Please BOX your answers.

\[ k = \frac{1}{4\pi\varepsilon_0} = 9 \times 10^9 \text{N m}^2/\text{C}^2 \quad \varepsilon_0 = 8.85 \times 10^{-12} \text{C}^2/\text{N m}^2 \]

1. Three charges are located as shown in the diagram. \( q_1 \) is at the origin and \( q_2 \) and \( q_3 \) are in the \( xy \) plane, \( r = 2 \text{ m} \) from the origin, 30° above and below the \( x \) axis, respectively. The charges are \( q_1 = +8 \times 10^{-6} \text{ C} \), \( q_2 = -3 \times 10^{-6} \text{ C} \), and \( q_3 = +3 \times 10^{-6} \text{ C} \). What are the magnitude and direction of the electric force on \( q_1 \) due to \( q_2 \) and \( q_3 \)? (4 points)

Use Coulomb’s law. The force on \( q_1 \) due to \( q_2 \) points towards \( q_2 \) and has magnitude \( k|q_1||q_2|/r^2 \). The force from \( q_3 \) points away from \( q_3 \) and has the same magnitude. The horizontal components of these forces cancel and the vertical components add. To find the vertical components we multiply the magnitude of each force by \( \sin 30 \). Altogether,

\[ F = 2 \left( \frac{9 \times 10^9 \cdot 8 \times 10^{-6} \cdot 3 \times 10^{-6}}{2^2} \right) \sin 30 = 0.054 \text{ N} \],

and the force points in the y direction.

Rewrite and sign the Honor Pledge: I pledge my honor that I have not violated the Honor Code during this examination.
2. A cube is located as shown in the diagram. One vertex is at the origin and three edges lie along the coordinate axes. The length of the cube edge is \( a = 0.4 \text{ m} \). The faces of the cube are numbered: 1–top, 2–bottom, 3–left, 4–right, 5–front, 6–back. There is a uniform electric field \( E_0 = 5 \text{ N/C} \) in the \( x \) direction throughout the region occupied by the cube.

(a) What is the electric flux through each face of the cube? Be sure to pay attention the the signs! (3 points)

The flux through each face is the perpendicular component of the electric field times the area of each face. It is positive if the field points out of the cube and negative if it points into the cube. For faces, 1, 2, 5, and 6, the field is parallel to the face and flux is 0. \( \Phi_1 = \Phi_2 = \Phi_5 = \Phi_6 = 0 \)

For face 3, the field is perpendicular to the face and points into the cube so the flux is \( \Phi_3 = -E_0a^2 = -0.8 \text{ N m}^2/\text{C} \). For face 4, the answer is the same except the electric field points out of the cube, so the flux is positive, \( \Phi_4 = E_0a^2 = +0.8 \text{ N m}^2/\text{C} \)

(b) What is the total flux through the cube? (You should be able to get this even if you couldn't do part (a).) (1 point)

One way to solve this is to add up the flux through all six faces from part (a). The result is \( \Phi = 0 \). Another way is to use the fact that the total flux is just the charge inside the surface divided by \( \epsilon_0 \). Since there is no charge inside, the result is \( \Phi = 0 \).

(c) A charge \( q = 3 \times 10^{-8} \text{ C} \) is placed at the center of the cube. Now what is the total flux throughout the cube? (2 points)

The flux is the net charge inside divided by \( \epsilon_0 \). \( \Phi = q/\epsilon_0 = 3 \times 10^{-8}/8.85 \times 10^{-12} = 3390 \text{ N m}^2/\text{C} \). Since the charge is at the center of the cube, the flux through each face is one-sixth the total. If the charge is moved off center (but still inside) the total remains the same, but the flux through each face changes.