Learning Objective: Electric Field and Potential Due to Point Charges

Problem 1. Two point charges with $q_1 = 20\ \mu$C and $q_2 = -40\ \mu$C are located in a free space at points with Cartesian coordinates $(1, 3, -1)$ m and $(-3, 1, -2)$ m, respectively.

(a) Determine the force $\mathbf{F_1}$ acting on charge q_1.

(b) Find the electric field $\mathbf{E}$ at $(3, 1, -2)$ m.

(c) Suppose a new point charge $q_3 = 80\ \mu$C is placed at $(3, 1, -2)$ m, determine the force $\mathbf{F_3}$ acting on charge q_3.

Learning Objective: Electric Field and Potential Due to Charge Distribution

Problem 2. A charge $+Q$ is evenly spread along the x-axis from $x = -L/2$ to $x = L/2$.

(a) Determine the line charge density ρ_l.

(b) Derive an expression of the electric field $\mathbf{E}$ along the x-axis where $a > L/2$.

(c) Derive an expression of the electric potential V along the x-axis where $a > L/2$.

(d) Derive an expression of the electric field $\mathbf{E}$ at $y = a$ where $a > 0$.

Problem 3. Consider a ring of radius $r = a$ in the $z = 0$ plane, centered at the origin, has a uniform line charge density ρ_l. Another circular disk of radius $r = a$ in the $z = d$ plane $(d > 0)$, centered at the origin, has a uniform surface charge density ρ_s.

(a) Derive an expression of the electric field $\mathbf{E}$ along the z-axis where $0 < z < d$.

(b) Derive an expression of the electric field $\mathbf{E}$ along the z-axis where $z > d$.

Learning Objective: Gauss's Law

Problem 4. Consider a sphere of radius $r = a$ centered at the origin has a uniform volume charge density ρ_v in a spherical coordinate.

(a) Determine the electric field $\mathbf{E}$ for $r > a$.

(b) Determine the electric field $\mathbf{E}$ for $0 < r < a$.

Learning Objective: Capacitance

Problem 5. Consider an n-channel MOSFET with a gate oxide thickness of 10 nm, gate width of 25 μm and gate length of 1 μm. A non-zero gate-to-source voltage V_{GS} is applied. Use $\epsilon_{ox} = 3.9\epsilon_0$, $n_i = 1.5 \times 10^{10}$ cm^{-3} if needed.

(a) Determine the gate capacitance of the MOSFET.

(b) Determine the total charge at the gate.

(c) Determine the electric field inside the oxide.