1. Two positive charges (q_1 and q_2), each 4.00 μC, and a negative charge, q_3 = -4.00 μC, are fixed at the vertices of a right triangle with a = 1 m as shown below. \( \frac{1}{4 \pi \varepsilon_0} = 9 \times 10^9 \text{Nm}^2/\text{C}^2 \).

a. Calculate the electrical force (magnitude and direction) acting on the negative charge.

\[
F_1 = F_2 = k \frac{q_3 q_1}{a^2} = k \frac{q_3 q_2}{a^2} = 9 \times 10^9 \frac{(4 \times 10^{-6})^2}{1^2} \]

\[
F_1 = F_2 = 0.144 \text{ N}
\]

\[
\vec{F} = \vec{F}_1 + \vec{F}_2 \quad F_{1x} = -F_{2x}, F_{1y} = F_{2y}
\]

\[
F_{1x} = 0, \quad F_{1y} = 2F_{2y} = 2(0.144) = 0.288 \text{ N}
\]

\[
F_{1x} = 0, \quad F_{1y} = 0.20 \text{ N}
\]

\[
\vec{F} = 0.2 \text{ N}, \quad \angle \vec{F} = 0.2 \text{ rad}
\]

b. Calculate the electric field (magnitude and direction) at point M shown in the figure.

At M, \( \vec{E}(q_1) + \vec{E}(q_2) = 0 \) since fields due to \( q_1 \) and \( q_2 \) are in opposite directions and same magnitude.

Total \( \vec{E} = \vec{E}(q_3) \)

\[
E = k \frac{|q_3|}{r^2} = 9 \times 10^9 \times \frac{4 \times 10^{-6}}{(1 \sqrt{2}/2)^2} = 72 \times 10^3 \text{ N/C}
\]

c. Calculate the electric potential at point M shown in the figure.

\[
V = V_1 + V_2 + V_3 = k \frac{q_1}{r_1} + k \frac{q_2}{r_2} + k \frac{q_3}{r_3}
\]

\[
V = 9 \times 10^9 \left( \frac{2 \times 4 \times 10^{-6}}{\sqrt{2}/2} \right) + 9 \times 10^9 \left( \frac{-4 \times 10^{-6}}{\sqrt{2}/2} \right)
\]

\[
V = (9 \times 10^9) (4x10^{-4}) = 5.04 \times 10^4 \text{ volts}
\]
d. Calculate the total electric potential energy of this system.

\[ U = k \left( \frac{9 \cdot 9_2}{R_{12}} + \frac{9 \cdot 9_3}{R_{13}} + \frac{9 \cdot 9_3}{R_{23}} \right) + \frac{a}{(4 \times 10^{-6})^2} + \frac{\frac{a}{(4 \times 10^{-6})^2}}{1} \]

2. Charge +Q is distributed uniformly over the length of a circular ring with radius a shown below.
   a. Calculate the expression for the electric potential at point M shown.

\[ dV = k \frac{dQ}{r} \quad r = \sqrt{R^2 + y^2} \]

\[ V = \int k \frac{dQ}{\sqrt{R^2 + y^2}} = \frac{k}{\sqrt{R^2 + y^2}} \]

\[ V = \frac{kQ}{\sqrt{R^2 + y^2}} \]

b. Use the expression for the electric potential to calculate the electric field magnitude and direction at M.

\[ E_x = E_z = 0 \]

\[ E_y = -\frac{\partial V}{\partial y} = -\frac{2}{a} \left( \frac{kQ}{\sqrt{R^2 + y^2}} \right) \]

\[ E_y = \frac{kQy}{(R^2 + y^2)^{3/2}} \]

Direction along y direction as shown.
3. A Charge Q is distributed uniformly over a spherical conducting shell with inner radius $R_1$ and outer radius $R_2$.
   
   a. Use Gauss’ law to calculate the magnitude and direction of electric field at a point inside the conducting shell (distance $r$ from the center $r < R_1$).

   \[ E_{\text{inside}} = 0 \quad r < R_1 \]

   Since there is no charge inside surface S shown.

   ![Diagram of a conducting shell with Gaussian surface]

   b. Use Gauss’ law to calculate the magnitude and direction of electric field at a point outside the conducting shell (distance $r$ from the center $r > R_2$).

   \[ \oint E \cdot d\mathbf{a} = \frac{Q_{\text{enc.}}}{\varepsilon_0} \]

   \[ E \times 4\pi r^2 = \frac{Q}{\varepsilon_0} \]

   \[ E = \frac{Q}{4\pi\varepsilon_0 r^2} \quad r > R_2 \]

   c. What is the electric field at a point inside the conducting shell ($R_1 < r < R_2$)?

   \[ E = 0 \quad \text{inside conducting material} \]

   Therefore, \[ E = 0 \quad \text{for } R_1 < r < R_2 \]
4. The constant electric field \( E = 300 \text{ V/m} \) is established between two parallel plates with equal and opposite charges as shown below. An electron is released from one end of the plates with initial velocity of 300 m/sec. Calculate the deflection of the electron from its initial path when it comes out of the plate. \( m_e = 9.1 \times 10^{-31} \text{ kg}, \quad q_e = 1.6 \times 10^{-19} \text{ C}. \quad l = 0.1 \text{ m} \)

\[
\begin{align*}
\text{along } x: & \quad F_x = 0 \quad a_x = 0 \quad x = v_0 t \\
\text{along } y: & \quad F_y = -q_e E \quad a_y = -\frac{q_e E}{m} \quad y = \frac{1}{2} a_y t^2 \\
X &= v_0 t, \quad t = \frac{x}{v_0} \\
y &= \frac{1}{2} a_y t^2 = \frac{1}{2} a_y \left( \frac{x}{v_0} \right)^2 \\
\text{deflection is } & \quad y \text{ and } X = l \\
y &= \frac{1}{2} \frac{q_e E}{m} \left( \frac{l}{v_0} \right)^2 \\
y &= \frac{1}{2} \frac{1.6 \times 10^{-19}}{9 \times 10^{-31}} \left( \frac{300}{300} \right) \left( \frac{0.1}{300} \right)^2
\end{align*}
\]

6. Insert letter T (for True statement) or F (for False statement) before each statement. Correct answer 2 points, wrong answer -2 points, no answer 0 point.

a) \( \underline{T} \) At the electric field lines and equipotential surfaces are perpendicular.

b) \( \underline{F} \) The force acting on a positive charge in an external electric field is in the opposite direction as the electric field.

c) \( \underline{T} \) We shoot a positive charge in a region with constant electric field in a direction perpendicular to the field. The charge will deflect from its initial path in the direction of the electric field.

d) \( \underline{T} \) We shoot a positive charge in a region with constant electric field in a direction perpendicular to the field. The charge will have a increasing velocity in the direction perpendicular to the electric field.

e) \( \underline{T} \) Two large parallel plates have equal and opposite charges. The electric field between the two plates is perpendicular to the plates and directs away from the plate with positive charge.

f) \( \underline{T} \) Positive charges are attracted toward lower potential.

g) \( \underline{F} \) Negative charges are accelerated toward lower potential.