Three point charges are on the x-axis: \( q_1 = -6.0 \mu \text{C} \) is at \( x = -3.0 \text{ m} \), \( q_2 = 4.0 \mu \text{C} \) is at the origin, and \( q_3 = -6.0 \mu \text{C} \) is at \( x = 3.0 \text{ m} \). Find the force on \( q_1 \):

\[
\vec{F}_{2,1} = \frac{kq_1q_2}{r_{1,2}^2} \hat{i} = \frac{9.0 \times 10^9 \text{ N m}^2}{\text{C}^2} \cdot \frac{6.0 \times 10^{-6} \text{ C} \times 4.0 \times 10^{-6} \text{ C}}{(3 \text{ m})^2} \hat{i} = 24.0 \times 10^{-3} \text{ N} \hat{i}
\]

\[
\vec{F}_{3,1} = -\frac{kq_1q_3}{r_{1,3}^2} \hat{i} = -\frac{9.0 \times 10^9 \text{ N m}^2}{\text{C}^2} \cdot \frac{6.0 \times 10^{-6} \text{ C} \times 6.0 \times 10^{-6} \text{ C}}{(6 \text{ m})^2} \hat{i} = -9.0 \times 10^{-3} \text{ N} \hat{i}
\]

\[
\vec{F}_{\text{tot}} = \vec{F}_{2,1} + \vec{F}_{3,1} = 15.0 \times 10^{-3} \text{ N} \hat{i}
\]

---

Three charges, each of magnitude 3 nC, are at separate corners of a square of side 5 cm. The two charges at opposite corners are positive, and the other charge is negative. Find the force exerted by these charges on a fourth charge \( q = +3 \text{ nC} \) at the remaining corner.

Put 4th charge at origin \((0,0)\)

\( q_1 \) and \( q_3 \) are opposite charges.

Find total force on \( q_0 \)

\[
\vec{F}_{1,0} = -\frac{kq_1q_0}{r_{1,0}^2} \hat{i} = -\frac{9.0 \times 10^9 \text{ N m}^2}{\text{C}^2} \frac{(3.0 \times 10^{-9} \text{ C})^2}{(0.05 \text{ m})^2} \hat{i} = -32.4 \mu \text{N} \hat{i}
\]

\[
\vec{F}_{2,0} = \frac{kq_2q_0}{r_{1,0}^2} \left( \left( \frac{\hat{i}}{2} \right) \frac{\hat{j}}{2} \right) = \frac{9.0 \times 10^9 \text{ N m}^2}{\text{C}^2} \frac{(3.0 \times 10^{-9} \text{ C})^2}{(0.05 \text{ m})^2} \left( \left( \frac{\hat{i}}{2} \right) \frac{\hat{j}}{2} \right) = 16.2 \mu \text{N} \left( \left( \frac{\hat{i}}{2} \right) \frac{\hat{j}}{2} \right)
\]

\[
\vec{F}_{3,0} = -\frac{kq_3q_0}{r_{3,0}^2} \hat{i} = -\frac{9.0 \times 10^9 \text{ N m}^2}{\text{C}^2} \frac{(3.0 \times 10^{-9} \text{ C})^2}{(0.05 \text{ m})^2} = -32.4 \mu \text{N} \hat{i}
\]

\[
\vec{F}_{\text{tot}} = 16.2 \mu \text{N} \left( \left( \frac{\hat{i}}{2} \right) \frac{\hat{j}}{2} \right) - 32.4 \mu \text{N} \hat{i}
\]
An electric dipole consists of two charges \( +q \) and \( -q \) separated by a very small distance \( 2a \). Its center is on the \( x \) axis at \( x = x_1 \), and it points along the \( x \) axis in the positive \( x \) direction. The dipole is in a nonuniform electric field, which is also in the \( x \) direction, given by \( \mathbf{E} = Cx \hat{\mathbf{x}} \), where \( C \) is a constant. (a) Find the force on the positive charge and that on the negative charge, and show that the net force on the dipole is \( Cpi \). (b) Show that, in general, if a dipole of moment \( \vec{p} \) lies along the \( x \) axis in an electric field in the \( x \) direction, the net force on the dipole is given approximately by \( (dE_x/dx)p \).

\[
\begin{align*}
\vec{F}_+ &= q \vec{E}(x_1+a) = q C (x_1+a) \hat{\mathbf{x}} \\
\vec{F}_- &= -q \vec{E}(x_1-a) = -q C (x_1-a) \hat{\mathbf{x}} \\
\vec{F}_{tot} &= \vec{F}_+ + \vec{F}_- = 2aq C \hat{\mathbf{x}} = C p \hat{\mathbf{x}} = \vec{F}_p \\
b) \quad \vec{F}_+ &= q \vec{E}(x+a) \\
\vec{F}_- &= -q \vec{E}(x-a) \\
F_{tot} &= q \left( \vec{E}(x+a) - \vec{E}(x-a) \right) \\
&= 2aq \frac{E_x(x+a) - E_x(x-a)}{2a} \hat{\mathbf{x}} \\
&\approx p \frac{dE_x}{dx} \hat{\mathbf{x}} \\
&\text{multiply by } 2a, \quad \frac{dE_x}{dx} a \to 0
\end{align*}
\]

Two charges \( q_1 \) and \( q_2 \) have a total charge of 6 \( \mu \text{C} \). When they are separated by 3 m, the force exerted by one charge on the other has a magnitude of 8 mN. Find \( q_1 \) and \( q_2 \) if (a) both are positive so that they repel each other, and (b) one is positive and the other is negative so that they attract each other.

\[\begin{align*}
q_1 + q_2 &= Q_0 \\
q_2 &= Q_0 - q_1 \\
\frac{k q_1 q_2}{r^2} &= F = \frac{k q_1 (Q_0 - q_1)}{r^2} \\
Fr^2 &= k q_1 Q_0 - k q_1^2 \\
q_1^2 - Q_0 q_1 + \frac{Fr^2}{k} &= 0 \quad \text{Eqn} \\
q_1 &= \frac{Q_0}{2} \pm \sqrt{\left(\frac{Q_0}{2}\right)^2 - \frac{Fr^2}{k}}
\end{align*}\]

\[\begin{align*}
a) \quad q_1 \neq q_2 \text{ both positive} \\
F &= +8 \text{ mN} \\
Q_0 &= 6 \mu \text{C} \\
Fr^2 &= \frac{8 \times 10^{-3} \text{N} \cdot \text{m}^2}{k} \\
&= \frac{9 \times 10^{-9} \text{N} \cdot \text{m} \cdot \text{C}^2}{k} \\
q_1 &= 3 \mu \text{C} + \sqrt{9 (\mu \text{C})^2 - 8 (\mu \text{C})^2} \\
q_1 &= 4 \mu \text{C} \\
q_2 &= 2 \mu \text{C} \\
b) \quad F \to -F \\
q_1 &= 3 \mu \text{C} + \sqrt{(3 \mu \text{C})^2 + 8 (\mu \text{C})^2} \\
q_1 &= (3 + \sqrt{17}) \mu \text{C} \\
q_2 &= (3 - \sqrt{17}) \mu \text{C}
\end{align*}\]
(a) \[ \vec{F_e} = -q_e \vec{E} = 1.6 \times 10^{-19} \text{C} \times 150 \text{N/C} \hat{J} = 2.4 \times 10^{-17} \text{N} \]

\[ \vec{F_{qv}} = -m_q \vec{g} \hat{J} = -9.1 \times 10^{-31} \text{kg} \times 9.8 \text{m/s}^2 \hat{J} = -8.9 \times 10^{-31} \text{N} \]

Electric force is much bigger

b) \[ \vec{F_{elec}} = \vec{Q} \cdot \vec{E} = -150 \text{N/C} \cdot \vec{Q} \hat{J} \]

\[ \vec{F_q} = m_q \vec{g} = -0.003 \text{kg} \times 9.8 \text{m/s}^2 \hat{J} = -2.9 \times 10^{-2} \text{N} \hat{J} \]

\[ \vec{F_{elec}} + \vec{F_q} = 0 = (-150 \text{N/C} \cdot \vec{Q} - 2.9 \times 10^{-2} \text{N}) \hat{J} \]

\[ 150 \text{N/C} \cdot \vec{Q} = -2.9 \times 10^{-2} \text{N} \Rightarrow \vec{Q} = \frac{-2.9 \times 10^{-2} \text{N}}{150 \text{N/C}} = -0.0002 \text{C} \]

An electron moves in a circular orbit about a stationary proton. The centripetal force is provided by the electrostatic force of attraction between the proton and the electron. The electron has a kinetic energy of \( 2.18 \times 10^{-18} \text{J} \). (a) What is the speed of the electron? (b) What is the radius of the orbit of the electron?

a) \[ KE = \frac{1}{2} m v^2 = 2.18 \times 10^{-18} \text{J} \]

\[ v^2 = \frac{2 KE}{m} = \frac{4.36 \times 10^{-18} \text{J}}{9.1 \times 10^{-31} \text{kg}} = 4.8 \times 10^1 \text{m/s}^2 \]

\[ v = 2.19 \times 10^6 \text{m/s} \]

b) \[ F = k \frac{q_e q_p}{r^2} = m a_c = \frac{m v^2}{r} = \frac{2 KE}{r} \Rightarrow r = \frac{k q_e q_p}{2 KE} = \frac{9.0 \times 10^9 \text{Nm}^2/(1.6 \times 10^{-19})}{4.36 \times 10^{-18} \text{J}} \]

\[ r = 5.3 \times 10^{-11} \text{m} \]