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1 [5points] The voltage between the cathode (negatively charged) and the screen of a computer monitor is 12 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? Electron charge is 1.6×10^{-19} C.

A) 8.8×10^7 m/s

D) 7.7×10^{15} m/s

B) 6.5×10^7 m/s

E) 5.3×10^7 m/s

C) 4.2×10^{15} m/s

2 [5 points] The electric field in a region is given by $\vec{E} = 2x^2 \hat{i} + 3y \hat{j}$ where the units are in V/m. What is the potential difference from the origin to $(x, y) = (2, 2)$ m?

A) $-27\frac{1}{3}$ V

D) -6 V

B) $-11\frac{1}{3}$ V

E) none of the above

C) $-5\frac{1}{3}$ V

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3 [5 points] Two charges Q_1 ($= +6 \mu\text{C}$) and Q_2 ($= -2 \mu\text{C}$) are brought from infinity to positions on the x-axis of $x = -4 \text{ cm}$ and $x = +4 \text{ cm}$, respectively. How much work was done in bringing the charges together?

A) $-1.80 \times 10^6 \text{ J}$

D) -1.35 J

B) $-9.00 \times 10^5 \text{ J}$

E) none of the above

C) -16.9 J

4 [6 points] A ring of radius 5 cm is the yz plane with its center at the origin. The ring carries a uniform charge of 10 nC. A small particle of mass $m = 10 \text{ mg}$ and charge $q_0 = 5 \text{ nC}$ is placed at $x = 12 \text{ cm}$ and $y = z = 0 \text{ cm}$ and released. The speed of the particle when it is a great distance from the ring is

A) 1.36 cm/s

D) 3.43 cm/s

B) 1.94 cm/s

E) None of these is correct.

C) 2.63 cm/s

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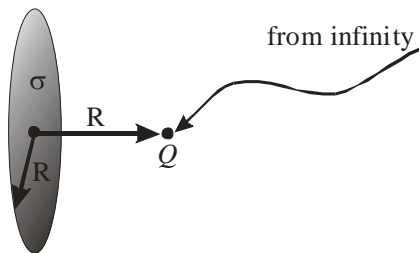
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5 [5 points] A solid spherical conductor of radius 20 cm has a charge $Q = 25 \text{ nC}$ on it. A second, initially uncharged, spherical conductor of radius 12 cm is moved toward the first until they touch and is then moved far away from it. How much charge is there on the second sphere after the two spheres have been separated?

- A) 15 nC **B) 9.4 nC** C) 25 nC D) 3.9 nC E) 2.1 nC

6 [6 points] Calculate the work done to bring a charge, $Q = 1 \text{ mC}$, from infinity and place it at a distance $R = 10 \text{ cm}$ along the axis of a uniformly charged disk with surface charge density $\sigma = 10 \text{ } \mu\text{C}/\text{m}^2$ and radius R .



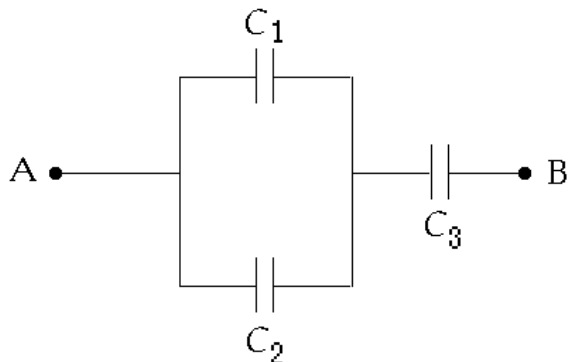
- A) 78.9 J **B) 23.4 J** C) 56.5 J D) 97.8 J E) zero

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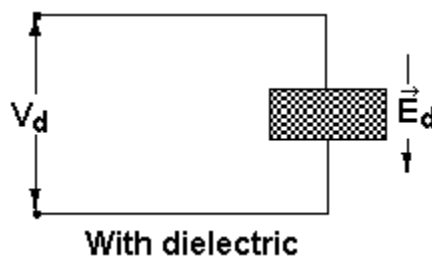
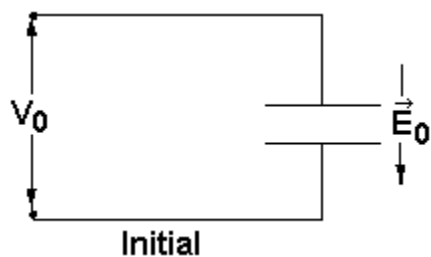
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7 [6 You connect three capacitors as shown in the diagram below. The effective capacitance of this points combination when $C_1 = 5.0 \mu\text{F}$, $C_2 = 4.0 \mu\text{F}$, and $C_3 = 3.0 \mu\text{F}$ is approximately

- A) $0.44 \mu\text{F}$ **B) $2.3 \mu\text{F}$** C) $3.5 \mu\text{F}$ D) $5.2 \mu\text{F}$ E) $12 \mu\text{F}$



8 [6 points] A charged capacitor has an initial electric field \vec{E}_0 and potential difference V_0 across its plates. Without connecting any source of emf, you insert a dielectric ($\kappa > 1$) slab between the plates to produce an electric field \vec{E}_d and a potential difference V_d across the capacitor. The pair of statements that best represents the relationships between the electric fields and potential differences is



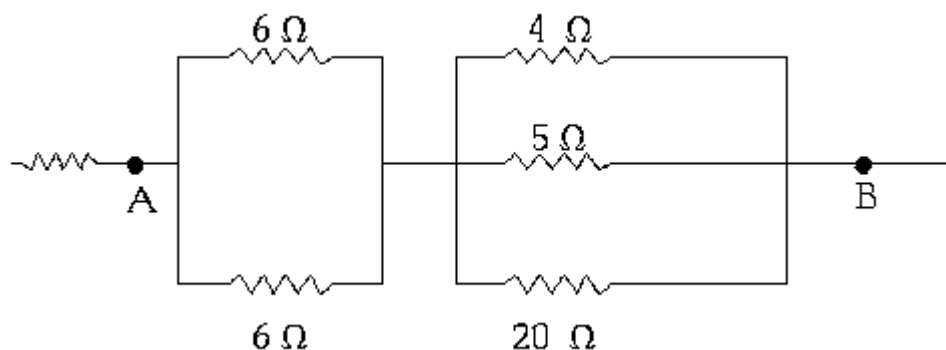
- A) $\vec{E}_d > \vec{E}_0$; $V_d > V_0$ D) $\vec{E}_d < \vec{E}_0$; $V_d > V_0$
 B) $\vec{E}_d = \vec{E}_0$; $V_d > V_0$ **E) $\vec{E}_d < \vec{E}_0$; $V_d < V_0$**
 C) $\vec{E}_d > \vec{E}_0$; $V_d = V_0$

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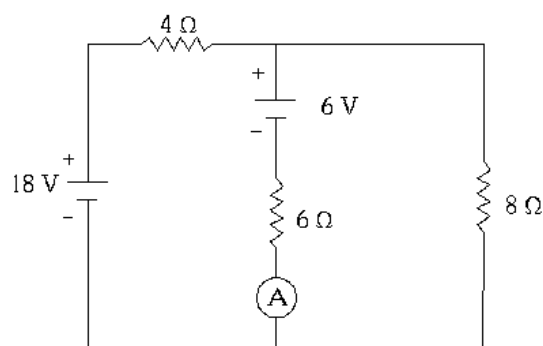
9 [6 points] A current of 1.2 A flows from A to B. Therefore, the magnitude of the potential difference between points A and B is approximately



- A) 1.0 V B) 4.2 V C) 4.6 V **D) 6.0 V** E) 20 V

10 [6 points] In this circuit, the batteries have negligible internal resistance and the ammeter has negligible resistance. The current through the ammeter is

- A) 0.30 A **B) 0.69 A** C) 2.1 A D) 4.2 A E) 3.6 A



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11. [25 points] Consider two identical parallel-plate capacitors $C_1 = 1\text{pF}$ and C_2 that are connected in parallel. In between the plates of capacitor C_1 there is air (which has basically the same permittivity as vacuum) while the capacitor C_2 has a dielectric and $C_2 = 3C_1$. A 200 V battery is connected across the combination until electrostatic equilibrium is established, and then the battery is disconnected. In all answers please show your work.

a) What is the positive charge on each capacitor?

$$Q_1 = C_1 V = 2 \times 10^{-10} \text{ C}$$

$$Q_2 = C_2 V = 6 \times 10^{-10} \text{ C}$$

b) What is the total stored energy of the capacitors?

$$U_b = \frac{1}{2} Q_1 V + \frac{1}{2} Q_2 V = 8 \times 10^{-8} \text{ J}$$

c) The dielectric is removed from C_2 . What is the total stored energy of the capacitors?

$$Q_1^{new} = Q_2^{new} = \frac{Q_1 + Q_2}{2}$$

$$U_c = \frac{(Q_1^{new})^2}{2C_1} + \frac{(Q_2^{new})^2}{2C_2} = 16 \times 10^{-8} \text{ J}$$

d) If the total energy changes, explain the reason for the change.

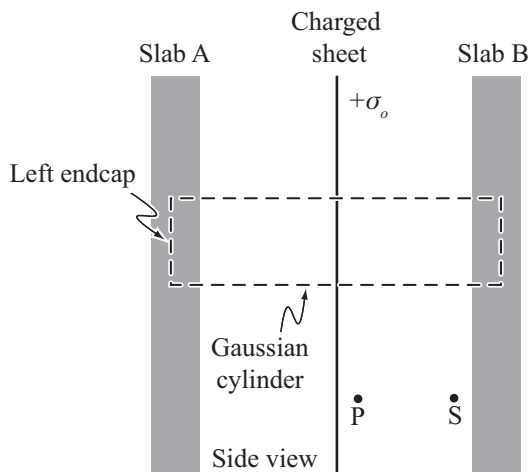
One had to extract the dielectric and perform work on the system (similarly to lifting a weight).

e) What is the final voltage across the two capacitors?

$$V_1^{new} = V_2^{new} = \frac{Q_1^{new}}{C_1} = 400 \text{ V}$$

- IV. [20 points total] An infinite, uniformly charged sheet, with positive charge density σ_o , is placed halfway between two infinite thick conducting slabs. Each slab has zero net charge.

The Gaussian cylinder shown has each end cap within a conducting slab and the cylinder has its axis perpendicular to the charged sheet. For each portion of the Gaussian surface, use area vectors consistent with fact that the entire surface is closed.



- A. [5 pts] Is the flux through the left end cap *greater than*, *less than*, or *equal to* zero? Explain your reasoning.

The left end cap is inside of a conductor. The electric field inside of a conductor is zero. Since flux is proportional to electric field, the flux through the left end cap is zero.

- B. [5 pts] Is the net flux through the entire cylinder *greater than*, *less than*, or *equal to* zero? Explain.

Since the system consists of infinite sheets, the electric field vectors must be parallel to the cylinder's axis. Therefore, at any point on the curved side of the cylinder, E and dA are perpendicular, making the flux through the curved side of the cylinder zero. By the same argument used in part A, the flux through each end cap is zero. Adding these we find a net flux of zero.

- C. [5 pts] Write an expression for the charge density induced on the left side of slab B, $\sigma_{L \text{ of } B}$, in terms of σ_o . If there is no charge density induced on the left side of slab B, state so explicitly.

If you don't have enough information to find an expression for $\sigma_{L \text{ of } B}$, explain what additional information you need. Explain your reasoning.

From part B we know that the net flux through the Gaussian cylinder is zero. From Gauss' law, the total enclosed charge is zero. A charge $+\sigma_o A$ from the sheet is enclosed. The induced charges on the right surface of slab A and the left surface of slab B will also be enclosed. Since the system is symmetric under reflections through the sheet, $\sigma_{R \text{ of } A} = \sigma_{L \text{ of } B}$. Putting this all together we find $\sigma_o A + \sigma_{R \text{ of } A} A + \sigma_{L \text{ of } B} A = \sigma_o A + 2\sigma_{L \text{ of } B} A = 0$, which implies that $\sigma_{L \text{ of } B} = -\sigma_o/2$.

- D. [5 pts] Is the potential at point P *greater than*, *less than*, or *equal to* the potential at point S? Explain.

We may treat the surface charges on the slabs as infinite sheet charges. The two conducting slabs are neutral, so the contributions from each side of a particular slab cancel to zero. This leaves just the electric field due to the charged sheet, so in the region between the sheet and slab B, the electric field points to the right. Thus, in moving a positive charge in a straight line from P to S, the electric field does positive work. Since $\Delta V = -W/q$ we see that $\Delta V < 0$. Therefore, the potential at point P is greater than the potential at point S.