The next three questions pertain to the following situation:

A system of capacitors, all of equal capacitance $C_1 = C_2 = C_3 = C$, is connected to an ideal battery of voltage $\mathcal{E} = 24$ V.

3. Calculate $C$ given that the charge on capacitor $C_2$ is measured to be $Q_2 = 98$ nC.
   a. $C = 43.9$ nF
   b. $C = 2.7$ nF
   c. $C = 312$ nF
   d. $C = 8.2$ nF
   e. $C = 126$ nF

4. What is $Q_3$, the amount of charge collected on the capacitor $C_3$?
   a. $Q_3 = 150$ µC
   b. $Q_3 = 300$ µC
   c. $Q_3 = 600$ µC

5. How much energy $U_{\text{total}}$ is stored in the capacitor network?
   a. $U_{\text{total}} = 0.9$ mJ
   b. $U_{\text{total}} = 3.2$ mJ
   c. $U_{\text{total}} = 10.8$ mJ
   d. $U_{\text{total}} = 58.2$ mJ
   e. $U_{\text{total}} = 36.8$ mJ

For the next two questions, assume that all of the capacitors have capacitance $C = 25$ µF and that their charges are unknown.
6. Consider an uncharged spherical conducting shell as shown. If charges are transferred to it, which statement is TRUE regarding their behavior?

   a. They will be distributed uniformly throughout the conductor.
   b. They will spread on the inner surface.
   c. They will spread on the outer surface.

7. Consider the circuit below. Which of the following equations is incorrect?

   a. $\varepsilon_1 - \varepsilon_2 - I_1R_1 - I_2R_2 = 0$
   b. $\varepsilon_1 - I_1R_1 - I_3R_3 = 0$
   c. $\varepsilon_2 - I_2R_2 - I_3R_3 = 0$
The next five questions pertain to the following situation.

Three point charges are positioned on the vertices of an equilateral triangle as shown.

8. What is the magnitude of the net electric force \( F \) on the charge \( Q_3 \)?

   a. \( F = 3.89 \text{ N} \)
   b. \( F = 112 \text{ N} \)
   c. \( F = 195 \text{ N} \)

9. What is the direction of the electric field at the origin, \( P \)?

   a. Along the positive y-axis.
   b. Along the negative y-axis.

10. What is the magnitude of the electric field \( E \) at the origin, \( P \)?

   a. \( E = 1.35 \times 10^7 \text{ N/C} \)
   b. \( E = 5.39 \times 10^8 \text{ N/C} \)
   c. \( E = 1.50 \times 10^8 \text{ N/C} \)
   d. \( E = 1.12 \times 10^8 \text{ N/C} \)
   e. \( E = 7.01 \times 10^8 \text{ N/C} \)

   \[ E = \frac{k|Q_3|}{r^2} \]
   where \( r^2 = (2 \text{ cm})^2 - (1 \text{ cm})^2 = 3 \text{ cm}^2 \)
   \( 1 \text{ cm}^2 = 10^{-4} \text{ m}^2 \)
The next two questions continue from the previous page.

11. How much work $W$ is required \textit{by you} to assemble the three charges to this configuration?

- a. $W = -0.0405$ J
- b. $W = -4.05$ J
- c. $W = 4.05$ J
- d. $W = -202.3$ J
- e. $W = 202.3$ J

\begin{itemize}
    \item [\circ] Bring in $Q_1$, \hspace{1cm} $W = 0$
    \item Bring in $Q_2$, \hspace{1cm} $W = \Delta U_{12} = k \frac{Q_1 Q_2}{2 cm}$
    \item Bring in $Q_3$, \hspace{1cm} $W = \Delta U_{13} + \Delta U_{23} = k \frac{Q_1 Q_3}{2 cm} + k \frac{Q_2 Q_3}{2 cm}$
\end{itemize}

Add them together: \[ \frac{k}{2 cm} \left[ Q_1 Q_2 + Q_1 Q_3 + Q_2 Q_3 \right] \]

Plug in charges with signs: \[ W_{\text{Tot}} = \frac{k}{2 cm} \left[ 1 \mu C \times 1 \mu C - 1 \mu C \times 5 \mu C - 5 \mu C \times 5 \mu C \right] \]

\[ = \frac{k}{2 cm} \left[ -9 \mu C^2 \right] = \frac{9 \times 10^1}{2 cm} \cdot (-9 \times 10^{-6}) \]

12. What is the electric potential $V$ due to the three charges at origin, $P$?

- a. $V = -202.3$ V
- b. $V = -2.34$ V
- c. $V = 1.35$ V
- d. $V = -1.35 \times 10^5$ V
- e. $V = -7.98 \times 10^5$ V

\begin{itemize}
    \item $V_1 = \frac{kQ_1}{r_1}$ \hspace{1cm} $r_1 = 1$ cm \hspace{1cm} $V_1 = V_2$
    \item $V_2 = \frac{kQ_2}{r_2}$ \hspace{1cm} $r_2 = 1$ cm
    \item $V_3 = \frac{kQ_3}{r_3}$ \hspace{1cm} $r_3 = 5$ cm \hspace{1cm} \text{from} \#10
\end{itemize}

\[ \Sigma V = 2 \left( \frac{k(10^{-6})}{.01} \right) + \frac{k(-5 \times 10^{-6})}{.01 \times \sqrt{3}} \]
The next three questions pertain to the following situation:

An ideal battery of voltage $E = 12$ V is connected to a circuit of resistors.

$$\begin{array}{c}
\begin{array}{c}
R_1 \\
R_2 \\
R_3 \quad E \\
R_4 \\
R_5
\end{array}
\end{array}$$

13. Assume all of the resistors have resistance $R$. What is the equivalent resistance, $C_{eq}$, for the circuit?
   
   a. $C_{eq} = 3R/2$
   
   b. $C_{eq} = 5R$
   
   c. $C_{eq} = 5R/7$
   
   d. $C_{eq} = 4R/3$
   
   e. $C_{eq} = 13R/9$

14. If the resistance of each resistor $R = 75 \, \Omega$, what is $P_1$, the power dissipated by resistor $R_1$?
   
   a. $P_1 = 1.9 \, \text{W}$
   
   b. $P_1 = 9.0 \, \text{W}$
   
   c. $P_1 = 5.7 \, \text{W}$

15. What is the voltage $V_{ab}$ difference between points $a$ and $b$, as labeled on the circuit?
   
   a. $V_{ab} = 2.4 \, \text{V}$
   
   b. $V_{ab} = 18.2 \, \text{V}$
   
   c. $V_{ab} = 6.0 \, \text{V}$
   
   d. $V_{ab} = 12.0 \, \text{V}$
   
   e. $V_{ab} = 4.8 \, \text{V}$
16. Two resistors are created using copper, which has resistivity $\rho = 1.72 \times 10^{-8} \, \Omega \cdot \text{m}$. The first resistor has radius $r$ and length $L$. The second resistor has radius $r/2$ and length $2L$. What is the ratio of the second resistor's resistance $R_2$ to that of the first resistor's resistance $R_1$?

\[ R_1 = \rho \frac{L}{\pi r^2} \]
\[ R_2 = \rho \frac{(2L)}{\pi (\frac{r}{2})^2} = \rho \frac{2L}{\pi \frac{r^2}{4}} = \rho \frac{8L}{\pi r^2} \]

- a. $R_2/R_1 = 1/4$
- b. $R_2/R_1 = 1/2$
- c. $R_2/R_1 = 2$
- d. $R_2/R_1 = 8$
- e. $R_2/R_1 = 16$
The next two questions pertain to the following situation.

A uniform electric field is generated by two parallel plate electrodes, positive and negative, respectively, as shown. The dashed lines indicate the electric field. The electric potential at the positive and the negative electrode is 5 V and −5 V, respectively. Consider a charge \( Q = +3 \text{ mC} \) with mass of 1 mg.

17. Imagine that you move the charge \( Q \) from point A to point B along the two paths shown. Let \( W_1 \) and \( W_2 \) be the work done by the electric field following Path 1 and Path 2, respectively. What is the relationship between \( W_1 \) and \( W_2 \)?

a. \( W_1 > W_2 \)
b. \( W_1 < W_2 \)
c. \( W_1 = W_2 \)

18. If the charge \( Q \) is released freely at A, what is its speed, \( v \), when arriving at B?

a. Not enough information is given.
b. \( v = 7.75 \text{ m/s} \)
c. \( v = 5.48 \text{ m/s} \)
d. \( v = 173 \text{ m/s} \)
e. \( v = 245 \text{ m/s} \)
The next two questions pertain to the following situation:

A capacitor is created by placing two circular metal plates of radius 2 mm a distance 5 µm apart. A material of dielectric constant $\kappa = 2.5$ is placed between the plates. The capacitor is then charged by placing a charge $Q_{\text{top}} = +3 \text{ nC}$ on the top plate and $Q_{\text{bottom}} = -3 \text{ nC}$ on the bottom plate. After charging, the capacitor is disconnected from all other elements, such as wires or a battery.

![Capacitor diagram]

19. What is the voltage difference $V$ measured between the two plates of this capacitor?

a. $V = 15 \text{ V}$

b. $V = 54 \text{ V}$

c. $V = 95 \text{ V}$

d. $V = 65 \text{ V}$

e. $V = 225 \text{ V}$

20. The plates are then pulled apart so that the distance between them is increased from 5 µm to 20 µm. How does the new charge on the top plate $Q_{\text{top,new}}$ compare to the original charge on the top plate $Q_{\text{top}}$?

a. $Q_{\text{top,new}} < Q_{\text{top}}$

b. $Q_{\text{top,new}} > Q_{\text{top}}$

c. $Q_{\text{top,new}} = Q_{\text{top}}$

The capacitor is disconnected so the charge cannot change.
The next three questions pertain to the following situation:

Consider the circuit below. $\varepsilon_1 = 15 \text{ V}$, $\varepsilon_2 = 5 \text{ V}$, $R_1 = 1 \Omega$, $R_2 = 2 \Omega$.
Initially the switch $S$ is open.

![Circuit Diagram](image)

21. What is the current $I_1$ in resistor $R_1$?

a. $I_1 = 0 \text{ A}$
b. $I_1 = 6.25 \text{ A}$
c. $I_1 = 3.33 \text{ A}$
d. $I_1 = 1.50 \text{ A}$
e. $I_1 = 17.5 \text{ A}$

22. Now the switch $S$ is closed. What is the current $I_3$? (This is a stretch for exam 2, but I'm giving the example anyway)

a. $I_3 = 0 \text{ A}$
b. $I_3 = 6.25 \text{ A}$
c. $I_3 = 3.33 \text{ A}$
d. $I_3 = 1.50 \text{ A}$
e. $I_3 = 17.5 \text{ A}$