1. **21-2:**
   
   Current \( I = 20,000 \text{ C/s} \) and \( t = 100 \mu s = 10^{-4} \text{ s} \)
   
   \( Q = It = 2.00 \text{ C} \) 
   
   \[ n_e = \frac{Q}{1.60 \times 10^{-19} \text{ C}} = 1.25 \times 10^{19}. \]

2. **21-5:**
   
   \( 1.80 \text{ mol} = 1.80 \times 6.02 \times 10^{23} \text{ H atoms} = 1.08 \times 10^{24} \text{ electrons.} \)
   
   Charge \( = -1.08 \times 10^{24} \times 1.60 \times 10^{-19} \text{ C} = -1.73 \times 10^5 \text{ C}. \)

3. **21-7:**
   
   a) Using Coulomb’s Law for equal charges, we find:
   
   \( F = 0.220 \text{ N} = \frac{1}{4\pi\epsilon_0} \frac{q^2}{(0.150 \text{ m})^2} \Rightarrow q = \sqrt{5.5 \times 10^{-13} \text{ C}^2} = 7.42 \times 10^{-7} \text{ C}. \)
   
   b) When one charge is four times the other, we have:
   
   \( F = 0.220 \text{ N} = \frac{1}{4\pi\epsilon_0} \frac{4q^2}{(0.150 \text{ m})^2} \Rightarrow q = \sqrt{1.375 \times 10^{-13} \text{ C}^2} = 3.71 \times 10^{-7} \text{ C}. \)
   
   So one charge is \( 3.71 \times 10^{-7} \text{ C} \), and the other is \( 1.484 \times 10^{-6} \text{ C}. \)

4. **21-14:**
   
   We only need the \( y \)-components, and each charge contributes equally.
   
   \[ F = \frac{1}{4\pi\epsilon_0} \frac{(2.0 \times 10^{-6} \text{ C})(4 \times 10^{-6} \text{ C})}{(0.500 \text{ m})^2} \sin \alpha = 0.173 \text{ N} \) (since \( \sin \alpha = 0.6). \)
   
   Therefore, the total force is \( 2F = 0.35 \text{ N} \), downward.

5. **21-20:**
   
   \( \vec{F} = \vec{F}_1 + \vec{F}_2 \) and \( F = F_1 - F_2 \) since they are acting in opposite directions at \( x = 0 \), so,
   
   \[ F = \frac{1}{4\pi\epsilon_0} (6.00 \times 10^{-9} \text{ C}) \left( \frac{4.00 \times 10^{-9} \text{ C}}{(0.200 \text{ m})^2} + \frac{5.00 \times 10^{-9} \text{ C}}{(0.300 \text{ m})^2} \right) = 2.4 \times 10^{-6} \text{ N to the right}. \]
6. 21-21:

a) 

\[ F_x = 0, \quad F_y = 2 \frac{1}{4\pi \varepsilon_0} \frac{qQ}{(a^2 + x^2)} \sin \theta \frac{1}{4\pi \varepsilon_0} \frac{2qQa}{(a^2 + x^2)^{3/2}} \]

b) At \( x = 0 \), \( F_y = \frac{1}{4\pi \varepsilon_0} \frac{2qQ}{a^2} \) in the +y direction.

d) 

\[ \theta \quad \text{---} \quad x \]

\[ -Q \]

7. 21-26:

(a) \( x = \frac{1}{2} at^2 \)

\[ a = \frac{2x}{t^2} = \frac{2(4.50 \text{ m})}{(3.00 \times 10^{-6} \text{ s})^2} = 1.00 \times 10^{12} \text{ m/s}^2 \]

\[ E = \frac{F}{q} = \frac{ma}{q} = \frac{(9.11 \times 10^{-31} \text{ kg})(1.00 \times 10^{12} \text{ m/s}^2)}{1.6 \times 10^{-19} \text{ C}} \]

\[ = 5.69 \text{ N/C} \]

The force is up, so the electric field must be downward since the electron is negative.

(b) The electron’s acceleration is \( \sim 10^{11} \) g, so gravity must be negligibly small compared to the electrical force.
8. **21-32:**

a) \( \vec{E}_1 = \frac{q_1}{4\pi \varepsilon_0 r_1^2} \hat{j} = \frac{(9 \times 10^9 \text{ N} \cdot \text{m}^2 / \text{C}^2) \times (-5.00 \times 10^{-9} \text{ C})}{(0.0400 \text{ m})^2} = (-2.813 \times 10^4 \text{ N/C}) \hat{j} \)

\[ |\vec{E}_2| = \frac{q_2}{r_2^2} = \frac{(9 \times 10^9 \text{ N} \cdot \text{m}^2 / \text{C}^2) \times (3.00 \times 10^{-9} \text{ C})}{(0.0300 \text{ m})^2 + (0.0400 \text{ m})^2} = 1.08 \times 10^4 \text{ N/C} \]

The angle of \( \vec{E}_2 \), measured from the x-axis is \( 180 - \tan^{-1}(\frac{4.00 \text{ cm}}{3.00 \text{ cm}}) = 126.9^\circ \). Thus

\[ \vec{E}_2 = (1.080 \times 10^4 \text{ N/C}) (\hat{i} \cos 126.9^\circ + \hat{j} \sin 126.9^\circ) = (-6.485 \times 10^3 \text{ N/C}) \hat{i} + (8.64 \times 10^3 \text{ N/C}) \hat{j} \]

b) The resultant field is

\[ \vec{E}_1 + \vec{E}_2 = (-6.485 \times 10^3 \text{ N/C}) \hat{i} + (-2.813 \times 10^4 \text{ N/C} + 8.64 \times 10^3 \text{ N/C}) \hat{j} = (-6.485 \times 10^3 \text{ N/C}) \hat{i} - (1.95 \times 10^4 \text{ N/C}) \hat{j} \]

9. **21-37:**

a) \( \tan^{-1} \left( \frac{-1.35}{0} \right) = -\frac{\pi}{2}, \hat{r} - \hat{j} \)

b) \( \tan^{-1} \left( \frac{12}{2} \right) = \frac{\pi}{4}, \hat{r} = \frac{\sqrt{2}}{2} \hat{i} + \frac{\sqrt{2}}{2} \hat{j} \)

c) \( \tan^{-1} \left( \frac{2.6}{1.10} \right) = 1.97 \text{ radians} = 112.9^\circ, \hat{r} = -0.39 \hat{i} + 0.92 \hat{j} \) (Second quadrant).

10. **21-44:**

A positive and negative charge, of equal magnitude \( q \), are on the x-axis, a distance \( a \) from the origin.

a) Halfway between them, \( \vec{E} = \frac{1}{4\pi \varepsilon_0} \frac{2q}{a^2} \), to the left.
b) At any position \( x \), \( E = \begin{cases} 
\frac{1}{4\pi\varepsilon_0} \left( -\frac{q}{(a + x)^2} - \frac{q}{(a - x)^2} \right), & |x| < a \\
\frac{1}{4\pi\varepsilon_0} \left( -\frac{q}{(a + x)^2} + \frac{q}{(a - x)^2} \right), & x > a \\
\frac{1}{4\pi\varepsilon_0} \left( -\frac{q}{(a + x)^2} - \frac{q}{(a - x)^2} \right), & x < -a 
\end{cases} \)

with "+" to the right. This is graphed below.

11. **21-46:**

Calculate in vector form the electric field for each charge, and add them.

\[
\vec{E}_- = -\frac{1}{4\pi\varepsilon_0} \left( 6.00 \times 10^{-9} \text{ C} \right) \frac{1}{(0.6 \text{ m})^2} \hat{i} = -150 \hat{i} \text{ N/C}
\]

\[
\vec{E}_+ = -\frac{1}{4\pi\varepsilon_0} \left( 4.00 \times 10^{-9} \text{ C} \right) \left( \frac{1}{(1.00 \text{ m})^2} (0.6) \hat{i} + \frac{1}{(1.00 \text{ m})^2} (0.8) \hat{j} \right) = 21.6 \hat{i} + 28.8 \hat{j} \text{ N/C}
\]

\( \Rightarrow E = \sqrt{(128.4)^2 + (28.8)^2} = 131.6 \text{ N/C} \), at \( \theta = \tan^{-1} \left( \frac{28.8}{128.4} \right) = 12.6^\circ \) up from \(-x\) axis.

12. **21-54:**

By superposition we can add the electric fields from two parallel sheets of charge.

a) \( E = 0 \).

b) \( E = 0 \).

c) \( E = 2 \frac{\sigma}{2\varepsilon_0} = \frac{\sigma}{\varepsilon_0} \), directing downward.
13. 21-59:

a) \( p = qd \Rightarrow (4.5 \times 10^{-9} \text{ C})(0.0031 \text{ m}) = 1.4 \times 10^{-11} \text{ C} \cdot \text{m} \), in the direction from and towards \( q_2 \).

b) If \( \vec{E} \) is at 36.9°, and the torque \( \tau = pE \sin \phi \), then:
\[
E = \frac{\tau}{p \sin \phi} = \frac{7.2 \times 10^{-9} \text{ N} \cdot \text{m}}{(1.4 \times 10^{-11} \text{ C} \cdot \text{m}) \sin 36.9^\circ} = 856.5 \text{ N} / \text{C}.
\]

14. 21-82:

First, the mass of the drop:
\[
m = \rho V = (1000 \text{ kg} / \text{m}^3) \left( \frac{4\pi(15.0 \times 10^{-6} \text{ m})^3}{3} \right) = 1.41 \times 10^{-11} \text{ kg}.
\]
Next, the time of flight: \( t = D / v = 0.02 / 20 = 0.00100 \text{ s} \) and the acceleration:
\[
d = \frac{1}{2} a t^2 \Rightarrow a = \frac{2d}{t^2} = \frac{2(3.00 \times 10^{-4} \text{ m})}{(0.001 \text{ s})^2} = 600 \text{ m} / \text{s}^2.
\]
So,
\[
a = F / m = qE / m \Rightarrow q = ma / E = \frac{(1.41 \times 10^{-11} \text{ kg})(600 \text{ m} / \text{s}^2)}{8.00 \times 10^4 \text{ N} / \text{C}} = 1.06 \times 10^{-13} \text{ C}.
\]

15. 21-87:

a) \( dE = \frac{k dq}{(x^2 + y^2)^{3/2}} = \frac{kQ dy}{a(x^2 + y^2)} \) with \( dE_x = \frac{kQx dy}{a(x^2 + y^2)^{3/2}} \) and \( dE_y = \frac{-kQy dx}{a(x^2 + y^2)^{3/2}} \). Thus:
\[
E_x = \frac{1}{4\pi \epsilon_0} \frac{Qx}{a} \int_0^y \frac{dy}{(x^2 + y^2)^{3/2}} = \frac{1}{4\pi \epsilon_0} \frac{Qx}{a} \left[ -\frac{1}{x^2 + a^2} \right] = \frac{1}{4\pi \epsilon_0} \frac{Q}{x(x^2 + a^2)^{1/2}}
\]
\[
E_y = -\frac{1}{4\pi \epsilon_0} \frac{Q}{a} \int_0^y \frac{dx}{(x^2 + y^2)^{3/2}} = -\frac{1}{4\pi \epsilon_0} \frac{Q}{a} \left[ 1 - \frac{1}{x^2 + a^2} \right] = \frac{1}{4\pi \epsilon_0} \frac{Q}{x(x^2 + a^2)^{1/2}}
\]

b) \( F_x = -qE_x \) and \( F_y = -qE_y \) where \( E_x \) and \( E_y \) are given in (a).

c) For \( x \gg a, F_y = \frac{1}{4\pi \epsilon_0} \frac{qQ}{ax} (1 - (1 + a^2 / x^2)^{-1/2}) \approx \frac{1}{4\pi \epsilon_0} \frac{qQ}{ax} \frac{a^2}{2x^2} = \frac{1}{4\pi \epsilon_0} \frac{qQa}{2x^3} \).

Looks dipole-like in \( y \)-direction \( F_x = -\frac{1}{4\pi \epsilon_0} \frac{qQ}{x^2} \left( 1 + \frac{a^2}{x^2} \right)^{-1/2} \approx \frac{qQ}{4\pi \epsilon_0 x^2} \).

Looks point-like along \( x \)-direction.
16. 21-98:

a) $E_x = E_y$, and $E_x = 2E_{\text{length of wire}}$, charge $Q = 2\frac{1}{4\pi \varepsilon_0} \frac{Q}{x\sqrt{x^2 + (\frac{a}{2})^2}}$, where

$$x = \frac{a}{2} \Rightarrow E_x = -\frac{\sqrt{2}Q}{\pi \varepsilon_0 a^2}, \quad E_y = -\frac{\sqrt{2}Q}{\pi \varepsilon_0 a^2}.$$ 

b) If all edges of the square had equal charge, the electric fields would cancel by symmetry at the center of the square.