitor *increase, decrease,* or *remain the same?* Explain.

C & Q remain the same for ~~both~~ the right capacitor, therefore $V = Q/C$ remains the same as well

B. [6 pts] Two point charges +Q (small dot) and –2Q (large dot) are located on the x-axis in the x-y plane.

On the grid at right, sketch a qualitatively correct set of **electric field lines** and **equipotential lines**. Use dashed lines for the equipotentials. If any of the equipotentials represents $V = 0$, mark it clearly.

V=0 somewhat closer to Q_{left}



V=0 line somewhere around here

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V. [20 points total] This question consists of two independent parts, A and B.

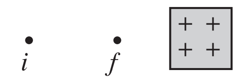
A. A negatively charged point charge is released at point *i* near a cube with a uniform positive charge distribution. It crosses point *f* with speed v_f.

i. [4 pts] Consider the system consisting of the point charge alone.

Is the total energy of the system *increasing, decreasing,* or *remaining the same?* Briefly explain.

The point charge starts from rest at point i (zero kinetic energy) and crosses point f with speed v_f (positive kinetic energy) so its change in kinetic energy is positive. The system only has one object in it, so there isn't any potential energy in the system. Thus the total energy of the system is ***increasing.***

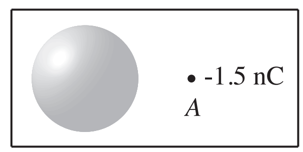
ii. [4 pts] Suppose the cube is moved to the left, closer to points *i* and *f* as shown. The point charge is again released at point *i*.



Is the magnitude of the electric potential difference between points *i* and *f greater than, less than,* or *equal to* what it was before the cube was moved? Briefly explain.

At every point between i and f the point charge is closer to the charges on the cube than before, so the electric force on the point charge is greater. Therefore the work done by the electric field, and the change in potential energy of the system, is greater. Since electric potential difference is the ratio of change in potential energy to test charge, and the test charge hasn't changed, the magnitude of the electric potential difference has ***increased.***

B. Test charge *A* (-1.5 nC) is held at rest 10 cm from the surface of a positively charged insulating sphere that is fixed in place. Charge *A* is released from rest, and reaches the surface of the sphere with 14 J of kinetic energy.



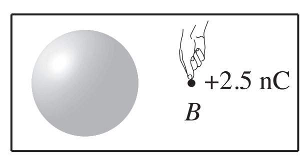
i. [4 pts] During the motion of charge *A*, does the electric potential energy U_E of the system consisting of charge *A* and the sphere *increase, decrease,* or *remain the same?* Briefly explain.

There are no external forces acting on the system, so by the work-energy theorem the total energy of the system remains constant. Since the kinetic energy of the test charge is increasing, the potential energy of the system is ***decreasing.***

ii. [4 pts] Find the absolute value of the electric potential difference ΔV_A between charge *A*'s starting point and the surface of the sphere.

$\Delta V_A = \Delta U_E / q_{test}$, and from part i above we know that if $\Delta K = 14$ J, $\Delta U_E = -14$ J. Substituting values, we find that $\Delta V_A = 9.33$ GV.

Test charge *B* (+2.5 nC) is also initially held at rest 10 cm from the surface of a positively charged sphere identical to the one above. Charge *B* is moved by a hand at constant velocity to the sphere's surface.



iii. [4 pts] Is the magnitude of the electric potential difference between charge *B*'s starting point and the surface of the sphere, ΔV_B, *greater than, less than,* or ***equal to*** the magnitude of ΔV_A? Briefly explain.

As we saw in tutorial, the electric potential difference is independent of test charge, so $\Delta V_B = \Delta V_A$. Whatever change is made to the test charge (in magnitude or sign) will result in an equivalent change in electric potential energy, so the electric potential difference will remain the same.