E1. Previous Unit Exam 1

Gerhard Müller
University of Rhode Island, gmuller@uri.edu

Abstract
Previous unit exams of course materials for Elementary Physics II (PHY 204), taught by Gerhard Müller at the University of Rhode Island. Documents will be updated periodically as more entries become presentable.

Some of the slides contain figures from the textbook, Paul A. Tipler and Gene Mosca. Physics for Scientists and Engineers, 5th/6th editions. The copyright to these figures is owned by W.H. Freeman. We acknowledge permission from W.H. Freeman to use them on this course web page. The textbook figures are not to be used or copied for any purpose outside this class without direct permission from W.H. Freeman.

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The electric field $\vec{E}$ generated by the two point charges, 3nC and $q_1$ (unknown), has the direction shown.

(a) Find the magnitude of $\vec{E}$.

(b) Find the value of $q_1$. 
The electric field $\vec{E}$ generated by the two point charges, 3nC and $q_1$ (unknown), has the direction shown.

(a) Find the magnitude of $\vec{E}$.
(b) Find the value of $q_1$.

Solution:

(a) 
\[ E_y = k \frac{3\text{nC}}{(2\text{m})^2} = 6.75\text{N/C}, \]
\[ E_x = E_y, \]
\[ E = \sqrt{E_x^2 + E_y^2} = 9.55\text{N/C}. \]
The electric field $\vec{E}$ generated by the two point charges, $3\text{nC}$ and $q_1$ (unknown), has the direction shown.

(a) Find the magnitude of $\vec{E}$.
(b) Find the value of $q_1$.

Solution:

(a) $E_y = k \frac{3\text{nC}}{(2\text{m})^2} = 6.75\text{N/C}$, 
$E_x = E_y$, 
$E = \sqrt{E_x^2 + E_y^2} = 9.55\text{N/C}$.

(b) $E_x = k \frac{(-q_1)}{(4\text{m})^2}$,
$q_1 = -\frac{(6.75\text{N/C})(16\text{m}^2)}{k} = -12\text{nC}$. 

\[ \text{Diagram:} \] 

\[ \text{3nC} \] 
\[ \text{4m} \] 
\[ \text{2m} \] 
\[ \text{45°} \] 
\[ \text{E} \] 
\[ \text{x} \] 
\[ \text{q}_1 \]
Consider a point charge $Q = 5\text{nC}$ fixed at position $x = 0$.

(a) Find the electric potential $V_1$ at position $x_1 = 3\text{m}$ and the electric potential $V_2$ at position $x_2 = 6\text{m}$.

(b) If a charged particle ($q = 4\text{nC}, m = 1.5\text{ng}$) is released from rest at $x_1$, what are its kinetic energy $K_2$ and its velocity $v_2$ when it reaches position $x_2$?

\[
Q = 5\text{nC}
\]

\[
\begin{aligned}
x &= 0 \\
x_1 &= 3\text{m} \\
x_2 &= 6\text{m}
\end{aligned}
\]
Consider a point charge $Q = 5 \text{nC}$ fixed at position $x = 0$.

(a) Find the electric potential $V_1$ at position $x_1 = 3 \text{m}$ and the electric potential $V_2$ at position $x_2 = 6 \text{m}$.

(b) If a charged particle ($q = 4 \text{nC}$, $m = 1.5 \text{ng}$) is released from rest at $x_1$, what are its kinetic energy $K_2$ and its velocity $v_2$ when it reaches position $x_2$?

Solution:

(a) $V_1 = k \frac{Q}{x_1} = 15 \text{V}$, $V_2 = k \frac{Q}{x_2} = 7.5 \text{V}$. 

\[ Q = 5 \text{nC} \]

\[ + \]

\[ x = 0 \quad x_1 = 3 \text{m} \quad x_2 = 6 \text{m} \]
Consider a point charge \( Q = 5 \text{nC} \) fixed at position \( x = 0 \).

(a) Find the electric potential \( V_1 \) at position \( x_1 = 3 \text{ m} \) and the electric potential \( V_2 \) at position \( x_2 = 6 \text{ m} \).

(b) If a charged particle \((q = 4 \text{nC}, \ m = 1.5 \text{ng})\) is released from rest at \( x_1 \), what are its kinetic energy \( K_2 \) and its velocity \( v_2 \) when it reaches position \( x_2 \)?

\[
Q = 5 \text{nC} \\
\text{(a) } V_1 = k \frac{Q}{x_1} = 15 \text{V}, \quad V_2 = k \frac{Q}{x_2} = 7.5 \text{V}.
\]

\[
\text{(b) } \Delta U = q(V_2 - V_1) = (4 \text{nC})(-7.5 \text{V}) = -30 \text{nJ} \quad \Rightarrow \quad \Delta K = -\Delta U = 30 \text{nJ}.
\]

\[
\Delta K = K_2 = \frac{1}{2} mv_2^2 \quad \Rightarrow \quad v_2 = \sqrt{\frac{2K_2}{m}} = 200 \text{m/s}.
\]
Consider two plane surfaces with area vectors $\vec{A}_1$ (pointing in positive $x$-direction) and $\vec{A}_2$ (pointing in positive $z$-direction). The region is filled with a uniform electric field $\vec{E} = (2\hat{i} + 7\hat{j} - 3\hat{k}) \text{N/C}$.

(a) Find the electric flux $\Phi_{E}^{(1)}$ through area $A_1$.

(b) Find the electric flux $\Phi_{E}^{(2)}$ through area $A_2$. 
Consider two plane surfaces with area vectors $\vec{A}_1$ (pointing in positive $x$-direction) and $\vec{A}_2$ (pointing in positive $z$-direction). The region is filled with a uniform electric field $\vec{E} = (2\hat{i} + 7\hat{j} - 3\hat{k}) \text{N/C}$.

(a) Find the electric flux $\Phi^{(1)}_E$ through area $A_1$.

(b) Find the electric flux $\Phi^{(2)}_E$ through area $A_2$.

Solution:

(a) $\vec{A}_1 = 6\hat{i} \text{ m}^2$,

$\Phi^{(1)}_E = \vec{E} \cdot \vec{A}_1 = (2 \text{N/C})(6 \text{m}^2) = 12 \text{Nm}^2/\text{C}$.
Consider two plane surfaces with area vectors $\vec{A}_1$ (pointing in positive $x$-direction) and $\vec{A}_2$ (pointing in positive $z$-direction). The region is filled with a uniform electric field $\vec{E} = (2\hat{i} + 7\hat{j} - 3\hat{k}) \text{N/C}$.

(a) Find the electric flux $\Phi_E^{(1)}$ through area $A_1$.

(b) Find the electric flux $\Phi_E^{(2)}$ through area $A_2$.

Solution:

(a) $\vec{A}_1 = 6\hat{i} \text{ m}^2$,
$$\Phi_E^{(1)} = \vec{E} \cdot \vec{A}_1 = (2 \text{N/C})(6 \text{m}^2) = 12 \text{Nm}^2/\text{C}.$$

(b) $\vec{A}_2 = 12\hat{k} \text{ m}^2$,
$$\Phi_E^{(2)} = \vec{E} \cdot \vec{A}_2 = (-3 \text{N/C})(12 \text{m}^2) = -36 \text{Nm}^2/\text{C}.$$
Consider two concentric conducting spherical shells. The total electric charge on the inner shell is $4 \text{C}$ and the total electric charge on the outer shell is $-3 \text{C}$. Find the electric charges $q_1, q_2, q_3, q_4$ on each surface of both shells as identified in the figure.
Consider two concentric conducting spherical shells. The total electric charge on the inner shell is $4\, \text{C}$ and the total electric charge on the outer shell is $-3\, \text{C}$. Find the electric charges $q_1, q_2, q_3, q_4$ on each surface of both shells as identified in the figure.

**Solution:**

Start with the innermost surface. Note that any excess charge is located at the surface of a conductor. Note also that the electric field inside a conductor at equilibrium vanishes.
Consider two concentric conducting spherical shells. The total electric charge on the inner shell is $4\text{C}$ and the total electric charge on the outer shell is $-3\text{C}$. Find the electric charges $q_1$, $q_2$, $q_3$, $q_4$ on each surface of both shells as identified in the figure.

**Solution:**

Start with the innermost surface. Note that any excess charge is located at the surface of a conductor. Note also that the electric field inside a conductor at equilibrium vanishes.

- Gauss’s law predicts $q_4 = 0$. 
Consider two concentric conducting spherical shells. The total electric charge on the inner shell is 4C and the total electric charge on the outer shell is −3C. Find the electric charges $q_1, q_2, q_3, q_4$ on each surface of both shells as identified in the figure.

Solution:

Start with the innermost surface. Note that any excess charge is located at the surface of a conductor. Note also that the electric field inside a conductor at equilibrium vanishes.

- Gauss’s law predicts $q_4 = 0$.
- Charge conservation then predicts $q_3 + q_4 = 4C$. Hence $q_3 = 4C$. 
Consider two concentric conducting spherical shells. The total electric charge on the inner shell is $4C$ and the total electric charge on the outer shell is $-3C$. Find the electric charges $q_1, q_2, q_3, q_4$ on each surface of both shells as identified in the figure.

Solution:

Start with the innermost surface. Note that any excess charge is located at the surface of a conductor. Note also that the electric field inside a conductor at equilibrium vanishes.

- Gauss’s law predicts $q_4 = 0$.
- Charge conservation then predicts $q_3 + q_4 = 4C$. Hence $q_3 = 4C$.
- Gauss’s law predicts $q_2 = -(q_3 + q_4) = -4C$. 

Consider two concentric conducting spherical shells. The total electric charge on the inner shell is 4C and the total electric charge on the outer shell is $-3C$. Find the electric charges $q_1, q_2, q_3, q_4$ on each surface of both shells as identified in the figure.

**Solution:**

Start with the innermost surface. Note that any excess charge is located at the surface of a conductor. Note also that the electric field inside a conductor at equilibrium vanishes.

- Gauss’s law predicts $q_4 = 0$.
- Charge conservation then predicts $q_3 + q_4 = 4C$. Hence $q_3 = 4C$.
- Gauss’s law predicts $q_2 = -(q_3 + q_4) = -4C$.
- Charge conservation then predicts $q_1 + q_2 = -3C$. Hence $q_1 = +1C$. 
Consider a point charge $q = +8\text{nC}$ at position $x = 4\text{m}$, $y = 0$ as shown.

(a) Find the electric field components $E_x$ and $E_y$ at point $P_1$.
(b) Find the electric field components $E_x$ and $E_y$ at point $P_2$.
(c) Find the electric potential $V$ at point $P_3$.
(d) Find the electric potential $V$ at point $P_2$. 
Consider a point charge \( q = +8 \text{nC} \) at position \( x = 4 \text{m}, y = 0 \) as shown.

(a) Find the electric field components \( E_x \) and \( E_y \) at point \( P_1 \).

(b) Find the electric field components \( E_x \) and \( E_y \) at point \( P_2 \).

(c) Find the electric potential \( V \) at point \( P_3 \).

(d) Find the electric potential \( V \) at point \( P_2 \).

Solution:

(a) \( E_x = 0 \), \( E_y = \frac{k \times 8 \text{nC}}{(3 \text{m})^2} = 7.99 \text{N/C} \).
Consider a point charge $q = +8 \text{nC}$ at position $x = 4 \text{m}, y = 0$ as shown.

(a) Find the electric field components $E_x$ and $E_y$ at point $P_1$.
(b) Find the electric field components $E_x$ and $E_y$ at point $P_2$.
(c) Find the electric potential $V$ at point $P_3$.
(d) Find the electric potential $V$ at point $P_2$.

Solution:

(a) $E_x = 0$, $E_y = k \frac{8 \text{nC}}{(3 \text{m})^2} = 7.99 \text{N/C}$.
(b) $E_x = -k \frac{8 \text{nC}}{(5 \text{m})^2} \cos \theta = -2.88 \text{N/C} \times \frac{4}{5} = -2.30 \text{N/C}$. 
$E_y = k \frac{8 \text{nC}}{(5 \text{m})^2} \sin \theta = 2.88 \text{N/C} \times \frac{3}{5} = 1.73 \text{N/C}$. 
Consider a point charge \( q = +8 \text{nC} \) at position \( x = 4 \text{m}, \ y = 0 \) as shown.

(a) Find the electric field components \( E_x \) and \( E_y \) at point \( P_1 \).
(b) Find the electric field components \( E_x \) and \( E_y \) at point \( P_2 \).
(c) Find the electric potential \( V \) at point \( P_3 \).
(d) Find the electric potential \( V \) at point \( P_2 \).

Solution:

(a) \( E_x = 0 \), \( E_y = k \frac{8 \text{nC}}{(3 \text{m})^2} = 7.99 \text{N/C} \).

(b) \( E_x = -k \frac{8 \text{nC}}{(5 \text{m})^2} \cos \theta = -2.88 \text{N/C} \times \frac{4}{5} = -2.30 \text{N/C} \).

\[ E_y = k \frac{8 \text{nC}}{(5 \text{m})^2} \sin \theta = 2.88 \text{N/C} \times \frac{3}{5} = 1.73 \text{N/C}. \]

(c) \( V = k \frac{8 \text{nC}}{4 \text{m}} = 17.98 \text{V} \).
Consider a point charge $q = +8\text{nC}$ at position $x = 4\text{m}$, $y = 0$ as shown.

(a) Find the electric field components $E_x$ and $E_y$ at point $P_1$.
(b) Find the electric field components $E_x$ and $E_y$ at point $P_2$.
(c) Find the electric potential $V$ at point $P_3$.
(d) Find the electric potential $V$ at point $P_2$.

**Solution:**

(a) $E_x = 0$, $E_y = k \frac{8\text{nC}}{(3\text{m})^2} = 7.99\text{N/C}$.

(b) $E_x = -k \frac{8\text{nC}}{(5\text{m})^2} \cos \theta = -2.88\text{N/C} \times \frac{4}{5} = -2.30\text{N/C}$.

$E_y = k \frac{8\text{nC}}{(5\text{m})^2} \sin \theta = 2.88\text{N/C} \times \frac{3}{5} = 1.73\text{N/C}$.

(c) $V = k \frac{8\text{nC}}{4\text{m}} = 17.98\text{V}$.

(d) $V = k \frac{8\text{nC}}{5\text{m}} = 14.38\text{V}$. 
Consider a conducting sphere of radius $r_1 = 1\text{m}$ and a conducting spherical shell of inner radius $r_2 = 3\text{m}$ and outer radius $r_3 = 5\text{m}$. The charge on the inner sphere is $Q_1 = -0.6 \mu\text{C}$. The net charge on the shell is zero.

(a) Find the charge $Q_2$ on the inner surface and the charge $Q_3$ on the outer surface of the shell.

(b) Find magnitude and direction of the electric field at point $A$ between the sphere and the shell.

(c) Find magnitude and direction of the electric field at point $B$ inside the shell.

(d) Find magnitude and direction of the electric field at point $C$ outside the shell.
Consider a conducting sphere of radius \( r_1 = 1 \text{m} \) and a conducting spherical shell of inner radius \( r_2 = 3 \text{m} \) and outer radius \( r_3 = 5 \text{m} \). The charge on the inner sphere is \( Q_1 = -0.6 \mu\text{C} \). The net charge on the shell is zero.

(a) Find the charge \( Q_2 \) on the inner surface and the charge \( Q_3 \) on the outer surface of the shell.

(b) Find magnitude and direction of the electric field at point \( A \) between the sphere and the shell.

(c) Find magnitude and direction of the electric field at point \( B \) inside the shell.

(d) Find magnitude and direction of the electric field at point \( C \) outside the shell.

**Solution:**

(a) Gauss’s law implies that \( Q_2 = -Q_1 = +0.6 \mu\text{C} \). Given that \( Q_2 + Q_3 = 0 \) we infer \( Q_3 = -0.6 \mu\text{C} \).
Consider a conducting sphere of radius \( r_1 = 1\, \text{m} \) and a conducting spherical shell of inner radius \( r_2 = 3\, \text{m} \) and outer radius \( r_3 = 5\, \text{m} \). The charge on the inner sphere is \( Q_1 = -0.6\, \mu\text{C} \). The net charge on the shell is zero.

(a) Find the charge \( Q_2 \) on the inner surface and the charge \( Q_3 \) on the outer surface of the shell.

(b) Find magnitude and direction of the electric field at point \( A \) between the sphere and the shell.

(c) Find magnitude and direction of the electric field at point \( B \) inside the shell.

(d) Find magnitude and direction of the electric field at point \( C \) outside the shell.

Solution:

(a) Gauss’s law implies that \( Q_2 = -Q_1 = +0.6\, \mu\text{C} \).

Given that \( Q_2 + Q_3 = 0 \) we infer \( Q_3 = -0.6\, \mu\text{C} \).

(b) \( E_A = k \frac{0.6\, \mu\text{C}}{(2\, \text{m})^2} = 1349\, \text{N/C} \) (inward).
Consider a conducting sphere of radius $r_1 = 1\text{m}$ and a conducting spherical shell of inner radius $r_2 = 3\text{m}$ and outer radius $r_3 = 5\text{m}$. The charge on the inner sphere is $Q_1 = -0.6\mu\text{C}$. The net charge on the shell is zero.

(a) Find the charge $Q_2$ on the inner surface and the charge $Q_3$ on the outer surface of the shell.

(b) Find magnitude and direction of the electric field at point $A$ between the sphere and the shell.

(c) Find magnitude and direction of the electric field at point $B$ inside the shell.

(d) Find magnitude and direction of the electric field at point $C$ outside the shell.

Solution:

(a) Gauss’s law implies that $Q_2 = -Q_1 = +0.6\mu\text{C}$. Given that $Q_2 + Q_3 = 0$ we infer $Q_3 = -0.6\mu\text{C}$.

(b) $E_A = k \frac{0.6\mu\text{C}}{(2\text{m})^2} = 1349\text{N}/\text{C}$ (inward).

(c) $E_B = 0$ inside conductor.
Consider a conducting sphere of radius $r_1 = 1\,\text{m}$ and a conducting spherical shell of inner radius $r_2 = 3\,\text{m}$ and outer radius $r_3 = 5\,\text{m}$. The charge on the inner sphere is $Q_1 = -0.6\,\mu\text{C}$. The net charge on the shell is zero.

(a) Find the charge $Q_2$ on the inner surface and the charge $Q_3$ on the outer surface of the shell.

(b) Find magnitude and direction of the electric field at point $A$ between the sphere and the shell.

(c) Find magnitude and direction of the electric field at point $B$ inside the shell.

(d) Find magnitude and direction of the electric field at point $C$ outside the shell.

Solution:

(a) Gauss’s law implies that $Q_2 = -Q_1 = +0.6\,\mu\text{C}$.

Given that $Q_2 + Q_3 = 0$ we infer $Q_3 = -0.6\,\mu\text{C}$.

(b) $E_A = k\frac{0.6\mu\text{C}}{(2\,\text{m})^2} = 1349\,\text{N/C}$ (inward).

(c) $E_B = 0$ inside conductor.

(d) $E_C = k\frac{0.6\mu\text{C}}{(6\,\text{m})^2} = 150\,\text{N/C}$ (inward).
Interchange Exam I: Problem #3 (Spring ’06)

Consider a region of uniform electric field as shown. A charged particle is projected at time $t = 0$ with initial velocity as shown. Ignore gravity.

(a) Find the components $a_x$ and $a_y$ of the acceleration at time $t = 0$.
(b) Find the components $v_x$ and $v_y$ of the velocity at time $t = 0$.
(c) Find the components $v_x$ and $v_y$ of the velocity at time $t = 1.2s$.
(d) Find the components $x$ and $y$ of the position at time $t = 1.2s$.
Consider a region of uniform electric field as shown. A charged particle is projected at time $t = 0$ with initial velocity as shown. Ignore gravity.

(a) Find the components $a_x$ and $a_y$ of the acceleration at time $t = 0$.

(b) Find the components $v_x$ and $v_y$ of the velocity at time $t = 0$.

(c) Find the components $v_x$ and $v_y$ of the velocity at time $t = 1.2$ s.

(d) Find the components $x$ and $y$ of the position at time $t = 1.2$ s.

Solution:

(a) $a_x = \frac{q}{m} E = \frac{6 \times 10^{-3} \text{C}}{3 \times 10^{-3} \text{kg}}(5 \text{N/C}) = 10 \text{m/s}^2$, $a_y = 0$. 

$E = 5 \text{N/C}$ 

$m = 3 \text{g}$ 

$q = 6 \text{mC}$ 

$v_0 = 2 \text{m/s}$
Consider a region of uniform electric field as shown. A charged particle is projected at time $t = 0$ with initial velocity as shown. Ignore gravity.

(a) Find the components $a_x$ and $a_y$ of the acceleration at time $t = 0$.
(b) Find the components $v_x$ and $v_y$ of the velocity at time $t = 0$.
(c) Find the components $v_x$ and $v_y$ of the velocity at time $t = 1.2s$.
(d) Find the components $x$ and $y$ of the position at time $t = 1.2s$.

Solution:

(a) $a_x = \frac{q}{m} E = \frac{6 \times 10^{-3} \text{C}}{3 \times 10^{-3} \text{kg}} (5 \text{N/C}) = 10 \text{m/s}^2$, $a_y = 0$.
(b) $v_x = 0$, $v_y = v_0 = 2 \text{m/s}$. 

$q = 6 \text{mC}$

$m = 3 \text{g}$

$E = 5 \text{N/C}$

$v_0 = 2 \text{m/s}$
Consider a region of uniform electric field as shown. A charged particle is projected at time $t = 0$ with initial velocity as shown. Ignore gravity.

(a) Find the components $a_x$ and $a_y$ of the acceleration at time $t = 0$.
(b) Find the components $v_x$ and $v_y$ of the velocity at time $t = 0$.
(c) Find the components $v_x$ and $v_y$ of the velocity at time $t = 1.2$s.
(d) Find the components $x$ and $y$ of the position at time $t = 1.2$s.

Solution:

(a) $a_x = \frac{q}{m}E = \frac{6 \times 10^{-3}C}{3 \times 10^{-3}kg} (5N/C) = 10m/s^2$, $a_y = 0$.
(b) $v_x = 0$, $v_y = v_0 = 2m/s$.
(c) $v_x = a_x t = (10m/s^2)(1.2s) = 12m/s$, $v_y = v_0 = 2m/s$. 
Consider a region of uniform electric field as shown. A charged particle is projected at time $t = 0$ with initial velocity as shown. Ignore gravity.

(a) Find the components $a_x$ and $a_y$ of the acceleration at time $t = 0$.
(b) Find the components $v_x$ and $v_y$ of the velocity at time $t = 0$.
(c) Find the components $v_x$ and $v_y$ of the velocity at time $t = 1.2\text{s}$.
(d) Find the components $x$ and $y$ of the position at time $t = 1.2\text{s}$.

Solution:

(a) $a_x = \frac{q}{m}E = \frac{6 \times 10^{-3}\text{C}}{3 \times 10^{-3}\text{kg}}(5\text{N/C}) = 10\text{m/s}^2$, $a_y = 0$.
(b) $v_x = 0$, $v_y = v_0 = 2\text{m/s}$.
(c) $v_x = a_xt = (10\text{m/s}^2)(1.2\text{s}) = 12\text{m/s}$, $v_y = v_0 = 2\text{m/s}$.
(d) $x = \frac{1}{2}a_xt^2 = 0.5(10\text{m/s}^2)(1.2\text{s})^2 = 7.2\text{m}$, $y = v_yt = (2\text{m/s})(1.2\text{s}) = 2.4\text{m}$. 
Consider the configuration of two point charges as shown.

(a) Find magnitude and direction of the force $F_{21}$ exerted by $q_2$ on $q_1$.
(b) Find magnitude and direction of the electric field $E_A$ at point $P_A$.
(c) Find the electric potential $V_B$ at point $P_B$.
Consider the configuration of two point charges as shown.

(a) Find magnitude and direction of the force $F_{21}$ exerted by $q_2$ on $q_1$.

(b) Find magnitude and direction of the electric field $E_A$ at point $P_A$.

(c) Find the electric potential $V_B$ at point $P_B$.

\[ \begin{align*}
q_1 &= +3 \text{nC} \\
q_2 &= -3 \text{nC}
\end{align*} \]

Solution:

(a) \[ F_{12} = k \frac{|3 \text{nC}|^2}{(8 \text{m})^2} = 1.27 \text{nN} \quad \text{(directed right)}. \]
Consider the configuration of two point charges as shown.

(a) Find magnitude and direction of the force $F_{21}$ exerted by $q_2$ on $q_1$.
(b) Find magnitude and direction of the electric field $E_A$ at point $P_A$.
(c) Find the electric potential $V_B$ at point $P_B$.

Solution:

(a) $F_{12} = k \frac{|3nC|^2}{(8m)^2} = 1.27nN$ (directed right).

(b) $E_A = 2k \frac{|3nC|}{(4m)^2} = 3.38N/C$ (directed right).
Consider the configuration of two point charges as shown.

(a) Find magnitude and direction of the force $F_{21}$ exerted by $q_2$ on $q_1$.

(b) Find magnitude and direction of the electric field $E_A$ at point $P_A$.

(c) Find the electric potential $V_B$ at point $P_B$.

Solution:

(a) $F_{12} = k \frac{|3nC|^2}{(8m)^2} = 1.27 \text{nN}$ (directed right).

(b) $E_A = 2k \frac{|3nC|}{(4m)^2} = 3.38 \text{N/C}$ (directed right).

(c) $V_B = k \frac{(+3nC)}{12m} + k \frac{(-3nC)}{4m} = -4.50 \text{V}$. 

\[
\begin{array}{ccc}
q_1 = +3nC & P_A & q_2 = -3nC \\
\bullet & & \bullet \\
4m & 4m & 4m
\end{array}
\]
A point charge $Q_p$ is positioned at the center of a conducting spherical shell of inner radius $r_2 = 3.00\text{m}$ and outer radius $r_3 = 5.00\text{m}$. The total charge on the shell $Q_s = +7.00\text{nC}$. The electric field at point $A$ has strength $E_A = 6.75\text{N/C}$ and is pointing radially inward.

(a) Find the value of $Q_p$ (point charge).
(b) Find the charge $Q_{int}$ on the inner surface of the shell.
(c) Find the charge $Q_{ext}$ on the outer surface of the shell.
(d) Find the electric field at point $B$. 

![Diagram of a point charge $Q_p$ at the center of a conducting spherical shell with inner radius $r_2 = 3.00\text{m}$ and outer radius $r_3 = 5.00\text{m}$, and a point $A$ with electric field $E_A = 6.75\text{N/C}$ pointing radially inward.]
A point charge $Q_p$ is positioned at the center of a conducting spherical shell of inner radius $r_2 = 3.00\, \text{m}$ and outer radius $r_3 = 5.00\, \text{m}$. The total charge on the shell $Q_s = +7.00\, \text{nC}$. The electric field at point $A$ has strength $E_A = 6.75\, \text{N/C}$ and is pointing radially inward.

(a) Find the value of $Q_p$ (point charge).
(b) Find the charge $Q_{int}$ on the inner surface of the shell.
(c) Find the charge $Q_{ext}$ on the outer surface of the shell.
(d) Find the electric field at point $B$.

Solution:

(a) Gauss’s law implies that $-E_A(4\pi r_A^2) = \frac{Q_p}{\varepsilon_0}$

$\Rightarrow Q_p = -3.00\, \text{nC}$. 

\[
- E_A \left(4\pi r_A^2\right) = \frac{Q_p}{\varepsilon_0}
\]

$\Rightarrow Q_p = -3.00\, \text{nC}$. 

A point charge $Q_p$ is positioned at the center of a conducting spherical shell of inner radius $r_2 = 3.00\,\text{m}$ and outer radius $r_3 = 5.00\,\text{m}$. The total charge on the shell $Q_s = +7.00\,\text{nC}$. The electric field at point $A$ has strength $E_A = 6.75\,\text{N/C}$ and is pointing radially inward.

(a) Find the value of $Q_p$ (point charge).
(b) Find the charge $Q_{\text{int}}$ on the inner surface of the shell.
(c) Find the charge $Q_{\text{ext}}$ on the outer surface of the shell.
(d) Find the electric field at point $B$.

Solution:

(a) Gauss’s law implies that $-E_A(4\pi r_A^2) = \frac{Q_p}{\epsilon_0}$

$\Rightarrow Q_p = -3.00\,\text{nC}.$

(b) Gauss’s law implies that $Q_{\text{int}} = -Q_p = +3.00\,\text{nC}.$
A point charge $Q_p$ is positioned at the center of a conducting spherical shell of inner radius $r_2 = 3.00\text{m}$ and outer radius $r_3 = 5.00\text{m}$. The total charge on the shell $Q_s = 7.00\text{nC}$. The electric field at point $A$ has strength $E_A = 6.75\text{N/C}$ and is pointing radially inward.

(a) Find the value of $Q_p$ (point charge).
(b) Find the charge $Q_{\text{int}}$ on the inner surface of the shell.
(c) Find the charge $Q_{\text{ext}}$ on the outer surface of the shell.
(d) Find the electric field at point $B$.

Solution:

(a) Gauss’s law implies that $-E_A(4\pi r_A^2) = \frac{Q_p}{\varepsilon_0}$
   \[ \Rightarrow Q_p = -3.00\text{nC}. \]
(b) Gauss’s law implies that $Q_{\text{int}} = -Q_p = +3.00\text{nC}$.
(c) Charge conservation, $Q_{\text{int}} + Q_{\text{ext}} = Q_s = 7.00\text{nC}$, then implies that $Q_{\text{ext}} = +4.00\text{nC}$. 

Diagram:

- A point charge $Q_p$ is positioned at the center of a conducting spherical shell.
- The shell has inner radius $r_2 = 3.00\text{m}$ and outer radius $r_3 = 5.00\text{m}$.
- The total charge on the shell is $Q_s = 7.00\text{nC}$.
- The electric field at point $A$ has strength $E_A = 6.75\text{N/C}$ and points radially inward.
- Point $B$ is at a distance of 4m from the center.
- Point $A$ is at a distance of 2m from the center.
A point charge $Q_p$ is positioned at the center of a conducting spherical shell of inner radius $r_2 = 3.00\text{m}$ and outer radius $r_3 = 5.00\text{m}$. The total charge on the shell $Q_s = +7.00\text{nC}$. The electric field at point $A$ has strength $E_A = 6.75\text{N/C}$ and is pointing radially inward.

(a) Find the value of $Q_p$ (point charge).

(b) Find the charge $Q_{\text{int}}$ on the inner surface of the shell.

(c) Find the charge $Q_{\text{ext}}$ on the outer surface of the shell.

(d) Find the electric field at point $B$.

Solution:

(a) Gauss’s law implies that $-E_A (4\pi r_A^2) = \frac{Q_p}{\epsilon_0}$

$\Rightarrow Q_p = -3.00\text{nC}$.

(b) Gauss’s law implies that $Q_{\text{int}} = -Q_p = +3.00\text{nC}$.

(c) Charge conservation, $Q_{\text{int}} + Q_{\text{ext}} = Q_s = 7.00\text{nC}$, then implies that $Q_{\text{ext}} = +4.00\text{nC}$.

(d) $E_B = 0$ inside conductor.
Consider two regions of uniform electric field as shown. Charged particles of mass \( m = 2\) kg and charge \( q = 1\) C are projected at time \( t = 0\) with initial velocities as shown. Both particles will hit the screen eventually. Ignore gravity.

(a) At what time \( t_1\) does the particle in region (1) hit the screen?
(b) At what height \( y_1\) does the particle in region (1) hit the screen?
(c) At what time \( t_2\) does the particle in region (2) hit the screen?
(d) At what height \( y_2\) does the particle in region (2) hit the screen?

\[ \begin{align*}
V_0 &= 2\text{ m/s} \\
E &= 5\text{ N/C} \\
\end{align*} \]
Consider two regions of uniform electric field as shown. Charged particles of mass $m = 2\text{kg}$ and charge $q = 1\text{C}$ are projected at time $t = 0$ with initial velocities as shown. Both particles will hit the screen eventually. Ignore gravity.

(a) At what time $t_1$ does the particle in region (1) hit the screen?

(b) At what height $y_1$ does the particle in region (1) hit the screen?

(c) At what time $t_2$ does the particle in region (2) hit the screen?

(d) At what height $y_2$ does the particle in region (2) hit the screen?

**Solution:**

(a) $x_1 = \frac{1}{2}at_1^2$ with $a = \frac{q}{m}E = 2.5\text{m/s}^2$,

$x_1 = 8\text{m} \Rightarrow t_1 = 2.53\text{s}$.
Consider two regions of uniform electric field as shown. Charged particles of mass $m = 2\text{kg}$ and charge $q = 1\text{C}$ are projected at time $t = 0$ with initial velocities as shown. Both particles will hit the screen eventually. Ignore gravity.

(a) At what time $t_1$ does the particle in region (1) hit the screen?
(b) At what height $y_1$ does the particle in region (1) hit the screen?
(c) At what time $t_2$ does the particle in region (2) hit the screen?
(d) At what height $y_2$ does the particle in region (2) hit the screen?

Solution:

(a) $x_1 = \frac{1}{2} a t_1^2$ with $a = \frac{q}{m}E = 2.5\text{m/s}^2$, $x_1 = 8\text{m}$ $\Rightarrow$ $t_1 = 2.53\text{s}$.

(b) $y_1 = v_0 t_1 = 5.06\text{m}$. 

15/9/2015 [tsl361 – 10/37]
Consider two regions of uniform electric field as shown. Charged particles of mass \( m = 2 \text{kg} \) and charge \( q = 1 \text{C} \) are projected at time \( t = 0 \) with initial velocities as shown. Both particles will hit the screen eventually. Ignore gravity.

(a) At what time \( t_1 \) does the particle in region (1) hit the screen?
(b) At what height \( y_1 \) does the particle in region (1) hit the screen?
(c) At what time \( t_2 \) does the particle in region (2) hit the screen?
(d) At what height \( y_2 \) does the particle in region (2) hit the screen?

**Solution:**

(a) \( x_1 = \frac{1}{2}at_1^2 \) with \( a = \frac{qE}{m} = 2.5 \text{m/s}^2 \),
\( x_1 = 8 \text{m} \Rightarrow t_1 = 2.53 \text{s} \).

(b) \( y_1 = v_0 t_1 = 5.06 \text{m} \).

(c) \( x_2 = v_0 t_2 \Rightarrow t_2 = \frac{8 \text{m}}{2 \text{m/s}} = 4 \text{s} \).
Consider two regions of uniform electric field as shown. Charged particles of mass $m = 2\text{kg}$ and charge $q = 1\text{C}$ are projected at time $t = 0$ with initial velocities as shown. Both particles will hit the screen eventually. Ignore gravity.

(a) At what time $t_1$ does the particle in region (1) hit the screen?
(b) At what height $y_1$ does the particle in region (1) hit the screen?
(c) At what time $t_2$ does the particle in region (2) hit the screen?
(d) At what height $y_2$ does the particle in region (2) hit the screen?

Solution:

(a) $x_1 = \frac{1}{2} a t_1^2$ with $a = \frac{q}{m} E = 2.5\text{m/s}^2$, $x_1 = 8\text{m} \implies t_1 = 2.53\text{s}$.

(b) $y_1 = v_0 t_1 = 5.06\text{m}$.

(c) $x_2 = v_0 t_2 \implies t_2 = \frac{8\text{m}}{2\text{m/s}} = 4\text{s}$.

(d) $y_2 = \frac{1}{2} a t_2^2 = 20\text{m}$.
Consider two point charges positioned in the $xy$-plane as shown.

(a) Find the magnitude $F$ of the force between the two charges.
(b) Find the components $E_x$ and $E_y$ of the electric field at point $O$.
(c) Find the electric potential $V$ at point $O$.
(d) Find the potential energy $U$ of charge $q_2$ in the presence of charge $q_1$. 

Charge $q_1 = -4 \, \text{nC}$ at $O$.
Charge $q_2 = +8 \, \text{nC}$ at $4 \, \text{m}$. 

Distance $3 \, \text{m}$ along the $y$-axis.
Consider two point charges positioned in the $xy$-plane as shown.

(a) Find the magnitude $F$ of the force between the two charges.
(b) Find the components $E_x$ and $E_y$ of the electric field at point $O$.
(c) Find the electric potential $V$ at point $O$.
(d) Find the potential energy $U$ of charge $q_2$ in the presence of charge $q_1$.

**Solution:**

(a) $F = k \frac{|q_1 q_2|}{r^2} = 1.15 \times 10^{-8} \text{ N.}$
Consider two point charges positioned in the $xy$-plane as shown.

(a) Find the magnitude $F$ of the force between the two charges.
(b) Find the components $E_x$ and $E_y$ of the electric field at point $O$.
(c) Find the electric potential $V$ at point $O$.
(d) Find the potential energy $U$ of charge $q_2$ in the presence of charge $q_1$.

Solution:

(a) $F = k \frac{|q_1 q_2|}{(5m)^2} = 1.15 \times 10^{-8}$ N.

(b) $E_x = -k \frac{|q_2|}{(4m)^2} = -4.5$ N/C,

$E_y = +k \frac{|q_1|}{(3m)^2} = +4.0$ N/C.
Consider two point charges positioned in the $xy$-plane as shown.
(a) Find the magnitude $F$ of the force between the two charges.
(b) Find the components $E_x$ and $E_y$ of the electric field at point $O$.
(c) Find the electric potential $V$ at point $O$.
(d) Find the potential energy $U$ of charge $q_2$ in the presence of charge $q_1$.

**Solution:**

(a) $F = k \frac{|q_1 q_2|}{(5m)^2} = 1.15 \times 10^{-8} \text{N}$.

(b) $E_x = -k \frac{|q_2|}{(4m)^2} = -4.5 \text{ N/C}$,

$E_y = +k \frac{|q_1|}{(3m)^2} = +4.0 \text{ N/C}$.

(c) $V = k \frac{q_2}{4m} + k \frac{q_1}{3m} = 18V - 12V = 6V$. 
Consider two point charges positioned in the $xy$-plane as shown.

(a) Find the magnitude $F$ of the force between the two charges.
(b) Find the components $E_x$ and $E_y$ of the electric field at point $O$.
(c) Find the electric potential $V$ at point $O$.
(d) Find the potential energy $U$ of charge $q_2$ in the presence of charge $q_1$.

Solution:

(a) $F = k\frac{|q_1 q_2|}{(5m)^2} = 1.15 \times 10^{-8} \text{N}$.

(b) $E_x = -k\frac{|q_2|}{(4m)^2} = -4.5 \text{ N/C}$,
    
    $E_y = +k\frac{|q_1|}{(3m)^2} = +4.0 \text{ N/C}$.

(c) $V = k\frac{q_2}{4m} + k\frac{q_1}{3m} = 18\text{V} - 12\text{V} = 6\text{V}$.

(d) $U = k\frac{q_1 q_2}{5m} = -57.6\text{nJ}$.
Consider a region of uniform electric field $E_x = -5 \text{N/C}$. A charged particle (charge $Q = 2 \text{C}$, mass $m = 3 \text{kg}$) is launched from initial position $x = 0$ with velocity $v_0 = 10 \text{m/s}$ in the positive $x$-direction.

(a) Find the (negative) acceleration $a_x$ experienced by the particle.

(b) Find the time $t_s$ it takes the particle to come to a stop.

(c) Find the position $x_s$ of the particle at time $t_s$.

(d) Find the work $W$ done by the electric field to bring the particle to a stop.
Consider a region of uniform electric field $E_x = -5\text{N/C}$. A charged particle (charge $Q = 2\text{C}$, mass $m = 3\text{kg}$) is launched from initial position $x = 0$ with velocity $v_0 = 10\text{m/s}$ in the positive $x$-direction.

(a) Find the (negative) acceleration $a_x$ experienced by the particle.
(b) Find the time $t_s$ it takes the particle to come to a stop.
(c) Find the position $x_s$ of the particle at time $t_s$.
(d) Find the work $W$ done by the electric field to bring the particle to a stop.

Solution:

(a) $a_x = \frac{2\text{C}}{3\text{kg}}(-5\text{N/C}) = -3.33\text{m/s}^2$. 

(b) The time $t_s$ it takes the particle to come to a stop is found by $t_s = \frac{v_0}{a_x} = \frac{10\text{m/s}}{-3.33\text{m/s}^2} = 3\text{s}$.

(c) The position $x_s$ of the particle at time $t_s$ is $x_s = x_0 + v_0 t_s = 0 + 10\text{m/s} \times 3\text{s} = 30\text{m}$.

(d) The work $W$ done by the electric field to bring the particle to a stop is $W = qE \Delta x = 2\text{C}(-5\text{N/C}) \times 30\text{m} = -300\text{J}$. 

\[ E_x = -5\text{N/C} \]
\[ m = 3\text{kg} \]
\[ Q = 2\text{C} \]
\[ v_0 = 10\text{m/s} \]
Consider a region of uniform electric field $E_x = -5\text{N/C}$. A charged particle (charge $Q = 2\text{C}$, mass $m = 3\text{kg}$) is launched from initial position $x = 0$ with velocity $v_0 = 10\text{m/s}$ in the positive $x$-direction.

(a) Find the (negative) acceleration $a_x$ experienced by the particle.
(b) Find the time $t_s$ it takes the particle to come to a stop.
(c) Find the position $x_s$ of the particle at time $t_s$.
(d) Find the work $W$ done by the electric field to bring the particle to a stop.

**Solution:**

(a) $a_x = \frac{2\text{C}}{3\text{kg}}(-5\text{N/C}) = -3.33\text{m/s}^2$.

(b) $t_s = \frac{v_0}{a_x} = 3.00\text{s}$.
Consider a region of uniform electric field $E_x = -5\text{N/C}$. A charged particle (charge $Q = 2\text{C}$, mass $m = 3\text{kg}$) is launched from initial position $x = 0$ with velocity $v_0 = 10\text{m/s}$ in the positive $x$-direction.

(a) Find the (negative) acceleration $a_x$ experienced by the particle.
(b) Find the time $t_s$ it takes the particle to come to a stop.
(c) Find the position $x_s$ of the particle at time $t_s$.
(d) Find the work $W$ done by the electric field to bring the particle to a stop.

Solution:

(a) $a_x = \frac{2\text{C}}{3\text{kg}}(-5\text{N/C}) = -3.33\text{m/s}^2$.
(b) $t_s = \frac{v_0}{|a_x|} = 3.00\text{s}$.
(c) $x_s = \frac{v_0^2}{2|a_x|} = 15.0\text{m}$.
Consider a region of uniform electric field $E_x = -5 \text{N/C}$. A charged particle (charge $Q = 2 \text{C}$, mass $m = 3 \text{kg}$) is launched from initial position $x = 0$ with velocity $v_0 = 10 \text{m/s}$ in the positive $x$-direction.

(a) Find the (negative) acceleration $a_x$ experienced by the particle.
(b) Find the time $t_s$ it takes the particle to come to a stop.
(c) Find the position $x_s$ of the particle at time $t_s$.
(d) Find the work $W$ done by the electric field to bring the particle to a stop.

**Solution:**

(a) $a_x = \frac{2 \text{C}}{3 \text{kg}} (-5 \text{N/C}) = -3.33 \text{m/s}^2$.

(b) $t_s = \frac{v_0}{|a_x|} = 3.00 \text{s}$.

(c) $x_s = \frac{v_0^2}{2|a_x|} = 15.0 \text{m}$.

(d) $W = \Delta K = -\frac{1}{2}mv_0^2 = -150 \text{J}$.
Consider a conducting spherical shell of inner radius $r_{int} = 3\text{m}$ and outer radius $r_{ext} = 5\text{m}$. The net charge on the shell is $Q_{shell} = 7\mu\text{C}$.

(a) Find the charge $Q_{int}$ on the inner surface and the charge $Q_{ext}$ on the outer surface of the shell.

(b) Find the direction (left/right/none) of the electric field at points $A$, $B$, $C$.

Now place a point charge $Q_{point} = -3\mu\text{C}$ into the center of the shell ($r = 0\text{m}$).

(c) Find the charge $Q_{int}$ on the inner surface and the charge $Q_{ext}$ on the outer surface of the shell.

(d) Find the direction (left/right/none) of the electric field at points $A$, $B$, $C$. 
Consider a conducting spherical shell of inner radius $r_{\text{int}} = 3\, \text{m}$ and outer radius $r_{\text{ext}} = 5\, \text{m}$. The net charge on the shell is $Q_{\text{shell}} = 7\, \mu\text{C}$.

(a) Find the charge $Q_{\text{int}}$ on the inner surface and the charge $Q_{\text{ext}}$ on the outer surface of the shell.

(b) Find the direction (left/right/none) of the electric field at points $A$, $B$, $C$.

Now place a point charge $Q_{\text{point}} = -3\, \mu\text{C}$ into the center of the shell ($r = 0\, \text{m}$).

(c) Find the charge $Q_{\text{int}}$ on the inner surface and the charge $Q_{\text{ext}}$ on the outer surface of the shell.

(d) Find the direction (left/right/none) of the electric field at points $A$, $B$, $C$.

Solution:

(a) $Q_{\text{int}} = 0$, $Q_{\text{ext}} = 7\, \mu\text{C}.$
Consider a conducting spherical shell of inner radius \( r_{\text{int}} = 3 \text{ m} \) and outer radius \( r_{\text{ext}} = 5 \text{ m} \). The net charge on the shell is \( Q_{\text{shell}} = 7 \mu \text{C} \).

(a) Find the charge \( Q_{\text{int}} \) on the inner surface and the charge \( Q_{\text{ext}} \) on the outer surface of the shell.

(b) Find the direction (left/right/none) of the electric field at points \( A, B, C \).

Now place a point charge \( Q_{\text{point}} = -3 \mu \text{C} \) into the center of the shell \((r = 0 \text{ m})\).

(c) Find the charge \( Q_{\text{int}} \) on the inner surface and the charge \( Q_{\text{ext}} \) on the outer surface of the shell.

(d) Find the direction (left/right/none) of the electric field at points \( A, B, C \).

Solution:

(a) \( Q_{\text{int}} = 0 \), \( Q_{\text{ext}} = 7 \mu \text{C} \).

(b) \( A \): none, \( B \): none, \( C \): right.
Consider a conducting spherical shell of inner radius \( r_{\text{int}} = 3\, \text{m} \) and outer radius \( r_{\text{ext}} = 5\, \text{m} \). The net charge on the shell is \( Q_{\text{shell}} = 7\, \mu\text{C} \).

(a) Find the charge \( Q_{\text{int}} \) on the inner surface and the charge \( Q_{\text{ext}} \) on the outer surface of the shell.

(b) Find the direction (left/right/none) of the electric field at points \( A, B, C \).

Now place a point charge \( Q_{\text{point}} = -3\, \mu\text{C} \) into the center of the shell \( (r = 0\, \text{m}) \).

(c) Find the charge \( Q_{\text{int}} \) on the inner surface and the charge \( Q_{\text{ext}} \) on the outer surface of the shell.

(d) Find the direction (left/right/none) of the electric field at points \( A, B, C \).

Solution:

(a) \( Q_{\text{int}} = 0, \quad Q_{\text{ext}} = 7\, \mu\text{C} \).

(b) \( A \): none, \( B \): none, \( C \): right.

(c) \( Q_{\text{int}} = 3\, \mu\text{C}, \quad Q_{\text{ext}} = 4\, \mu\text{C} \).
Consider a conducting spherical shell of inner radius $r_{int} = 3$ m and outer radius $r_{ext} = 5$ m. The net charge on the shell is $Q_{shell} = 7 \mu$C.

(a) Find the charge $Q_{int}$ on the inner surface and the charge $Q_{ext}$ on the outer surface of the shell.

(b) Find the direction (left/right/none) of the electric field at points $A$, $B$, $C$.

Now place a point charge $Q_{point} = -3 \mu$C into the center of the shell ($r = 0$ m).

(c) Find the charge $Q_{int}$ on the inner surface and the charge $Q_{ext}$ on the outer surface of the shell.

(d) Find the direction (left/right/none) of the electric field at points $A$, $B$, $C$.

Solution:

(a) $Q_{int} = 0$, $Q_{ext} = 7 \mu$C.

(b) $A$: none, $B$: none, $C$: right.

(c) $Q_{int} = 3 \mu$C, $Q_{ext} = 4 \mu$C.

(d) $A$: left, $B$: none, $C$: right.
Consider two point charges positioned on the $x$-axis as shown.

(a) Find magnitude and direction of the electric field at point P.
(b) Find the electric potential at point P.
(c) Find the electric potential energy of an electron (mass $m = 9.1 \times 10^{-31}$ kg, charge $q = -1.6 \times 10^{-19}$ C) when placed at point P.
(d) Find magnitude and direction of the acceleration the electron experiences when released at point P.
Consider two point charges positioned on the $x$-axis as shown.

(a) Find magnitude and direction of the electric field at point P.

(b) Find the electric potential at point P.

(c) Find the electric potential energy of an electron (mass $m = 9.1 \times 10^{-31}$ kg, charge $q = -1.6 \times 10^{-19}$ C) when placed at point P.

(d) Find magnitude and direction of the acceleration the electron experiences when released at point P.

Solution:

(a) $E_x = +k \frac{8\text{nC}}{(4\text{m})^2} + k \frac{(-8\text{nC})}{(2\text{m})^2} = 4.5\text{N/C} - 18\text{N/C} = -13.5\text{N/C}$ (directed left).
Consider two point charges positioned on the $x$-axis as shown.
(a) Find magnitude and direction of the electric field at point P.
(b) Find the electric potential at point P.
(c) Find the electric potential energy of an electron (mass $m = 9.1 \times 10^{-31}$ kg, charge $q = -1.6 \times 10^{-19}$ C) when placed at point P.
(d) Find magnitude and direction of the acceleration the electron experiences when released at point P.

Solution:

(a) $E_x = +k \frac{8nC}{(4m)^2} + k \frac{(-8nC)}{(2m)^2} = 4.5N/C - 18N/C = -13.5N/C$ (directed left).
(b) $V = +k \frac{8nC}{4m} + k \frac{(-8nC)}{2m} = 18V - 36V = -18V.$
Consider two point charges positioned on the $x$-axis as shown.

(a) Find magnitude and direction of the electric field at point P.
(b) Find the electric potential at point P.
(c) Find the electric potential energy of an electron (mass $m = 9.1 \times 10^{-31}$ kg, charge $q = -1.6 \times 10^{-19}$ C) when placed at point P.
(d) Find magnitude and direction of the acceleration the electron experiences when released at point P.

![Diagram of two point charges](image)

**Solution:**

(a) $E_x = +k \frac{8 \text{nC}}{(4 \text{m})^2} + k \frac{(-8 \text{nC})}{(2 \text{m})^2} = 4.5 \text{N/C} - 18 \text{N/C} = -13.5 \text{N/C}$ (directed left).

(b) $V = +k \frac{8 \text{nC}}{4 \text{m}} + k \frac{(-8 \text{nC})}{2 \text{m}} = 18 \text{V} - 36 \text{V} = -18 \text{V}$.

(c) $U = qV = (-18 \text{V})(-1.6 \times 10^{-19} \text{C}) = 2.9 \times 10^{-18} \text{J}$. 
Consider two point charges positioned on the $x$-axis as shown.

(a) Find magnitude and direction of the electric field at point $P$.
(b) Find the electric potential at point $P$.
(c) Find the electric potential energy of an electron (mass $m = 9.1 \times 10^{-31}$ kg, charge $q = -1.6 \times 10^{-19}$ C) when placed at point $P$.
(d) Find magnitude and direction of the acceleration the electron experiences when released at point $P$.

Solution:

(a) $E_x = +k \frac{8\text{nC}}{(4\text{m})^2} + k \frac{(-8\text{nC})}{(2\text{m})^2} = 4.5 \text{N/C} - 18 \text{N/C} = -13.5 \text{N/C}$ (directed left).

(b) $V = +k \frac{8\text{nC}}{4\text{m}} + k \frac{(-8\text{nC})}{2\text{m}} = 18 \text{V} - 36 \text{V} = -18 \text{V}$.

(c) $U = qV = (-18 \text{V})(-1.6 \times 10^{-19} \text{C}) = 2.9 \times 10^{-18} \text{J}$.

(d) $a_x = \frac{qE_x}{m} = \frac{(-1.6 \times 10^{-19} \text{C})(-13.5 \text{N/C})}{9.1 \times 10^{-31} \text{kg}} = 2.4 \times 10^{12} \text{ms}^{-2}$ (directed right).
Consider two very large uniformly charged parallel sheets as shown. The charge densities are \( \sigma_A = +7 \times 10^{-12}\text{Cm}^{-2} \) and \( \sigma_B = -4 \times 10^{-12}\text{Cm}^{-2} \), respectively. Find magnitude and direction (left/right) of the electric fields \( E_1 \), \( E_2 \), and \( E_3 \).
Consider two very large uniformly charged parallel sheets as shown. The charge densities are 
\( \sigma_A = +7 \times 10^{-12} \text{Cm}^{-2} \) and \( \sigma_B = -4 \times 10^{-12} \text{Cm}^{-2} \), respectively. Find magnitude and direction (left/right) of the electric fields \( E_1 \), \( E_2 \), and \( E_3 \).

**Solution:**

\[
E_A = \frac{|\sigma_A|}{2\varepsilon_0} = 0.40 \text{N/C} \quad \text{(directed away from sheet A)}.
\]
Consider two very large uniformly charged parallel sheets as shown. The charge densities are \( \sigma_A = +7 \times 10^{-12} \text{Cm}^{-2} \) and \( \sigma_B = -4 \times 10^{-12} \text{Cm}^{-2} \), respectively. Find magnitude and direction (left/right) of the electric fields \( E_1 \), \( E_2 \), and \( E_3 \).

Solution:

\[
E_A = \frac{|\sigma_A|}{2\epsilon_0} = 0.40 \text{N/C} \quad \text{(directed away from sheet A)}.
\]

\[
E_B = \frac{|\sigma_B|}{2\epsilon_0} = 0.23 \text{N/C} \quad \text{(directed toward sheet B)}.
\]
Consider two very large uniformly charged parallel sheets as shown. The charge densities are
\( \sigma_A = +7 \times 10^{-12} \text{Cm}^{-2} \) and \( \sigma_B = -4 \times 10^{-12} \text{Cm}^{-2} \), respectively. Find magnitude and direction (left/right) of the electric fields \( E_1, E_2, \) and \( E_3 \).

**Solution:**

\[
E_A = \frac{|\sigma_A|}{2\epsilon_0} = 0.40 \text{N/C} \quad \text{(directed away from sheet A)}.
\]

\[
E_B = \frac{|\sigma_B|}{2\epsilon_0} = 0.23 \text{N/C} \quad \text{(directed toward sheet B)}.
\]

\[
E_1 = E_A - E_B = 0.17 \text{N/C} \quad \text{(directed left)}.
\]
Consider two very large uniformly charged parallel sheets as shown. The charge densities are \( \sigma_A = +7 \times 10^{-12} \text{Cm}^{-2} \) and \( \sigma_B = -4 \times 10^{-12} \text{Cm}^{-2} \), respectively. Find magnitude and direction (left/right) of the electric fields \( E_1, E_2, \) and \( E_3 \).

Solution:

\[
E_A = \frac{|\sigma_A|}{2\varepsilon_0} = 0.40 \text{N/C} \quad \text{(directed away from sheet A)}.
\]

\[
E_B = \frac{|\sigma_B|}{2\varepsilon_0} = 0.23 \text{N/C} \quad \text{(directed toward sheet B)}.
\]

\[
E_1 = E_A - E_B = 0.17 \text{N/C} \quad \text{(directed left)}.
\]

\[
E_2 = E_A + E_B = 0.63 \text{N/C} \quad \text{(directed right)}.
\]
Consider two very large uniformly charged parallel sheets as shown. The charge densities are $\sigma_A = +7 \times 10^{-12} \text{Cm}^{-2}$ and $\sigma_B = -4 \times 10^{-12} \text{Cm}^{-2}$, respectively. Find magnitude and direction (left/right) of the electric fields $E_1$, $E_2$, and $E_3$.

**Solution:**

$$E_A = \frac{|\sigma_A|}{2\varepsilon_0} = 0.40 \text{N/C} \quad \text{(directed away from sheet A)}.$$

$$E_B = \frac{|\sigma_B|}{2\varepsilon_0} = 0.23 \text{N/C} \quad \text{(directed toward sheet B)}.$$

$$E_1 = E_A - E_B = 0.17 \text{N/C} \quad \text{(directed left)}.$$

$$E_2 = E_A + E_B = 0.63 \text{N/C} \quad \text{(directed right)}.$$

$$E_2 = E_A - E_B = 0.17 \text{N/C} \quad \text{(directed right)}.$$
(a) Consider a conducting box with no net charge on it. Inside the box are two small charged conducting cubes. For the given charges on the surface of one cube and on the inside surface of the box find the charges $Q_1$ on the surface of the other cube and $Q_2$ on the outside surface of the box.

(b) Consider a conducting box with two compartments and no net charge on it. Inside one compartment is a small charged conducting cube. For the given charge on the surface of the cube find the charges $Q_3$, $Q_4$, and $Q_5$ on the three surfaces of the box.
(a) Consider a conducting box with no net charge on it. Inside the box are two small charged conducting cubes. For the given charges on the surface of one cube and on the inside surface of the box find the charges $Q_1$ on the surface of the other cube and $Q_2$ on the outside surface of the box.

(b) Consider a conducting box with two compartments and no net charge on it. Inside one compartment is a small charged conducting cube. For the given charge on the surface of the cube find the charges $Q_3$, $Q_4$, and $Q_5$ on the three surfaces of the box.

Solution:

(a) Gauss’s law implies $Q_1 + 3C + (-5C) = 0 \Rightarrow Q_1 = +2C$.

Net charge on the box: $Q_2 + (-5C) = 0 \Rightarrow Q_2 = +5C$. 

(b) [Diagram of the box with charges labeled $Q_3$, $Q_4$, and $Q_5$.]
(a) Consider a conducting box with no net charge on it. Inside the box are two small charged conducting cubes. For the given charges on the surface of one cube and on the inside surface of the box find the charges $Q_1$ on the surface of the other cube and $Q_2$ on the outside surface of the box.

(b) Consider a conducting box with two compartments and no net charge on it. Inside one compartment is a small charged conducting cube. For the given charge on the surface of the cube find the charges $Q_3$, $Q_4$, and $Q_5$ on the three surfaces of the box.

Solution:

(a) Gauss’s law implies $Q_1 + 3C + (-5C) = 0 \implies Q_1 = +2C$.
Net charge on the box: $Q_2 + (-5C) = 0 \implies Q_2 = +5C$.

(b) Gauss’s law implies $Q_3 + (-6C) = 0 \implies Q_3 = +6C$.
Gauss’s law implies $Q_4 = 0$.
Net charge on box: $Q_3 + Q_4 + Q_5 = 0 \implies Q_5 = -6C$. 
Consider two point charges positioned as shown.

(a) Find the magnitude of the electric field at point $A$.
(b) Find the electric potential at point $A$.
(c) Find the magnitude of the electric field at point $B$.
(d) Find the electric potential at point $B$. 
Consider two point charges positioned as shown.

(a) Find the magnitude of the electric field at point $A$.
(b) Find the electric potential at point $A$.
(c) Find the magnitude of the electric field at point $B$.
(d) Find the electric potential at point $B$.

Solution:

(a) $E_A = 2k \frac{|7 \text{nC}|}{(5 \text{m})^2} = 2(2.52 \text{V/m}) = 5.04 \text{V/m}$.
Consider two point charges positioned as shown.

(a) Find the magnitude of the electric field at point A.
(b) Find the electric potential at point A.
(c) Find the magnitude of the electric field at point B.
(d) Find the electric potential at point B.

Solution:

(a) \[ E_A = 2k\frac{|7\text{nC}|}{(5\text{m})^2} = 2(2.52\text{V/m}) = 5.04\text{V/m} \]

(b) \[ V_A = k\frac{(+7\text{nC})}{5\text{m}} + k\frac{(-7\text{nC})}{5\text{m}} = 12.6\text{V} - 12.6\text{V} = 0 \]
Consider two point charges positioned as shown.

(a) Find the magnitude of the electric field at point $A$.
(b) Find the electric potential at point $A$.
(c) Find the magnitude of the electric field at point $B$.
(d) Find the electric potential at point $B$.

Solution:

(a) $E_A = 2k \frac{|7nC|}{(5m)^2} = 2(2.52V/m) = 5.04V/m$.

(b) $V_A = k \frac{(7nC)}{5m} + k \frac{(-7nC)}{5m} = 12.6V - 12.6V = 0$.

(c) $E_B = \sqrt{\left( k \frac{|7nC|}{(6m)^2} \right)^2 + \left( k \frac{|7nC|}{(8m)^2} \right)^2} \Rightarrow E_B = \sqrt{(1.75V/m)^2 + (0.98V/m)^2} = 2.01V/m$. 
Consider two point charges positioned as shown.

(a) Find the magnitude of the electric field at point $A$.
(b) Find the electric potential at point $A$.
(c) Find the magnitude of the electric field at point $B$.
(d) Find the electric potential at point $B$.

Solution:

(a) $E_A = 2k \frac{|7\text{nC}|}{(5\text{m})^2} = 2(2.52\text{V/m}) = 5.04\text{V/m}$.

(b) $V_A = k \frac{(+7\text{nC})}{5\text{m}} + k \frac{(-7\text{nC})}{5\text{m}} = 12.6\text{V} - 12.6\text{V} = 0$.

(c) $E_B = \sqrt{\left(k \frac{|7\text{nC}|}{(6\text{m})^2}\right)^2 + \left(k \frac{|7\text{nC}|}{(8\text{m})^2}\right)^2} \Rightarrow E_B = \sqrt{(1.75\text{V/m})^2 + (0.98\text{V/m})^2} = 2.01\text{V/m}$.

(d) $V_B = k \frac{(+7\text{nC})}{6\text{m}} + k \frac{(-7\text{nC})}{8\text{m}} = 10.5\text{V} - 7.9\text{V} = 2.6\text{V}$.
A point charge $Q_p$ is positioned at the center of a conducting spherical shell of inner radius $r_{int} = 3\text{m}$ and outer radius $r_{ext} = 5\text{m}$. The charge on the inner surface of the shell is $Q_{int} = -4\text{nC}$ and the charge on the outer surface is $Q_{ext} = +3\text{nC}$.

(a) Find the value of the point charge $Q_p$.
(b) Find direction (up/down/none) and magnitude of the electric field at point $A$.
(c) Find direction (up/down/none) and magnitude of the electric field at point $B$.
(d) Find direction (up/down/none) and magnitude of the electric field at point $C$. [not on exam]
A point charge $Q_p$ is positioned at the center of a conducting spherical shell of inner radius $r_{int} = 3\text{m}$ and outer radius $r_{ext} = 5\text{m}$. The charge on the inner surface of the shell is $Q_{int} = -4\text{nC}$ and the charge on the outer surface is $Q_{ext} = +3\text{nC}$.

(a) Find the value of the point charge $Q_p$.

(b) Find direction (up/down/none) and magnitude of the electric field at point $A$.

(c) Find direction (up/down/none) and magnitude of the electric field at point $B$.

(d) Find direction (up/down/none) and magnitude of the electric field at point $C$. [not on exam]

Solution:

(a) $Q_p = -Q_{int} = +4\text{nC}$. 

![Diagram showing a spherical shell with charges and points A, B, and C]
A point charge $Q_p$ is positioned at the center of a conducting spherical shell of inner radius $r_{int} = 3\text{m}$ and outer radius $r_{ext} = 5\text{m}$. The charge on the inner surface of the shell is $Q_{int} = -4\text{nC}$ and the charge on the outer surface is $Q_{ext} = +3\text{nC}$.

(a) Find the value of the point charge $Q_p$.
(b) Find direction (up/down/none) and magnitude of the electric field at point $A$.
(c) Find direction (up/down/none) and magnitude of the electric field at point $B$.
(d) Find direction (up/down/none) and magnitude of the electric field at point $C$. [not on exam]

Solution:

(a) $Q_p = -Q_{int} = +4\text{nC}$.
(b) $E_A = 0$ inside conductor (no direction).
A point charge $Q_p$ is positioned at the center of a conducting spherical shell of inner radius $r_{int} = 3\text{m}$ and outer radius $r_{ext} = 5\text{m}$. The charge on the inner surface of the shell is $Q_{int} = -4nC$ and the charge on the outer surface is $Q_{ext} = +3nC$.

(a) Find the value of the point charge $Q_p$.

(b) Find direction (up/down/none) and magnitude of the electric field at point $A$.

(c) Find direction (up/down/none) and magnitude of the electric field at point $B$.

(d) Find direction (up/down/none) and magnitude of the electric field at point $C$. [not on exam]

Solution:

(a) $Q_p = -Q_{int} = +4nC$.

(b) $E_A = 0$ inside conductor (no direction).

(c) $E_B[4\pi(6m)^2] = \frac{Q_p + Q_{int} + Q_{ext}}{\epsilon_0}$

$\Rightarrow E_B = k \frac{3nC}{(6m)^2} = 0.75\text{N/C}$ (down).
A point charge \( Q_p \) is positioned at the center of a conducting spherical shell of inner radius \( r_{int} = 3\,\text{m} \) and outer radius \( r_{ext} = 5\,\text{m} \). The charge on the inner surface of the shell is \( Q_{int} = -4\,\text{nC} \) and the charge on the outer surface is \( Q_{ext} = +3\,\text{nC} \).

(a) Find the value of the point charge \( Q_p \).
(b) Find direction (up/down/none) and magnitude of the electric field at point \( A \).
(c) Find direction (up/down/none) and magnitude of the electric field at point \( B \).
(d) Find direction (up/down/none) and magnitude of the electric field at point \( C \). [not on exam]

Solution:

(a) \( Q_p = -Q_{int} = +4\,\text{nC} \).
(b) \( E_A = 0 \) inside conductor (no direction).
(c) \( E_B [4\pi(6\,\text{m})^2] = \frac{Q_p + Q_{int} + Q_{ext}}{\epsilon_0} \)
\[ \Rightarrow E_B = k \frac{3\,\text{nC}}{(6\,\text{m})^2} = 0.75\,\text{N/C} \] (down).
(d) \( E_C [4\pi(2\,\text{m})^2] = \frac{Q_p}{\epsilon_0} \Rightarrow E_C = k \frac{4\,\text{nC}}{(2\,\text{m})^2} = 9\,\text{N/C} \) (down).
An electron \((m = 9.11 \times 10^{-31} \text{kg}, q = -1.60 \times 10^{-19} \text{C})\) and a proton \((m = 1.67 \times 10^{-27} \text{kg}, q = +1.60 \times 10^{-19} \text{C})\) are released from rest midway between oppositely charged parallel plates. The plates are at the electric potentials shown.

(a) Find the magnitude of the electric field between the plates.
(b) What direction (left/right) does the electric field have?
(c) Which particle (electron/proton/both) is accelerated to the left?
(d) Why does the electron reach the plate before the proton?
(e) Find the kinetic energy of the proton when it reaches the plate.
An electron ($m = 9.11 \times 10^{-31}$ kg, $q = -1.60 \times 10^{-19}$ C) and a proton ($m = 1.67 \times 10^{-27}$ kg, $q = +1.60 \times 10^{-19}$ C) are released from rest midway between oppositely charged parallel plates. The plates are at the electric potentials shown.

(a) Find the magnitude of the electric field between the plates.
(b) What direction (left/right) does the electric field have?
(c) Which particle (electron/proton/both) is accelerated to the left?
(d) Why does the electron reach the plate before the proton?
(e) Find the kinetic energy of the proton when it reaches the plate.

Solution:

(a) $E = \frac{6 \text{ V}}{0.2 \text{ m}} = 30 \text{ V/m}$. 
An electron ($m = 9.11 \times 10^{-31} \text{kg}, \ q = -1.60 \times 10^{-19} \text{C}$) and a proton ($m = 1.67 \times 10^{-27} \text{kg}, \ q = +1.60 \times 10^{-19} \text{C}$) are released from rest midway between oppositely charged parallel plates. The plates are at the electric potentials shown.

(a) Find the magnitude of the electric field between the plates.
(b) What direction (left/right) does the electric field have?
(c) Which particle (electron/proton/both) is accelerated to the left?
(d) Why does the electron reach the plate before the proton?
(e) Find the kinetic energy of the proton when it reaches the plate.

Solution:

(a) $E = \frac{6\text{V}}{0.2\text{m}} = 30\text{V/m}$.
(b) left
An electron \( (m = 9.11 \times 10^{-31} \text{kg}, \, q = -1.60 \times 10^{-19} \text{C}) \) and a proton \( (m = 1.67 \times 10^{-27} \text{kg}, \, q = +1.60 \times 10^{-19} \text{C}) \) are released from rest midway between oppositely charged parallel plates. The plates are at the electric potentials shown.

(a) Find the magnitude of the electric field between the plates.
(b) What direction (left/right) does the electric field have?
(c) Which particle (electron/proton/both) is accelerated to the left?
(d) Why does the electron reach the plate before the proton?
(e) Find the kinetic energy of the proton when it reaches the plate.

**Solution:**

(a) \( E = \frac{6 \text{V}}{0.2 \text{m}} = 30 \text{V/m} \).
(b) left
(c) proton (positive charge)
An electron \((m = 9.11 \times 10^{-31} \text{ kg}, q = -1.60 \times 10^{-19} \text{ C})\) and a proton \((m = 1.67 \times 10^{-27} \text{ kg}, q = +1.60 \times 10^{-19} \text{ C})\) are released from rest midway between oppositely charged parallel plates. The plates are at the electric potentials shown.

(a) Find the magnitude of the electric field between the plates.
(b) What direction (left/right) does the electric field have?
(c) Which particle (electron/proton/both) is accelerated to the left?
(d) Why does the electron reach the plate before the proton?
(e) Find the kinetic energy of the proton when it reaches the plate.

**Solution:**
(a) \(E = \frac{6 \text{ V}}{0.2 \text{ m}} = 30 \text{ V/m}\).
(b) left
(c) proton (positive charge)
(d) smaller \(m\), equal \(|q|\) ⇒ larger \(|q|E/m\)
An electron \((m = 9.11 \times 10^{-31} \text{kg}, q = -1.60 \times 10^{-19} \text{C})\) and a proton \((m = 1.67 \times 10^{-27} \text{kg}, q = +1.60 \times 10^{-19} \text{C})\) are released from rest midway between oppositely charged parallel plates. The plates are at the electric potentials shown.

(a) Find the magnitude of the electric field between the plates.

(b) What direction (left/right) does the electric field have?

(c) Which particle (electron/proton/both) is accelerated to the left?

(d) Why does the electron reach the plate before the proton?

(e) Find the kinetic energy of the proton when it reaches the plate.

**Solution:**

(a) \(E = 6 \text{V} / 0.2 \text{m} = 30 \text{V/m}\).

(b) left

(c) proton (positive charge)

(d) smaller \(m\), equal \(|q|\) \Rightarrow larger \(|q|E/m\)

(e) \(K = |q\Delta V| = (1.6 \times 10^{-19} \text{C})(3 \text{V}) = 4.8 \times 10^{-19} \text{J}\).
The point charge $Q$ has a fixed position as shown.

(a) Find the components $E_x$ and $E_y$ of the electric field at point $A$.
(b) Find the electric potential $V$ at point $A$.

Now place a proton ($m = 1.67 \times 10^{-27}\text{kg}$, $q = 1.60 \times 10^{-19}\text{C}$) at point $A$.

(c) Find the electric force $F$ (magnitude only) experienced by the proton.
(d) Find the electric potential energy $U$ of the proton.
The point charge $Q$ has a fixed position as shown.

(a) Find the components $E_x$ and $E_y$ of the electric field at point $A$.
(b) Find the electric potential $V$ at point $A$.

Now place a proton ($m = 1.67 \times 10^{-27} \text{kg}$, $q = 1.60 \times 10^{-19} \text{C}$) at point $A$.

(c) Find the electric force $F$ (magnitude only) experienced by the proton.
(d) Find the electric potential energy $U$ of the proton.

Solution:

(a) $E = k \frac{\left| 7 \text{nC} \right|}{(5 \text{m})^2} = 2.52 \text{N/C}$,

$E_x = \frac{4}{5} E = 2.02 \text{N/C}, \quad E_y = -\frac{3}{5} E = -1.51 \text{N/C}$
The point charge $Q$ has a fixed position as shown.
(a) Find the components $E_x$ and $E_y$ of the electric field at point $A$.
(b) Find the electric potential $V$ at point $A$.
Now place a proton ($m = 1.67 \times 10^{-27} \text{kg}, \ q = 1.60 \times 10^{-19} \text{C}$) at point $A$.
(c) Find the the electric force $F$ (magnitude only) experienced by the proton.
(d) Find the electric potential energy $U$ of the proton.

Solution:

(a) $E = k \frac{|7 \text{nC}|}{(5 \text{m})^2} = 2.52 \text{N/C}$,
   $E_x = \frac{4}{5}E = 2.02 \text{N/C}, \quad E_y = -\frac{3}{5}E = -1.51 \text{N/C}$
(b) $V = k \frac{7 \text{nC}}{5 \text{m}} = 12.6 \text{V}$. 

\[ \begin{array}{c}
\text{y} \\
\downarrow \\
Q = 7 \text{nC} \\
\text{3m} \\
\downarrow \\
\text{4m} \\
\downarrow \\
A \\
\text{x}
\end{array} \]
The point charge $Q$ has a fixed position as shown.
(a) Find the components $E_x$ and $E_y$ of the electric field at point $A$.
(b) Find the electric potential $V$ at point $A$.

Now place a proton ($m = 1.67 \times 10^{-27}$ kg, $q = 1.60 \times 10^{-19}$ C) at point $A$.
(c) Find the the electric force $F$ (magnitude only) experienced by the proton.
(d) Find the electric potential energy $U$ of the proton.

Solution:

(a) $E = k \frac{|7\text{nC}|}{(5\text{m})^2} = 2.52 \text{N/C}$,

$E_x = \frac{4}{5}E = 2.02 \text{N/C}$, \quad $E_y = -\frac{3}{5}E = -1.51 \text{N/C}$

(b) $V = k \frac{7\text{nC}}{5\text{m}} = 12.6 \text{V}$.

(c) $F = qE = 4.03 \times 10^{-19} \text{N}$. 
The point charge $Q$ has a fixed position as shown.

(a) Find the components $E_x$ and $E_y$ of the electric field at point $A$.

(b) Find the electric potential $V$ at point $A$.

Now place a proton ($m = 1.67 \times 10^{-27} \text{kg}, \; q = 1.60 \times 10^{-19} \text{C}$) at point $A$.

(c) Find the electric force $F$ (magnitude only) experienced by the proton.

(d) Find the electric potential energy $U$ of the proton.

Solution:

(a) $E = k \frac{|7\text{nC}|}{(5\text{m})^2} = 2.52 \text{N/C}$,

$E_x = \frac{4}{5}E = 2.02 \text{N/C}, \quad E_y = -\frac{3}{5}E = -1.51 \text{N/C}$

(b) $V = k \frac{7\text{nC}}{5\text{m}} = 12.6 \text{V}$.

(c) $F = qE = 4.03 \times 10^{-19} \text{N}$.

(d) $U = qV = 2.02 \times 10^{-18} \text{J}$. 
The charged conducting spherical shell has a 2m inner radius and a 4m outer radius. The charge on the outer surface is $Q_{\text{ext}} = 8\text{nC}$. There is a point charge $Q_{p} = 3\text{nC}$ at the center.

(a) Find the charge $Q_{\text{int}}$ on the inner surface of the shell.
(b) Find the surface charge density $\sigma_{\text{ext}}$ on the outer surface of the shell.
(c) Find the electric flux $\Phi_{E}$ through a Gaussian sphere of radius $r = 5\text{m}$.
(d) Find the magnitude of the electric field $E$ at radius $r = 3\text{m}$. 

![Diagram of a charged conducting spherical shell with a point charge at the center and a Gaussian sphere of radius 5m]
The charged conducting spherical shell has a 2m inner radius and a 4m outer radius. The charge on the outer surface is $Q_{\text{ext}} = 8\text{nC}$. There is a point charge $Q_p = 3\text{nC}$ at the center.

(a) Find the charge $Q_{\text{int}}$ on the inner surface of the shell.
(b) Find the surface charge density $\sigma_{\text{ext}}$ on the outer surface of the shell.
(c) Find the electric flux $\Phi_E$ through a Gaussian sphere of radius $r = 5\text{m}$.
(d) Find the magnitude of the electric field $E$ at radius $r = 3\text{m}$.

Solution:

(a) $Q_{\text{int}} = -Q_p = -3\text{nC}$. 
The charged conducting spherical shell has a 2m inner radius and a 4m outer radius. The charge on the outer surface is $Q_{\text{ext}} = 8\, \text{nC}$. There is a point charge $Q_p = 3\, \text{nC}$ at the center.

(a) Find the charge $Q_{\text{int}}$ on the inner surface of the shell.
(b) Find the surface charge density $\sigma_{\text{ext}}$ on the outer surface of the shell.
(c) Find the electric flux $\Phi_E$ through a Gaussian sphere of radius $r = 5\, \text{m}$.
(d) Find the magnitude of the electric field $E$ at radius $r = 3\, \text{m}$.

Solution:

(a) $Q_{\text{int}} = -Q_p = -3\, \text{nC}$.
(b) $\sigma_{\text{ext}} = \frac{Q_{\text{ext}}}{4\pi(4\, \text{m})^2} = 3.98 \times 10^{-11} \, \text{C/m}^2$. 
The charged conducting spherical shell has a 2m inner radius and a 4m outer radius. The charge on the outer surface is $Q_{\text{ext}} = 8\text{nC}$. There is a point charge $Q_p = 3\text{nC}$ at the center.

(a) Find the charge $Q_{\text{int}}$ on the inner surface of the shell.
(b) Find the surface charge density $\sigma_{\text{ext}}$ on the outer surface of the shell.
(c) Find the electric flux $\Phi_E$ through a Gaussian sphere of radius $r = 5\text{m}$.
(d) Find the magnitude of the electric field $E$ at radius $r = 3\text{m}$.

Solution:

(a) $Q_{\text{int}} = -Q_p = -3\text{nC}$.

(b) $\sigma_{\text{ext}} = \frac{Q_{\text{ext}}}{4\pi(4\text{m})^2} = 3.98 \times 10^{-11}\text{C/m}^2$.

(c) $\Phi_E = \frac{Q_{\text{ext}}}{\epsilon_0} = 904\text{Nm}^2/\text{C}$. 

\[ Q_{\text{ext}} \]

\[ Q_{\text{int}} \]

\[ Q_p \]

\[ r \]

1m 3m 5m
Consider a region of space with a uniform electric field $\mathbf{E} = 0.5\,\text{V/m} \, \hat{i}$. Ignore gravity.

(a) If the electric potential vanishes at point 0, what are the electric potentials at points 1 and 2?

(b) If an electron ($m = 9.11 \times 10^{-31}\,\text{kg}$, $q = -1.60 \times 10^{-19}\,\text{C}$) is released from rest at point 0, toward which point will it start moving?

(c) What will be the speed of the electron when it gets there?
Consider a region of space with a uniform electric field $\mathbf{E} = 0.5\text{V/m} \hat{i}$. Ignore gravity.

(a) If the electric potential vanishes at point 0, what are the electric potentials at points 1 and 2?

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(c) What will be the speed of the electron when it gets there?

Solution:

(a) $V_1 = -(0.5\text{V/m})(2\text{m}) = -1\text{V}$, $V_2 = 0$. 

![Diagram of electric field and points](image)
Consider a region of space with a uniform electric field $\mathbf{E} = 0.5 \text{ V/m} \hat{i}$. Ignore gravity.

(a) If the electric potential vanishes at point 0, what are the electric potentials at points 1 and 2?
(b) If an electron ($m = 9.11 \times 10^{-31} \text{ kg}, q = -1.60 \times 10^{-19} \text{ C}$) is released from rest at point 0, toward which point will it start moving?
(c) What will be the speed of the electron when it gets there?

Solution:

(a) $V_1 = -(0.5 \text{ V/m})(2 \text{ m}) = -1 \text{ V}$, $V_2 = 0$.
(b) $\mathbf{F} = q\mathbf{E} = -|qE|\hat{i}$ (toward point 3).
Consider a region of space with a uniform electric field $\mathbf{E} = 0.5\text{V/m} \hat{i}$. Ignore gravity.

(a) If the electric potential vanishes at point 0, what are the electric potentials at points 1 and 2?

(b) If an electron ($m = 9.11 \times 10^{-31}\text{kg}, q = -1.60 \times 10^{-19}\text{C}$) is released from rest at point 0, toward which point will it start moving?

(c) What will be the speed of the electron when it gets there?

Solution:

(a) $V_1 = -(0.5\text{V/m})(2\text{m}) = -1\text{V}, \quad V_2 = 0$.

(b) $\mathbf{F} = q\mathbf{E} = -|qE|\hat{i}$ (toward point 3).

(c) $\Delta V = (V_3 - V_0) = 1\text{V}, \quad \Delta U = q\Delta V = -1.60 \times 10^{-19}\text{J}$,

$K = -\Delta U = 1.60 \times 10^{-19}\text{J}, \quad v = \sqrt{\frac{2K}{m}} = 5.93 \times 10^5\text{m/s}$.

Alternatively:

$F = qE = 8.00 \times 10^{-20}\text{N}, \quad a = \frac{F}{m} = 8.78 \times 10^{10}\text{m/s}^2$,

$|\Delta x| = 2\text{m}, \quad v = \sqrt{2a|\Delta x|} = 5.93 \times 10^5\text{m/s}$.
Consider two point charges at the positions shown.
(a) Find the magnitude $E$ of the electric field at point $P_1$.
(b) Find the components $E_x$ and $E_y$ of the electric field at point $P_2$.
(c) Draw the direction of the electric field at points $P_1$ and $P_2$ in the diagram.
(d) Calculate the potential difference $\Delta V = V_2 - V_1$ between point $P_2$ and $P_1$. 
Consider two point charges at the positions shown.
(a) Find the magnitude $E$ of the electric field at point $P_1$.
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(c) Draw the direction of the electric field at points $P_1$ and $P_2$ in the diagram.
(d) Calculate the potential difference $\Delta V = V_2 - V_1$ between point $P_2$ and $P_1$.

**Solution:**
(a) $E = 2k \frac{2nC}{(5\text{cm})^2} = 1.44 \times 10^4 \text{ N/C}$. 
Consider two point charges at the positions shown.
(a) Find the magnitude $E$ of the electric field at point $P_1$.
(b) Find the components $E_x$ and $E_y$ of the electric field at point $P_2$.
(c) Draw the direction of the electric field at points $P_1$ and $P_2$ in the diagram.
(d) Calculate the potential difference $\Delta V = V_2 - V_1$ between point $P_2$ and $P_1$.

Solution:

(a) $E = 2k \frac{2\text{nC}}{(5\text{cm})^2} = 1.44 \times 10^4 \text{N/C}$.

(b) $E_x = -k \frac{2\text{nC}}{(8\text{cm})^2} = -2.81 \times 10^3 \text{N/C}$.

$E_y = k \frac{2\text{nC}}{(6\text{cm})^2} = 5.00 \times 10^3 \text{N/C}$. 
Consider two point charges at the positions shown.
(a) Find the magnitude $E$ of the electric field at point $P_1$.
(b) Find the components $E_x$ and $E_y$ of the electric field at point $P_2$.
(c) Draw the direction of the electric field at points $P_1$ and $P_2$ in the diagram.
(d) Calculate the potential difference $\Delta V = V_2 - V_1$ between point $P_2$ and $P_1$.

Solution:

(a) $E = 2k \frac{2nC}{(5cm)^2} = 1.44 \times 10^4 N/C$.

(b) $E_x = -k \frac{2nC}{(8cm)^2} = -2.81 \times 10^3 N/C$.

$E_y = k \frac{2nC}{(6cm)^2} = 5.00 \times 10^3 N/C$.

(c) $E_1$ up and left toward negative charge; $E_2$ more up and less left
Consider two point charges at the positions shown.
(a) Find the magnitude $E$ of the electric field at point $P_1$.
(b) Find the components $E_x$ and $E_y$ of the electric field at point $P_2$.
(c) Draw the direction of the electric field at points $P_1$ and $P_2$ in the diagram.
(d) Calculate the potential difference $\Delta V = V_2 - V_1$ between point $P_2$ and $P_1$.

Solution:

(a) $E = 2k \frac{2nC}{(5cm)^2} = 1.44 \times 10^4 N/C$.

(b) $E_x = -k \frac{2nC}{(8cm)^2} = -2.81 \times 10^3 N/C$.

$E_y = k \frac{2nC}{(6cm)^2} = 5.00 \times 10^3 N/C$.

(c) $\mathbf{E}_1$ up and left toward negative charge; $\mathbf{E}_2$ more up and less left

(d) $\Delta V = V_2 - 0 = k \frac{2nC}{6cm} + k \frac{-2nC}{8cm} = 300V - 225V = 75V$. 
Two very large, thin, uniformly charged, parallel sheets are positioned as shown. Find the values of the charge densities (charge per area), $\sigma_A$ and $\sigma_B$, if you know the electric fields $E_1$, $E_2$, and $E_3$.

Consider two situations.
(a) $E_1 = 2\text{N/C}$ (directed left), $E_2 = 0$, $E_3 = 2\text{N/C}$ (directed right).
(b) $E_1 = 0$, $E_2 = 2\text{N/C}$ (directed right), $E_3 = 0$. 
Two very large, thin, uniformly charged, parallel sheets are positioned as shown. Find the values of the charge densities (charge per area), $\sigma_A$ and $\sigma_B$, if you know the electric fields $E_1$, $E_2$, and $E_3$.

Consider two situations.
(a) $E_1 = 2\text{N/C}$ (directed left), $E_2 = 0$, $E_3 = 2\text{N/C}$ (directed right).
(b) $E_1 = 0$, $E_2 = 2\text{N/C}$ (directed right), $E_3 = 0$.

Solution:
(a) The two sheets are equally charged:
$\sigma_A = \sigma_B = 2\varepsilon_0 (1\text{N/C}) = 1.77 \times 10^{-11} \text{C/m}^2$. 
Two very large, thin, uniformly charged, parallel sheets are positioned as shown. Find the values of the charge densities (charge per area), $\sigma_A$ and $\sigma_B$, if you know the electric fields $E_1$, $E_2$, and $E_3$.

Consider two situations.
(a) $E_1 = 2\text{N/C}$ (directed left), $E_2 = 0$, $E_3 = 2\text{N/C}$ (directed right).
(b) $E_1 = 0$, $E_2 = 2\text{N/C}$ (directed right), $E_3 = 0$.

Solution:
(a) The two sheets are equally charged:
$\sigma_A = \sigma_B = 2\varepsilon_0(1\text{N/C}) = 1.77 \times 10^{-11}\text{C/m}^2$.
(b) The two sheets are oppositely charged:
$\sigma_A = -\sigma_B = 2\varepsilon_0(1\text{N/C}) = 1.77 \times 10^{-11}\text{C/m}^2$. 
Consider a region of uniform electric field $E_x = +7\text{N/C}$. A charged particle (charge $Q = -3\text{C}$, mass $m = 5\text{kg}$) is launched at time $t = 0$ from initial position $x = 0$ with velocity $v_0 = 10\text{m/s}$ in the positive $x$-direction. Ignore gravity.

(a) Find the force $F_x$ acting on the particle at time $t = 0$.
(b) Find the force $F_x$ acting on the particle at time $t = 3\text{s}$.
(c) Find the kinetic energy of the particle at time $t = 0$.
(d) Find the kinetic energy of the particle at time $t = 3\text{s}$.
(e) Find the work done on the particle between $t = 0$ and $t = 3\text{s}$.
Consider a region of uniform electric field $E_x = +7 \text{N/C}$. A charged particle (charge $Q = -3 \text{C}$, mass $m = 5 \text{kg}$) is launched at time $t = 0$ from initial position $x = 0$ with velocity $v_0 = 10 \text{m/s}$ in the positive $x$-direction. Ignore gravity.

(a) Find the force $F_x$ acting on the particle at time $t = 0$.
(b) Find the force $F_x$ acting on the particle at time $t = 3 \text{s}$.
(c) Find the kinetic energy of the particle at time $t = 0$.
(d) Find the kinetic energy of the particle at time $t = 3 \text{s}$.
(e) Find the work done on the particle between $t = 0$ and $t = 3 \text{s}$.

Solution:

(a) $F_x = QE_x = (-3 \text{C})(7 \text{N/C}) = -21 \text{N}$. 

\[ \text{Solution:} \]

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(d) Find the kinetic energy of the particle at time $t = 3 \text{s}$.
(e) Find the work done on the particle between $t = 0$ and $t = 3 \text{s}$.

Solution:

(a) $F_x = QE_x = (-3 \text{C})(7 \text{N/C}) = -21 \text{N}$.
(b) no change from (a).
Consider a region of uniform electric field \( E_x = +7\text{N/C} \). A charged particle (charge \( Q = -3\text{C} \), mass \( m = 5\text{kg} \)) is launched at time \( t = 0 \) from initial position \( x = 0 \) with velocity \( v_0 = 10\text{m/s} \) in the positive \( x \)-direction. Ignore gravity.

(a) Find the force \( F_x \) acting on the particle at time \( t = 0 \).
(b) Find the force \( F_x \) acting on the particle at time \( t = 3\text{s} \).
(c) Find the kinetic energy of the particle at time \( t = 0 \).
(d) Find the kinetic energy of the particle at time \( t = 3\text{s} \).
(e) Find the work done on the particle between \( t = 0 \) and \( t = 3\text{s} \).

Solution:

(a) \( F_x = QE_x = (-3\text{C})(7\text{N/C}) = -21\text{N} \).
(b) no change from (a).
(c) \( K = \frac{1}{2}(5\text{kg})(10\text{m/s})^2 = 250\text{J} \).
Consider a region of uniform electric field $E_x = +7 \text{N/C}$. A charged particle (charge $Q = -3 \text{C}$, mass $m = 5 \text{kg}$) is launched at time $t = 0$ from initial position $x = 0$ with velocity $v_0 = 10 \text{m/s}$ in the positive $x$-direction. Ignore gravity.

(a) Find the force $F_x$ acting on the particle at time $t = 0$.
(b) Find the force $F_x$ acting on the particle at time $t = 3 \text{s}$.
(c) Find the kinetic energy of the particle at time $t = 0$.
(d) Find the kinetic energy of the particle at time $t = 3 \text{s}$.
(e) Find the work done on the particle between $t = 0$ and $t = 3 \text{s}$.

Solution:

(a) $F_x = QE_x = (-3 \text{C})(7 \text{N/C}) = -21 \text{N}$.
(b) no change from (a).
(c) $K = \frac{1}{2}(5 \text{kg})(10 \text{m/s})^2 = 250 \text{J}$.
(d) $v_x = v_0 + a_xt = v_0 + (F_x/m)t = 10 \text{m/s} + (-21 \text{N/5kg})(3 \text{s}) = -2.6 \text{m/s}$.
   $$K = \frac{1}{2}(5 \text{kg})(-2.6 \text{m/s})^2 = 16.9 \text{J}.$$
Consider a region of uniform electric field $E_x = +7 \text{N/C}$. A charged particle (charge $Q = -3 \text{C}$, mass $m = 5 \text{kg}$) is launched at time $t = 0$ from initial position $x = 0$ with velocity $v_0 = 10 \text{m/s}$ in the positive $x$-direction. Ignore gravity.

(a) Find the force $F_x$ acting on the particle at time $t = 0$.
(b) Find the force $F_x$ acting on the particle at time $t = 3 \text{s}$.
(c) Find the kinetic energy of the particle at time $t = 0$.
(d) Find the kinetic energy of the particle at time $t = 3 \text{s}$.
(e) Find the work done on the particle between $t = 0$ and $t = 3 \text{s}$.

Solution:

(a) $F_x = QE_x = (-3 \text{C})(7 \text{N/C}) = -21 \text{N}$.
(b) no change from (a).
(c) $K = \frac{1}{2}(5 \text{kg})(10 \text{m/s})^2 = 250 \text{J}$.
(d) $v_x = v_0 + a_x t = v_0 + (F_x/m)t = 10 \text{m/s} + (-21 \text{N}/5 \text{kg})(3 \text{s}) = -2.6 \text{m/s}$.
   $K = \frac{1}{2}(5 \text{kg})(-2.6 \text{m/s})^2 = 16.9 \text{J}$.
(e) $W = \Delta K = 16.9 \text{J} - 250 \text{J} = -233 \text{J}$.
Consider two point charges positioned on the $x$-axis as shown.

(a) Find magnitude and direction of the electric field at points A and B.

(b) Find the electric potential at points A and B.

(c) Find the electric potential energy of a proton (mass $m = 1.67 \times 10^{-27}$ kg, charge $q = 1.60 \times 10^{-19}$ C) when placed at point A or point B.

(d) Find magnitude and direction of the acceleration the proton experiences when released at point A or point B.
Solution:

(a) \[ E_x = -k \frac{4nC}{(2m)^2} - k \frac{(-7nC)}{(5m)^2} = -9.00\text{N/C} + 2.52\text{N/C} = -6.48\text{N/C}. \]
\[ E_x = k \frac{4nC}{(6m)^2} + k \frac{(-7nC)}{(3m)^2} = 1.00\text{N/C} - 7.00\text{N/C} = -6.00\text{N/C}. \]

(b) \[ V = +k \frac{4nC}{2m} + k \frac{(-7nC)}{5m} = 18.0V - 12.6V = 5.4V. \]
\[ V = +k \frac{4nC}{6m} + k \frac{(-7nC)}{3m} = 6.0V - 21.0V = -15.0V. \]

(c) \[ U = qV = (5.4V)(1.6 \times 10^{-19}\text{C}) = 8.64 \times 10^{-19}\text{J}. \]
\[ U = qV = (-15.0V)(1.6 \times 10^{-19}\text{C}) = -2.40 \times 10^{-18}\text{J}. \]

(d) \[ a_x = \frac{qE_x}{m} = \frac{(1.6 \times 10^{-19}\text{C})(-6.48\text{N/C})}{1.67 \times 10^{-27}\text{kg}} = -6.21 \times 10^8\text{ms}^{-2}. \]
\[ a_x = \frac{qE_x}{m} = \frac{(1.6 \times 10^{-19}\text{C})(-6.00\text{N/C})}{1.67 \times 10^{-27}\text{kg}} = -5.75 \times 10^8\text{ms}^{-2}. \]
Consider three plane surfaces (one circle and two rectangles) with area vectors $\vec{A}_1$ (pointing in positive $x$-direction), $\vec{A}_2$ (pointing in negative $z$-direction), and $\vec{A}_3$ (pointing in negative $y$-direction) as shown. The region is filled with a uniform electric field $\vec{E} = (-3\hat{i} + 9\hat{j} - 4\hat{k})\text{N/C}$ or $\vec{E} = (2\hat{i} - 6\hat{j} + 5\hat{k})\text{N/C}$.

(a) Find the electric flux $\Phi_{E}^{(1)}$ through surface 1.

(b) Find the electric flux $\Phi_{E}^{(2)}$ through surface 2.

(c) Find the electric flux $\Phi_{E}^{(3)}$ through surface 3.
Solution:

(a) \( \vec{A}_1 = \pi(1.5\text{m})^2 \hat{i} = 7.07\text{m}^2 \hat{i}, \quad \Phi^{(1)}_E = \vec{E} \cdot \vec{A}_1 = (-3\text{N/C})(7.07\text{m}^2) = -21.2\text{Nm}^2/C. \)

\( \vec{A}_1 = \pi(1.5\text{m})^2 \hat{i} = 7.07\text{m}^2 \hat{i}, \quad \Phi^{(1)}_E = \vec{E} \cdot \vec{A}_1 = (2\text{N/C})(7.07\text{m}^2) = 14.1\text{Nm}^2/C. \)

(b) \( \vec{A}_2 = (3\text{m})(4\text{m})(-\hat{k}) = -12\text{m}^2 \hat{k}, \quad \Phi^{(2)}_E = \vec{E} \cdot \vec{A}_2 = (-4\text{N/C})(-12\text{m}^2) = 48\text{Nm}^2/C. \)

\( \vec{A}_2 = (3\text{m})(4\text{m})(-\hat{k}) = -12\text{m}^2 \hat{k}, \quad \Phi^{(2)}_E = \vec{E} \cdot \vec{A}_2 = (5\text{N/C})(-12\text{m}^2) = -60\text{Nm}^2/C. \)

(b) \( \vec{A}_3 = (3\text{m})(4\text{m})(-\hat{j}) = -12\text{m}^2 \hat{j}, \quad \Phi^{(3)}_E = \vec{E} \cdot \vec{A}_3 = (9\text{N/C})(-12\text{m}^2) = -108\text{Nm}^2/C. \)

\( \vec{A}_3 = (3\text{m})(4\text{m})(-\hat{j}) = -12\text{m}^2 \hat{j}, \quad \Phi^{(3)}_E = \vec{E} \cdot \vec{A}_3 = (-6\text{N/C})(-12\text{m}^2) = 72\text{Nm}^2/C. \)
An electron \((m_e = 9.11 \times 10^{-31} \text{kg}, q_e = -1.60 \times 10^{-19} \text{C})\) and a proton \((m_p = 1.67 \times 10^{-27} \text{kg}, q_p = +1.60 \times 10^{-19} \text{C})\) are released from rest midway between oppositely charged parallel plates. The electric field between the plates is uniform and has strength \(E = 40 \text{V/m}\). Ignore gravity.

(a) Which plate is positively (negatively) charged?

(b) Find the electric forces \(\vec{F}_p\) acting on the proton and \(\vec{F}_e\) acting on the electron (magnitude and direction).

(c) Find the accelerations \(\vec{a}_p\) of the proton and \(\vec{a}_e\) of the electron (magnitude and direction).

(d) If plate 1 is at potential \(V_1 = 1 \text{V}\) at what potential \(V_2\) is plate 2?
If plate 2 is at potential \(V_2 = 2 \text{V}\) at what potential \(V_1\) is plate 1?
Solution:

(a) plate 1 (plate 2)

(b) \( F_p = |q_p|E = 6.40 \times 10^{-18} \text{N}. \) (directed right).
\( F_e = |q_e|E = 6.40 \times 10^{-18} \text{N}. \) (directed left).

(c) \( a_p = F_p/m_p = 3.83 \times 10^9 \text{m/s}^2. \) (directed right).
\( a_e = F_e/m_e = 7.03 \times 10^{12} \text{m/s}^2. \) (directed left).

(d) \( V_2 = 1\text{V} - (40\text{V/m})(0.4\text{m}) = -15\text{V}. \)
\( V_1 = 2\text{V} + (40\text{V/m})(0.4\text{m}) = 18\text{V}. \)
Consider two point charges positioned as shown.

- Find the magnitude of the electric field at point $A$.
- Find the electric potential at point $B$.
- Find the magnitude of the electric field at point $C$.
- Find the electric potential at point $D$. 
Consider two point charges positioned as shown.

- Find the magnitude of the electric field at point $A$.
- Find the electric potential at point $B$.
- Find the magnitude of the electric field at point $C$.
- Find the electric potential at point $D$.

Solution:

$$E_A = k \left( \frac{|5 \text{nC}|}{(3 \text{m})^2} + \frac{|-9 \text{nC}|}{(7 \text{m})^2} \right) = 5.00 \text{V/m} + 1.65 \text{V/m} = 6.65 \text{V/m}.$$
Consider two point charges positioned as shown.

- Find the magnitude of the electric field at point $A$.
- Find the electric potential at point $B$.
- Find the magnitude of the electric field at point $C$.
- Find the electric potential at point $D$.

Solution:

- $E_A = k \frac{|5\text{nC}|}{(3\text{m})^2} + k \frac{|-9\text{nC}|}{(7\text{m})^2} = 5.00\text{V/m} + 1.65\text{V/m} = 6.65\text{V/m}$.
- $V_B = k \frac{(5\text{nC})}{6\text{m}} + k \frac{(-9\text{nC})}{8\text{m}} = 7.50\text{V} - 10.13\text{V} = -2.63\text{V}$. 
Consider two point charges positioned as shown.

- Find the magnitude of the electric field at point $A$.
- Find the electric potential at point $B$.
- Find the magnitude of the electric field at point $C$.
- Find the electric potential at point $D$.

Solution:

- $E_A = k \frac{|5 \text{nC}|}{(3 \text{m})^2} + k \frac{|-9 \text{nC}|}{(7 \text{m})^2} = 5.00 \text{V/m} + 1.65 \text{V/m} = 6.65 \text{V/m}$.

- $V_B = k \frac{(5 \text{nC})}{6 \text{m}} + k \frac{(-9 \text{nC})}{8 \text{m}} = 7.50 \text{V} - 10.13 \text{V} = -2.63 \text{V}$.

- $E_C = k \frac{|5 \text{nC}|}{(6 \text{m})^2} + k \frac{|-9 \text{nC}|}{(4 \text{m})^2} = 1.25 \text{V/m} + 5.06 \text{V/m} = 6.31 \text{V/m}$.
Consider two point charges positioned as shown.

- Find the magnitude of the electric field at point $A$.
- Find the electric potential at point $B$.
- Find the magnitude of the electric field at point $C$.
- Find the electric potential at point $D$.

Solution:

- $E_A = k \frac{|5\text{nC}|}{(3\text{m})^2} + k \frac{|-9\text{nC}|}{(7\text{m})^2} = 5.00\text{V/m} + 1.65\text{V/m} = 6.65\text{V/m}$.
- $V_B = k \frac{(+5\text{nC})}{6\text{m}} + k \frac{(-9\text{nC})}{8\text{m}} = 7.50\text{V} - 10.13\text{V} = -2.63\text{V}$.
- $E_C = k \frac{|5\text{nC}|}{(6\text{m})^2} + k \frac{|-9\text{nC}|}{(4\text{m})^2} = 1.25\text{V/m} + 5.06\text{V/m} = 6.31\text{V/m}$.
- $V_D = k \frac{(+5\text{nC})}{8\text{m}} + k \frac{(-9\text{nC})}{6\text{m}} = 5.63\text{V} - 13.5\text{V} = -7.87\text{V}$.
Consider a conducting sphere of radius $r_1 = 2\text{cm}$ and a conducting spherical shell of inner radius $r_2 = 6\text{cm}$ and outer radius $r_3 = 10\text{cm}$. The charges on the two surfaces of the shell are $Q_2 = Q_3 = 1.3\text{nC}$ [3.1nC].

(a) Find the charge $Q_1$ on the surface of the conducting sphere.
(b) Find the magnitude of the electric field at points $A$ and $B$.
(c) Find the surface charge density $\sigma_3$ on the outermost surface.
Consider a conducting sphere of radius \( r_1 = 2 \text{cm} \) and a conducting spherical shell of inner radius \( r_2 = 6 \text{cm} \) and outer radius \( r_3 = 10 \text{cm} \). The charges on the two surfaces of the shell are \( Q_2 = Q_3 = 1.3 \text{nC} \) [3.1nC].

(a) Find the charge \( Q_1 \) on the surface of the conducting sphere.
(b) Find the magnitude of the electric field at points \( A \) and \( B \).
(c) Find the surface charge density \( \sigma_3 \) on the outermost surface.

Solution:

(a) Gauss’ law implies that
\[
Q_1 = -Q_2 = -1.3 \text{nC} \quad [-3.1 \text{nC}].
\]
Consider a conducting sphere of radius \( r_1 = 2 \text{ cm} \) and a conducting spherical shell of inner radius \( r_2 = 6 \text{ cm} \) and outer radius \( r_3 = 10 \text{ cm} \). The charges on the two surfaces of the shell are \( Q_2 = Q_3 = 1.3 \text{nC} \) [3.1nC].

(a) Find the charge \( Q_1 \) on the surface of the conducting sphere.
(b) Find the magnitude of the electric field at points \( A \) and \( B \).
(c) Find the surface charge density \( \sigma_3 \) on the outermost surface.

**Solution:**

(a) Gauss’ law implies that \( Q_1 = -Q_2 = -1.3 \text{nC} \) [−3.1nC].

(b) \( E_A = k \frac{1.3 \text{nC}}{(4 \text{ cm})^2} = 7.31 \times 10^3 \text{ N/C} \)

\[ \left[ k \frac{3.1 \text{nC}}{(4 \text{ cm})^2} = 1.74 \times 10^4 \text{ N/C} \right]. \]

\( E_B = 0 \) inside conductor.
Consider a conducting sphere of radius $r_1 = 2\text{cm}$ and a conducting spherical shell of inner radius $r_2 = 6\text{cm}$ and outer radius $r_3 = 10\text{cm}$. The charges on the two surfaces of the shell are $Q_2 = Q_3 = 1.3\text{nC} \ [3.1\text{nC}]$.  
(a) Find the charge $Q_1$ on the surface of the conducting sphere.
(b) Find the magnitude of the electric field at points $A$ and $B$.
(c) Find the surface charge density $\sigma_3$ on the outermost surface.

**Solution:**

(a) Gauss’ law implies that 
$Q_1 = -Q_2 = -1.3\text{nC} \ [-3.1\text{nC}]$.

(b) $E_A = k \frac{1.3\text{nC}}{(4\text{cm})^2} = 7.31 \times 10^3 \text{N/C} \\
\left[ k \frac{3.1\text{nC}}{(4\text{cm})^2} = 1.74 \times 10^4 \text{N/C} \right].$

$E_B = 0$ inside conductor.

(c) $\sigma_3 = \frac{Q_3}{4\pi r_3^2} = \frac{1.3\text{nC}}{1257\text{cm}^2} = 1.03 \times 10^{-8} \text{C/m}^2$ \\
$\left[ \frac{3.1\text{nC}}{1257\text{cm}^2} = 2.47 \times 10^{-8} \text{C/m}^2 \right]$. 

$\sigma_3 = \frac{Q_3}{4\pi r_3^2} \approx 1.03 \times 10^{-8} \text{C/m}^2$
Consider a point charge $Q = 6\text{nC}$ fixed at position $x = 0$.

(a) Find the electric potential energy $U_4$ of a charged particle with mass $m = 1\text{mg}$ and charge $q = 2\mu\text{C}$ placed at position $x = 4\text{cm}$.

(b) Find the electric potential energy $U_8$ of a charged particle with mass $m = 2\text{mg}$ and charge $q = -1\mu\text{C}$ placed at position $x = 8\text{cm}$.

(c) Find the kinetic energy $K_8$ of that particle, released from rest at $x = 4\text{cm}$, when it has reached position $x = 8\text{cm}$.

(d) Find the kinetic energy $K_4$ of that particle, released from rest at $x = 8\text{cm}$, when it has reached position $x = 4\text{cm}$.

(e) Find the velocity $v_8$ of that particle at $x = 8\text{cm}$.

(f) Find the velocity $v_4$ of that particle at $x = 4\text{cm}$.
Consider a point charge \( Q = 6 \text{nC} \) fixed at position \( x = 0 \).
(a) Find the electric potential energy \( U_4 \) of a charged particle with mass \( m = 1 \text{mg} \) and charge \( q = 2 \mu \text{C} \) placed at position \( x = 4 \text{cm} \).
(b) Find the electric potential energy \( U_8 \) of a charged particle with mass \( m = 2 \text{mg} \) and charge \( q = -1 \mu \text{C} \) placed at position \( x = 8 \text{cm} \).
(c) Find the kinetic energy \( K_8 \) of that particle, released from rest at \( x = 4 \text{cm} \), when it has reached position \( x = 8 \text{cm} \).
(d) Find the kinetic energy \( K_4 \) of that particle, released from rest at \( x = 8 \text{cm} \), when it has reached position \( x = 4 \text{cm} \).
(e) Find the velocity \( v_8 \) of that particle at \( x = 8 \text{cm} \).
(f) Find the velocity \( v_4 \) of that particle at \( x = 4 \text{cm} \).

Solution:

(a) \( U_4 = k \frac{qQ}{4 \text{cm}} = 2.7 \text{mJ} \).
Consider a point charge $Q = 6\text{nC}$ fixed at position $x = 0$.
(a) Find the electric potential energy $U_4$ of a charged particle with mass $m = 1\text{mg}$ and charge $q = 2\mu\text{C}$ placed at position $x = 4\text{cm}$.
(b) Find the electric potential energy $U_8$ of a charged particle with mass $m = 2\text{mg}$ and charge $q = -1\mu\text{C}$ placed at position $x = 8\text{cm}$.
(c) Find the kinetic energy $K_8$ of that particle, released from rest at $x = 4\text{cm}$, when it has reached position $x = 8\text{cm}$.
(d) Find the kinetic energy $K_4$ of that particle, released from rest at $x = 8\text{cm}$, when it has reached position $x = 4\text{cm}$.
(e) Find the velocity $v_8$ of that particle at $x = 8\text{cm}$.
(f) Find the velocity $v_4$ of that particle at $x = 4\text{cm}$.

Solution:
(a) $U_4 = k \frac{qQ}{4\text{cm}} = 2.7\text{mJ}$.
(c) $K_8 = (2.7 - 1.35)\text{mJ} = 1.35\text{mJ}$. 
Consider a point charge $Q = 6\, \text{nC}$ fixed at position $x = 0$.

(a) Find the electric potential energy $U_4$ of a charged particle with mass $m = 1\, \text{mg}$ and charge $q = 2\, \mu\text{C}$ placed at position $x = 4\, \text{cm}$.

(b) Find the electric potential energy $U_8$ of a charged particle with mass $m = 2\, \text{mg}$ and charge $q = -1\, \mu\text{C}$ placed at position $x = 8\, \text{cm}$.

(c) Find the kinetic energy $K_8$ of that particle, released from rest at $x = 4\, \text{cm}$, when it has reached position $x = 8\, \text{cm}$.

(d) Find the kinetic energy $K_4$ of that particle, released from rest at $x = 8\, \text{cm}$, when it has reached position $x = 4\, \text{cm}$.

(e) Find the velocity $v_8$ of that particle at $x = 8\, \text{cm}$.

(f) Find the velocity $v_4$ of that particle at $x = 4\, \text{cm}$.

Solution:

(a) $U_4 = k \frac{qQ}{4\, \text{cm}} = 2.7\, \text{mJ}$.

(c) $K_8 = (2.7 - 1.35)\, \text{mJ} = 1.35\, \text{mJ}$.

(e) $v_8 = \sqrt{\frac{2K_8}{m}} = 52.0\, \text{m/s}$.
Consider a point charge $Q = 6\, \text{nC}$ fixed at position $x = 0$.
(a) Find the electric potential energy $U_4$ of a charged particle with mass $m = 1\, \text{mg}$ and charge $q = 2\, \mu\text{C}$ placed at position $x = 4\, \text{cm}$.
(b) Find the electric potential energy $U_8$ of a charged particle with mass $m = 2\, \text{mg}$ and charge $q = -1\, \mu\text{C}$ placed at position $x = 8\, \text{cm}$.
(c) Find the kinetic energy $K_8$ of that particle, released from rest at $x = 4\, \text{cm}$, when it has reached position $x = 8\, \text{cm}$.
(d) Find the kinetic energy $K_4$ of that particle, released from rest at $x = 8\, \text{cm}$, when it has reached position $x = 4\, \text{cm}$.
(e) Find the velocity $v_8$ of that particle at $x = 8\, \text{cm}$.
(f) Find the velocity $v_4$ of that particle at $x = 4\, \text{cm}$.

Solution:
(a) $U_4 = k \frac{qQ}{4\, \text{cm}} = 2.7\, \text{mJ}$.
(b) $U_8 = k \frac{qQ}{8\, \text{cm}} = -0.675\, \text{mJ}$.
(c) $K_8 = (2.7 - 1.35)\, \text{mJ} = 1.35\, \text{mJ}$.
(e) $v_8 = \sqrt{\frac{2K_8}{m}} = 52.0\, \text{m/s}$. 

Diagram:
- $Q = 6\, \text{nC}$
- $x = 0$ to $x = 8\, \text{cm}$
- Charged particle at $x = 4\, \text{cm}$
Consider a point charge \( Q = 6 \text{nC} \) fixed at position \( x = 0 \).

(a) Find the electric potential energy \( U_4 \) of a charged particle with mass \( m = 1 \text{mg} \) and charge \( q = 2 \text{\micro C} \) placed at position \( x = 4 \text{cm} \).

(b) Find the electric potential energy \( U_8 \) of a charged particle with mass \( m = 2 \text{mg} \) and charge \( q = -1 \text{\micro C} \) placed at position \( x = 8 \text{cm} \).

(c) Find the kinetic energy \( K_8 \) of that particle, released from rest at \( x = 4 \text{cm} \), when it has reached position \( x = 8 \text{cm} \).

(d) Find the kinetic energy \( K_4 \) of that particle, released from rest at \( x = 8 \text{cm} \), when it has reached position \( x = 4 \text{cm} \).

(e) Find the velocity \( v_8 \) of that particle at \( x = 8 \text{cm} \).

(f) Find the velocity \( v_4 \) of that particle at \( x = 4 \text{cm} \).

Solution:

(a) \( U_4 = k \frac{qQ}{4 \text{cm}} = 2.7 \text{mJ} \).

(b) \( U_8 = k \frac{qQ}{8 \text{cm}} = -0.675 \text{mJ} \).

(c) \( K_8 = (2.7 - 1.35) \text{mJ} = 1.35 \text{mJ} \).

(d) \( K_4 = (1.35 - 0.675) \text{mJ} = 0.675 \text{mJ} \).

(e) \( v_8 = \sqrt{\frac{2K_8}{m}} = 52.0 \text{m/s} \).
Consider a point charge \( Q = 6\text{nC} \) fixed at position \( x = 0 \).

(a) Find the electric potential energy \( U_4 \) of a charged particle with mass \( m = 1\text{mg} \) and charge \( q = 2\mu\text{C} \) placed at position \( x = 4\text{cm} \).

(b) Find the electric potential energy \( U_8 \) of a charged particle with mass \( m = 2\text{mg} \) and charge \( q = -1\mu\text{C} \) placed at position \( x = 8\text{cm} \).

(c) Find the kinetic energy \( K_8 \) of that particle, released from rest at \( x = 4\text{cm} \), when it has reached position \( x = 8\text{cm} \).

(d) Find the kinetic energy \( K_4 \) of that particle, released from rest at \( x = 8\text{cm} \), when it has reached position \( x = 4\text{cm} \).

(e) Find the velocity \( v_8 \) of that particle at \( x = 8\text{cm} \).

(f) Find the velocity \( v_4 \) of that particle at \( x = 4\text{cm} \).

\[
Q = 6\text{nC}
\]

\[
\begin{array}{ccc}
\text{+} & \quad & \text{x = 0} \quad \text{x = 4cm} \quad \text{x = 8cm}
\end{array}
\]

\[\text{Solution:}\]

(a) \( U_4 = k \frac{qQ}{4\text{cm}} = 2.7\text{mJ} \).

(b) \( U_8 = k \frac{qQ}{8\text{cm}} = -0.675\text{mJ} \).

(c) \( K_8 = (2.7 - 1.35)\text{mJ} = 1.35\text{mJ} \).

(d) \( K_4 = (1.35 - 0.675)\text{mJ} = 0.675\text{mJ} \).

(e) \( v_8 = \sqrt{\frac{2K_8}{m}} = 52.0\text{m/s} \).

(f) \( v_4 = \sqrt{\frac{2K_4}{m}} = 26.0\text{m/s} \).
Two point charges are placed in the $xy$-plane as shown.
(a) Find the components $E_x$ and $E_y$ of the electric field at point $O$.
(b) Draw an arrow indicating the direction of $\vec{E}$ at point $O$.
(c) Find the electric potential $V$ at point $O$.
(d) Find the magnitude $F$ of the electric force between the two charges.
Two point charges are placed in the $xy$-plane as shown.
(a) Find the components $E_x$ and $E_y$ of the electric field at point $O$.
(b) Draw an arrow indicating the direction of $\vec{E}$ at point $O$.
(c) Find the electric potential $V$ at point $O$.
(d) Find the magnitude $F$ of the electric force between the two charges.

Solution:

(a) $E_x = -k \frac{|6\text{nC}|}{(4\text{m})^2} = -3.38\text{N/C}$

$E_y = +k \frac{|5\text{nC}|}{(2\text{m})^2} = 11.25\text{N/C}$.
Two point charges are placed in the \(xy\)-plane as shown.
(a) Find the components \(E_x\) and \(E_y\) of the electric field at point \(O\).
(b) Draw an arrow indicating the direction of \(\vec{E}\) at point \(O\).
(c) Find the electric potential \(V\) at point \(O\).
(d) Find the magnitude \(F\) of the electric force between the two charges.

**Solution:**

(a) \[
E_x = -k \frac{|6\text{nC}|}{(4\text{m})^2} = -3.38\text{N/C}
\]
\[
E_y = +k \frac{|5\text{nC}|}{(2\text{m})^2} = 11.25\text{N/C}.
\]
(b) Up and left.
Two point charges are placed in the $xy$-plane as shown. 

(a) Find the components $E_x$ and $E_y$ of the electric field at point $O$.

(b) Draw an arrow indicating the direction of $\vec{E}$ at point $O$.

(c) Find the electric potential $V$ at point $O$.

(d) Find the magnitude $F$ of the electric force between the two charges.

**Solution:**

(a) $E_x = -k \frac{|6\text{nC}|}{(4\text{m})^2} = -3.38 \text{N/C}$

$E_y = +k \frac{|5\text{nC}|}{(2\text{m})^2} = 11.25 \text{N/C}.$

(b) Up and left.

(c) $V = k \frac{6\text{nC}}{4\text{m}} + k \frac{5\text{nC}}{2\text{m}} = 13.5 \text{V} + 22.5 \text{V} = 36 \text{V}.$
Two point charges are placed in the $xy$-plane as shown.

(a) Find the components $E_x$ and $E_y$ of the electric field at point $O$.

(b) Draw an arrow indicating the direction of $\vec{E}$ at point $O$.

(c) Find the electric potential $V$ at point $O$.

(d) Find the magnitude $F$ of the electric force between the two charges.

Solution:

(a) $E_x = -k \frac{|6\text{nC}|}{(4\text{m})^2} = -3.38 \text{N/C}$

$E_y = +k \frac{|5\text{nC}|}{(2\text{m})^2} = 11.25 \text{N/C}$.

(b) Up and left.

(c) $V = k \frac{6\text{nC}}{4\text{m}} + k \frac{5\text{nC}}{2\text{m}} = 13.5 \text{V} + 22.5 \text{V} = 36 \text{V}$.

(d) $F = k \frac{|6\text{nC}||5\text{nC}|}{20\text{m}^2} = 13.5 \text{nN}$. 
The conducting spherical shell shown in cross section has a 4cm inner radius and an 8cm outer radius. A point charge $Q_p$ is placed at the center. The charges on the inner and outer surfaces of the shell are $Q_{\text{int}} = 5\text{nC}$ and $Q_{\text{ext}} = 7\text{nC}$, respectively.

(a) Find the charge $Q_p$.
(b) Find the magnitude of the electric field $E$ at radius $r = 10\text{cm}$.
(c) Find the surface charge density $\sigma_{\text{int}}$ on the inner surface of the shell.
(d) Find the electric flux $\Phi_E$ through a Gaussian sphere of radius $r = 6\text{cm}$. 
The conducting spherical shell shown in cross section has a 4cm inner radius and an 8cm outer radius. A point charge $Q_p$ is placed at the center. The charges on the inner and outer surfaces of the shell are $Q_{\text{int}} = 5\text{nC}$ and $Q_{\text{ext}} = 7\text{nC}$, respectively.

(a) Find the charge $Q_p$.
(b) Find the magnitude of the electric field $E$ at radius $r = 10\text{cm}$.
(c) Find the surface charge density $\sigma_{\text{int}}$ on the inner surface of the shell.
(d) Find the electric flux $\Phi_E$ through a Gaussian sphere of radius $r = 6\text{cm}$.

Solution:

(a) $Q_p = -Q_{\text{int}} = -5\text{nC}$. 
The conducting spherical shell shown in cross section has a 4cm inner radius and an 8cm outer radius. A point charge $Q_p$ is placed at the center. The charges on the inner and outer surfaces of the shell are $Q_{\text{int}} = 5\text{nC}$ and $Q_{\text{ext}} = 7\text{nC}$, respectively.

(a) Find the charge $Q_p$.

(b) Find the magnitude of the electric field $E$ at radius $r = 10\text{cm}$.

(c) Find the surface charge density $\sigma_{\text{int}}$ on the inner surface of the shell.

(d) Find the electric flux $\Phi_E$ through a Gaussian sphere of radius $r = 6\text{cm}$.

Solution:

(a) $Q_p = -Q_{\text{int}} = -5\text{nC}$.

(b) $E[4\pi(10\text{cm})^2] = \frac{Q_p + Q_{\text{int}} + Q_{\text{ext}}}{\epsilon_0} = \frac{Q_{\text{ext}}}{\epsilon_0}$

$\Rightarrow E = 6300\text{N/C}$.
The conducting spherical shell shown in cross section has a 4cm inner radius and an 8cm outer radius. A point charge $Q_p$ is placed at the center. The charges on the inner and outer surfaces of the shell are $Q_{\text{int}} = 5\text{nC}$ and $Q_{\text{ext}} = 7\text{nC}$, respectively.

(a) Find the charge $Q_p$.

(b) Find the magnitude of the electric field $E$ at radius $r = 10\text{cm}$.

(c) Find the surface charge density $\sigma_{\text{int}}$ on the inner surface of the shell.

(d) Find the electric flux $\Phi_E$ through a Gaussian sphere of radius $r = 6\text{cm}$.

Solution:

(a) $Q_p = -Q_{\text{int}} = -5\text{nC}$.

(b) $E[4\pi(10\text{cm})^2] = \frac{Q_p + Q_{\text{int}} + Q_{\text{ext}}}{\epsilon_0} = \frac{Q_{\text{ext}}}{\epsilon_0}$

$\Rightarrow E = 6300\text{N/C}$.

(c) $\sigma_{\text{int}} = \frac{Q_{\text{int}}}{4\pi(4\text{cm})^2} = 2.49 \times 10^{-7}\text{C/m}^2$. 

$[\text{Image}]$
The conducting spherical shell shown in cross section has a 4cm inner radius and an 8cm outer radius. A point charge \( Q_p \) is placed at the center. The charges on the inner and outer surfaces of the shell are \( Q_{\text{int}} = 5 \text{nC} \) and \( Q_{\text{ext}} = 7 \text{nC} \), respectively.

(a) Find the charge \( Q_p \).
(b) Find the magnitude of the electric field \( E \) at radius \( r = 10 \text{cm} \).
(c) Find the surface charge density \( \sigma_{\text{int}} \) on the inner surface of the shell.
(d) Find the electric flux \( \Phi_E \) through a Gaussian sphere of radius \( r = 6 \text{cm} \).

Solution:

(a) \( Q_p = -Q_{\text{int}} = -5 \text{nC} \).

(b) \[
E[4\pi(10\text{cm})^2] = \frac{Q_p + Q_{\text{int}} + Q_{\text{ext}}}{\varepsilon_0} = \frac{Q_{\text{ext}}}{\varepsilon_0} \]
\( \Rightarrow E = 6300 \text{N/C} \).

(c) \( \sigma_{\text{int}} = \frac{Q_{\text{int}}}{4\pi(4\text{cm})^2} = 2.49 \times 10^{-7} \text{C/m}^2 \).

(d) \( \Phi_E = 0 \) inside conducting material.
Consider a region of uniform electric field as shown. A charged particle is projected at time $t = 0$ with initial velocity as shown.

(a) Find the components $a_x$ and $a_y$ of the acceleration at time $t = 0$.
(b) Find the components $v_x$ and $v_y$ of the velocity at time $t = 2s$.
(c) Find the kinetic energy at time $t = 2s$.
(d) Sketch the path of the particle as it moves from the initial position.
Consider a region of uniform electric field as shown. A charged particle is projected at time $t = 0$ with initial velocity as shown.

(a) Find the components $a_x$ and $a_y$ of the acceleration at time $t = 0$.
(b) Find the components $v_x$ and $v_y$ of the velocity at time $t = 2s$.
(c) Find the kinetic energy at time $t = 2s$.
(d) Sketch the path of the particle as it moves from the initial position.

Solution:

(a) $a_x = 0$, $a_y = \frac{q}{m}E = \frac{3 \times 10^{-3} \text{C}}{7 \times 10^{-3} \text{kg}}(2 \text{N/C}) = 0.857 \text{m/s}^2$. 

\[ m = 7 \text{g}, \quad q = 3 \text{mC} \]

\[ v_0 = 4 \text{m/s} \]
Consider a region of uniform electric field as shown. A charged particle is projected at time \( t = 0 \) with initial velocity as shown.

(a) Find the components \( a_x \) and \( a_y \) of the acceleration at time \( t = 0 \).
(b) Find the components \( v_x \) and \( v_y \) of the velocity at time \( t = 2s \).
(c) Find the kinetic energy at time \( t = 2s \).
(d) Sketch the path of the particle as it moves from the initial position.

Solution:

(a) \( a_x = 0 \), \( a_y = \frac{q}{m}E = \frac{3 \times 10^{-3}C}{7 \times 10^{-3}kg}(2N/C) = 0.857m/s^2 \).

(b) \( v_x = v_0 = 4m/s \), \( v_y = a_y t = (0.857m/s^2)(2s) = 1.71m/s \).
Consider a region of uniform electric field as shown. A charged particle is projected at time $t = 0$ with initial velocity as shown.

(a) Find the components $a_x$ and $a_y$ of the acceleration at time $t = 0$.

(b) Find the components $v_x$ and $v_y$ of the velocity at time $t = 2s$.

(c) Find the kinetic energy at time $t = 2s$.

(d) Sketch the path of the particle as it moves from the initial position.

**Solution:**

(a) $a_x = 0, \quad a_y = \frac{q}{m}E = \frac{3 \times 10^{-3} \text{C}}{7 \times 10^{-3} \text{kg}}(2 \text{N/C}) = 0.857 \text{m/s}^2$.

(b) $v_x = v_0 = 4 \text{m/s}, \quad v_y = a_y t = (0.857 \text{m/s}^2)(2 \text{s}) = 1.71 \text{m/s}$.

(c) $E = \frac{1}{2}(7 \times 10^{-3} \text{kg})[(4 \text{m/s})^2 + (1.71 \text{m/s})^2] = 6.62 \times 10^{-2} \text{J}$.
Consider a region of uniform electric field as shown. A charged particle is projected at time \( t = 0 \) with initial velocity as shown.

(a) Find the components \( a_x \) and \( a_y \) of the acceleration at time \( t = 0 \).

(b) Find the components \( v_x \) and \( v_y \) of the velocity at time \( t = 2s \).

(c) Find the kinetic energy at time \( t = 2s \).

(d) Sketch the path of the particle as it moves from the initial position.

**Solution:**

(a) \( a_x = 0 \), \( a_y = \frac{qE}{m} = \frac{3 \times 10^{-3} \text{C}}{7 \times 10^{-3} \text{kg}} (2 \text{N/C}) = 0.857 \text{m/s}^2 \).

(b) \( v_x = v_0 = 4 \text{m/s} \), \( v_y = a_y t = (0.857 \text{m/s}^2)(2 \text{s}) = 1.71 \text{m/s} \).

(c) \( E = \frac{1}{2}(7 \times 10^{-3} \text{kg})[(4 \text{m/s})^2 + (1.71 \text{m/s})^2] = 6.62 \times 10^{-2} \text{J} \).

(d) Upright parabolic path.
Consider two point charges positioned as shown.

(a) Find the magnitude of the electric force acting between the two charges.
(b) Find the electric potential at point $B$.
(c) Find the magnitude and direction of the electric field at point $A$. 
Consider two point charges positioned as shown.

(a) Find the magnitude of the electric force acting between the two charges.
(b) Find the electric potential at point $B$.
(c) Find the magnitude and direction of the electric field at point $A$.

Solution:

(a) $F = k \frac{|(9\text{nC})(13\text{nC})|}{(10\text{m})^2} = 10.53\text{nN}$. 
Consider two point charges positioned as shown.

(a) Find the magnitude of the electric force acting between the two charges.
(b) Find the electric potential at point \( B \).
(c) Find the magnitude and direction of the electric field at point \( A \).

Solution:

(a) \( F = k \frac{|(9\text{nC})(13\text{nC})|}{(10m)^2} = 10.53\text{nN} \).

(b) \( V_B = k \frac{(9\text{nC})}{6m} + k \frac{(13\text{nC})}{8m} = 13.5\text{V} + 14.6\text{V} = 28.1\text{V} \).
Consider two point charges positioned as shown.

(a) Find the magnitude of the electric force acting between the two charges.
(b) Find the electric potential at point $B$.
(c) Find the magnitude and direction of the electric field at point $A$.

Solution:

(a) $F = k \frac{|(9nC)(13nC)|}{(10m)^2} = 10.53nN$.

(b) $V_B = k \frac{(9nC)}{6m} + k \frac{(13nC)}{8m} = 13.5V + 14.6V = 28.1V$.

(c) $E_A = k \frac{9nC}{(5m)^2} - k \frac{13nC}{(5m)^2} = |3.24N/C - 4.68N/C| = 1.44N/C$.

Direction along hypotenuse toward upper left.
The conducting spherical shell shown in cross section has a 4cm inner radius and an 8cm outer radius. The excess charges on its inner and outer surfaces are $Q_{\text{int}} = +7\text{nC}$ and $Q_{\text{ext}} = +11\text{nC}$, respectively. There is a point charge $Q_p$ at the center of the cavity.

(a) Find the point charge $Q_p$.
(b) Find the surface charge density $\sigma_{\text{int}}$ on the inner surface of the shell.
(c) Find the magnitude $E$ of the electric field at radius $r = 10\text{cm}$.
The conducting spherical shell shown in cross section has a 4cm inner radius and an 8cm outer radius. The excess charges on its inner and outer surfaces are \( Q_{\text{int}} = +7 \text{nC} \) and \( Q_{\text{ext}} = +11 \text{nC} \), respectively. There is a point charge \( Q_p \) at the center of the cavity.

(a) Find the point charge \( Q_p \).
(b) Find the surface charge density \( \sigma_{\text{int}} \) on the inner surface of the shell.
(c) Find the magnitude \( E \) of the electric field at radius \( r = 10 \text{ cm} \).

Solution:

(a) \( Q_p = -Q_{\text{int}} = -7 \text{nC} \).
The conducting spherical shell shown in cross section has a 4cm inner radius and an 8cm outer radius. The excess charges on its inner and outer surfaces are \( Q_{\text{int}} = +7 \text{nC} \) and \( Q_{\text{ext}} = +11 \text{nC} \), respectively. There is a point charge \( Q_p \) at the center of the cavity.

(a) Find the point charge \( Q_p \).
(b) Find the surface charge density \( \sigma_{\text{int}} \) on the inner surface of the shell.
(c) Find the magnitude \( E \) of the electric field at radius \( r = 10 \text{cm} \).

Solution:

(a) \( Q_p = -Q_{\text{int}} = -7 \text{nC} \).

(b) \( \sigma_{\text{int}} = \frac{Q_{\text{int}}}{4\pi(4\text{cm})^2} = 3.48 \times 10^{-7} \text{C/m}^2 \).
The conducting spherical shell shown in cross section has a 4cm inner radius and an 8cm outer radius. The excess charges on its inner and outer surfaces are $Q_{\text{int}} = +7\text{nC}$ and $Q_{\text{ext}} = +11\text{nC}$, respectively. There is a point charge $Q_p$ at the center of the cavity.

(a) Find the point charge $Q_p$.

(b) Find the surface charge density $\sigma_{\text{int}}$ on the inner surface of the shell.

(c) Find the magnitude $E$ of the electric field at radius $r = 10\text{cm}$.

Solution:

(a) $Q_p = -Q_{\text{int}} = -7\text{nC}$.

(b) $\sigma_{\text{int}} = \frac{Q_{\text{int}}}{4\pi(4\text{cm})^2} = 3.48 \times 10^{-7} \text{ C/m}^2$.

(c) $E = \frac{kQ_{\text{ext}}}{(10\text{cm})^2} = 9900\text{N/C}$. 
Consider a region of uniform electric field $\mathbf{E} = -7\hat{i}$ N/C. At time $t = 0$ a charged particle (charge $q = -5\text{nC}$, mass $m = 4 \times 10^{-6}\text{kg}$) is released from rest at the origin of the coordinate system as shown.

(a) Find the acceleration, the velocity, and the position of the particle at $t = 0$.
(b) Find the acceleration, the velocity, and the position of the particle at $t = 3\text{s}$.
(c) Find the work $W$ done by the electric field on the particle between $t = 0$ and $t = 3\text{s}$. 

\[\text{Diagram of particle and electric field}\]
Consider a region of uniform electric field \( \mathbf{E} = -7\hat{i} \text{N/C} \). At time \( t = 0 \) a charged particle (charge \( q = -5\text{nC} \), mass \( m = 4 \times 10^{-6} \text{kg} \)) is released from rest at the origin of the coordinate system as shown.

(a) Find the acceleration, the velocity, and the position of the particle at \( t = 0 \).

(b) Find the acceleration, the velocity, and the position of the particle at \( t = 3 \text{s} \).

(c) Find the work \( W \) done by the electric field on the particle between \( t = 0 \) and \( t = 3 \text{s} \).

Solution:

(a) \[ a_x = \frac{(-5\text{nC})}{4 \times 10^{-6} \text{kg}} (-7\text{N/C}) = 8.75 \times 10^{-3} \text{m/s}^2, \]
\[ v_x = 0, \quad x = 0. \]
Consider a region of uniform electric field \( \mathbf{E} = -7 \hat{i} \text{N/C} \). At time \( t = 0 \) a charged particle (charge \( q = -5 \text{nC} \), mass \( m = 4 \times 10^{-6} \text{kg} \)) is released from rest at the origin of the coordinate system as shown.

(a) Find the acceleration, the velocity, and the position of the particle \( t = 0 \).

(b) Find the acceleration, the velocity, and the position of the particle at \( t = 3 \text{s} \).

(c) Find the work \( W \) done by the electric field on the particle between \( t = 0 \) and \( t = 3 \text{s} \).

Solution:

(a) \( a_x = \frac{(-5 \text{nC})}{4 \times 10^{-6} \text{kg}} (-7 \text{N/C}) = 8.75 \times 10^{-3} \text{m/s}^2 \), 
\( v_x = 0 \), \( x = 0 \).

(b) \( a_x = 8.75 \times 10^{-3} \text{m/s}^2 \), 
\( v_x = a_x t = (8.75 \times 10^{-3} \text{m/s}^2)(3 \text{s}) = 2.63 \times 10^{-2} \text{m/s} \), 
\( x = \frac{1}{2} a_x t^2 = (0.5)(8.75 \times 10^{-3} \text{m/s}^2)(3 \text{s})^2 = 3.94 \times 10^{-2} \text{m} \).
Consider a region of uniform electric field \( \mathbf{E} = -7\hat{i} \) N/C. At time \( t = 0 \) a charged particle (charge \( q = -5\text{nC} \), mass \( m = 4 \times 10^{-6}\text{kg} \)) is released from rest at the origin of the coordinate system as shown.

(a) Find the acceleration, the velocity, and the position of the particle \( t = 0 \).

(b) Find the acceleration, the velocity, and the position of the particle at \( t = 3\text{s} \).

(c) Find the work \( W \) done by the electric field on the particle between \( t = 0 \) and \( t = 3\text{s} \).

**Solution:**

(a) \( a_x = \frac{(-5\text{nC})}{4 \times 10^{-6}\text{kg}}(-7\text{N/C}) = 8.75 \times 10^{-3}\text{m/s}^2 \),
\( v_x = 0 \), \( x = 0 \).

(b) \( a_x = 8.75 \times 10^{-3}\text{m/s}^2 \),
\( v_x = a_x t = (8.75 \times 10^{-3}\text{m/s}^2)(3\text{s}) = 2.63 \times 10^{-2}\text{m/s} \),
\( x = \frac{1}{2}a_x t^2 = (0.5)(8.75 \times 10^{-3}\text{m/s}^2)(3\text{s})^2 = 3.94 \times 10^{-2}\text{m} \).

(c) \( W = F\Delta x = (-5\text{nC})(-7\text{N/C})(3.94 \times 10^{-2}\text{m}) = 1.38\text{nJ} \).
\( W = \Delta K = \frac{1}{2}(4 \times 10^{-6}\text{kg})(2.63 \times 10^{-2}\text{m/s})^2 = 1.38\text{nJ} \).