Pearson Physics Level 30
Unit VI Forces and Fields: Chapter 11
Solutions

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Concept Check

Since the baseball moves perpendicular to Earth's gravitational field, it follows a parabolic path toward home plate.

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Concept Check

Both vector arrows point toward the centre of the charged sphere, indicating that the direction of the field is the same. However, the longer vector arrow at position I indicates that the magnitude of the field is stronger there.

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Example 11.1 Practice Problems

1. ***Given***
   magnitude of the ion's charge $q_2 = 1.60 \times 10^{-19}$ C
   magnitude of the electric field $|\vec{E}| = 1.00 \times 10^{3}$ N/C

   Required
   magnitude of the electrostatic force on the ion ($|\vec{F}_e|$)

   Analysis and Solution
   To determine the magnitude of the electrostatic force on the ion, use:

$$|\vec{E}| = \frac{|\vec{F}_e|}{q_2}$$

$$\begin{aligned} |\vec{F}_e| &= |\vec{E}| q_2 \\ &= \left(1.00 \times 10^{3}\ \frac{\text{N}}{\cancel{\text{C}}}\right)(1.60 \times 10^{-19}\ \cancel{\text{C}}) \\ &= 1.60 \times 10^{-16}\ \text{N} \end{aligned}$$

   Paraphrase
   The magnitude of the electrostatic force on the ion is 1.60×10^{-16} N.

2. ***Given***
   magnitude of the electrostatic force on the small charged sphere $|\vec{F}_e| = 3.42 \times 10^{-18}$ N
   magnitude of the electric field $|\vec{E}| = 5.34$ N/C

   Required
   magnitude of the charge on the small charged sphere (q_2)

Analysis and Solution

To determine the magnitude of the charge on the small charged sphere, use:

$$|\vec{E}| = \frac{|\vec{F}_e|}{q_2}$$

$$q_2 = \frac{|\vec{F}_e|}{|\vec{E}|}$$

$$= \frac{3.42 \times 10^{-18}\ \cancel{\text{N}}}{5.34\ \frac{\cancel{\text{N}}}{\text{C}}}$$

$$= 6.40 \times 10^{-19}\ \text{C}$$

Paraphrase

The magnitude of the charge is 6.40×10^{-19} C.

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Example 11.2 Practice Problems

1. ***Given***

magnitude of the electric field $|\vec{E}| = 40.0$ N/C

$r = 2.00\ \text{cm} = 2.00 \times 10^{-2}\ \text{m}$

Required

charge producing the electric field (q)

Analysis and Solution

To calculate the charge producing the electric field, use:

$$|\vec{E}| = \frac{kq}{r^2}$$

$$q = \frac{|\vec{E}|r^2}{k}$$

$$= \frac{\left(40.0\ \frac{\cancel{\text{N}}}{\cancel{\text{C}}}\right)(2.00 \times 10^{-2}\ \cancel{\text{m}})^2}{8.99 \times 10^9\ \frac{\cancel{\text{N} \cdot \text{m}^2}}{\text{C}^{\cancel{2}}}}$$

$$= 1.78 \times 10^{-12}\ \text{C}$$

The electric field is directed away from the charge, so the source charge is positive.

Paraphrase

The source charge is $+1.78 \times 10^{-12}$ C.

2. ***Given***

magnitude of the electron's charge $q = 1.60 \times 10^{-19}$ C

magnitude of the electric field $|\vec{E}| = 5.14 \times 10^{11}$ N/C

Required

distance from the electron to point P in the field (r)

Analysis and Solution
To determine the distance from the electron,

$$\left|\vec{E}\right| = \frac{kq}{r^2}$$

$$r = \sqrt{\frac{kq}{\left|\vec{E}\right|}}$$

$$= \sqrt{\frac{\left(8.99 \times 10^9 \ \frac{\cancel{\text{N}} \cdot \text{m}^2}{\cancel{\text{C}^2}}\right)(1.60 \times 10^{-19}\ \cancel{\text{C}})}{5.14 \times 10^{11}\ \frac{\cancel{\text{N}}}{\cancel{\text{C}}}}}$$

$$= 5.29 \times 10^{-11}\ \text{m}$$

Paraphrase
The distance from the electron is 5.29×10^{-11} m.

Concept Check

Similarities between gravitational and electrostatic fields:
- Both fields exert force from a distance (action at a distance).
- The force exerted for point charges or masses follows the inverse square law.
- Both fields are infinite in range.

Differences between gravitational and electrostatic fields:
- Gravitational fields are due to mass, whereas electrostatic fields are due to charges.
- Gravitational fields produce forces of attraction only, whereas electrostatic fields produce forces of attraction and repulsion.

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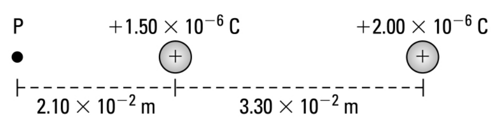
Example 11.3 Practice Problems

1. ***Given***

$q_1 = 1.50 \times 10^{-6}$ C

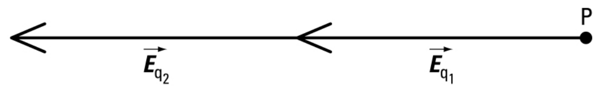
$q_2 = 2.00 \times 10^{-6}$ C

$r_{q_1 \text{ to } q_2} = 3.30 \times 10^{-2}$ m



Required
net electric field at point P, 2.10×10^{-2} m left of q_1 ($\vec{E}_{\text{net}}$)

Analysis and Solution
As shown in the following diagram, the electric field at point P created by q_1 is directed away from q_1 to the left.
The electric field at point P created by q_2 is directed away from q_2 to the left.



Use vector addition to determine the net electric field at point P:

$\vec{E}_{net} = \vec{E}_{q_1} + \vec{E}_{q_2}$

The distance between q_1 and point P is:

$r_{q_1 \text{ to P}} = 2.10 \times 10^{-2}$ m

The distance between q_2 and point P is:

$$r_{q_2 \text{ to P}} = 3.30 \times 10^{-2}\ \text{m} + 2.10 \times 10^{-2}\ \text{m}$$
$$= 5.40 \times 10^{-2}\ \text{m}$$

Consider right to be positive.

$$E_{net} = E_{q_1} + E_{q_2}$$
$$= \left(-\frac{kq_1}{r^2_{\text{P to } q_1}}\right) + \left(-\frac{kq_2}{r^2_{\text{P to } q_2}}\right)$$
$$= \left(-\frac{\left(8.99 \times 10^9\ \frac{\text{N}\cdot\text{m}^2}{\text{C}^{\not 2}}\right)(1.50 \times 10^{-6}\ \not\text{C})}{(2.10 \times 10^{-2}\ \text{m})^2}\right) + \left(-\frac{\left(8.99 \times 10^9\ \frac{\text{N}\cdot\text{m}^2}{\text{C}^{\not 2}}\right)(2.00 \times 10^{-6}\ \not\text{C})}{(5.40 \times 10^{-2}\ \text{m})^2}\right)$$
$$= (-3.058 \times 10^7\ \text{N/C}) + (-6.166 \times 10^6\ \text{N/C})$$
$$= -3.67 \times 10^7\ \text{N/C}$$

Paraphrase

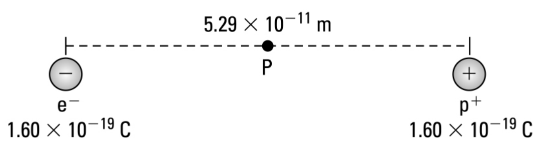
The net electric field at point P is 3.67×10^7 N/C [left].

2. ***Given***

$q_1 = -1.60 \times 10^{-19}$ C

$q_2 = +1.60 \times 10^{-19}$ C

$r_{q_1 \text{ to } q_2} = 5.29 \times 10^{-11}$ m



Required

net electric field at point P on an imaginary line midway between the two charges ($\vec{E}_{net}$)

Analysis and Solution

The electric field at point P created by the electron (q_1) is to the left.

The electric field at point P created by the proton (q_2) is to the left.

Use vector addition to determine the net electric field at point P:

$\vec{E}_{net} = \vec{E}_{q_1} + \vec{E}_{q_2}$

The distance between q_1 and point P and q_2 and point P is

$$r_{q_1 \text{ to P}} = \frac{5.29\times10^{-11}\ \text{m}}{2}$$

$$= 2.645\times10^{-11}\ \text{m}$$

Consider right to be positive.

$$E_{\text{net}} = E_{q_1} + E_{q_2}$$

$$= \left(-\frac{kq_1}{r^2_{\text{P to } q_1}}\right) + \left(-\frac{kq_2}{r^2_{\text{P to } q_2}}\right)$$

$$= \left(-\frac{\left(8.99\times10^9\ \frac{\text{N}\cdot\text{m}^2}{\text{C}^{\not 2}}\right)(1.60\times10^{-19}\ \not{\text{C}})}{(2.645\times10^{-11}\ \text{m})^2}\right) + \left(-\frac{\left(8.99\times10^9\ \frac{\text{N}\cdot\text{m}^2}{\text{C}^{\not 2}}\right)(1.60\times10^{-19}\ \not{\text{C}})}{(2.645\times10^{-11}\ \text{m})^2}\right)$$

$$= (-2.056\times10^{12}\ \text{N/C}) + (-2.056\times10^{12}\ \text{N/C})$$

$$= -4.11\times10^{12}\ \text{N/C}$$

Paraphrase

The net electric field at point P is 4.11×10^{12} N/C [left] or toward the electron.

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Example 11.4 Practice Problems

1. ***Given***

$q_A = 2.00$ C

$q_B = 2.00$ C

$r_{q_A \text{ to P}} = 1.00\times10^{-1}$ m

$r_{q_B \text{ to P}} = 1.00\times10^{-1}$ m

$\theta_{q_A} = 72.5°$ to the horizontal

$\theta_{q_B} = 72.5°$ to the horizontal

Required

net electric field at point P ($\vec{E}_{\text{net}}$)

Analysis and Solution

Since q_A is a positive charge, the electric field created by q_A at point P is directed away from q_A and away from point P along the imaginary line between q_A and P.

Since q_B is a positive charge, the electric field created by q_B at point P is directed away from q_B and away from point P along the imaginary line between q_B and P.

The distance between q_A and P is 1.00×10^{-1} m.

The distance between q_B and P is 1.00×10^{-1} m.

Resolve each electric field into x and y components. Use vector addition to determine the resultant electric field.

Determine the magnitude of the electric field created by q_A at point P:

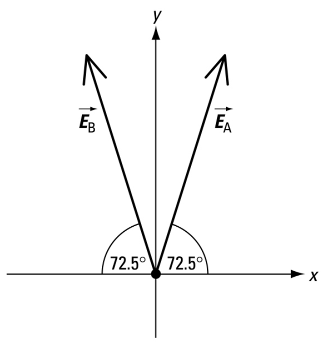
$$\left|\vec{E}_A\right| = \frac{kq_A}{r^2_{q_A \text{ to P}}}$$

$$= \frac{\left(8.99 \times 10^9 \ \frac{\text{N} \cdot \text{m}^2}{\text{C}^{\not{2}}}\right)(2.00 \ \not{\text{C}})}{(1.00 \times 10^{-1} \ \text{m})^2}$$

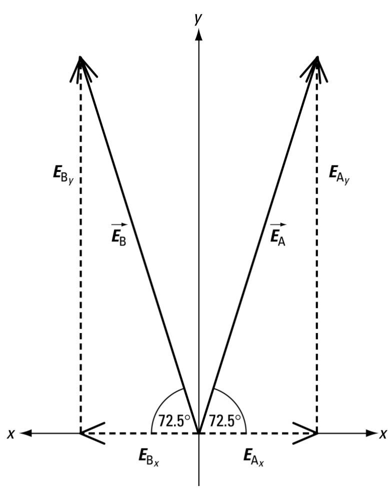
$$= 1.798 \times 10^{12} \ \text{N/C}$$

Since the charge and the distance to point P are the same, $\left|\vec{E}_B\right|$ also equals 1.798×10^{12} N/C .

The directions of $\vec{E}_A$ and $\vec{E}_B$ are shown below.



The x and y components for $\vec{E}_A$ and $\vec{E}_B$ are shown below.



$$E_{A_x} = (1.798 \times 10^{12} \text{ N/C})(\cos 72.5°)$$
$$= 5.407 \times 10^{11} \text{ N/C}$$
$$E_{A_y} = (1.798 \times 10^{12} \text{ N/C})(\sin 72.5°)$$
$$= 1.715 \times 10^{12} \text{ N/C}$$

Similarly,

$$E_{B_x} = -(1.798 \times 10^{12} \text{ N/C})(\cos 72.5°)$$
$$= -5.407 \times 10^{11} \text{ N/C}$$

$E_{B_y} = (1.798 \times 10^{12}\ \text{N/C})(\sin 72.5°)$

$= 1.715 \times 10^{12}\ \text{N/C}$

$E_{\text{net}_x} = (5.407 \times 10^{11}\ \text{N/C}) + (-5.407 \times 10^{11}\ \text{N/C})$

$= 0$

$E_{\text{net}_y} = (1.715 \times 10^{12}\ \text{N/C}) + (1.715 \times 10^{12}\ \text{N/C})$

$= 3.43 \times 10^{12}\ \text{N/C}$

Since $E_{\text{net}_x} = 0$, $E_{\text{net}} = E_{\text{net}_y}$. Since the angles with respect to the *x*-axis are the same, the direction of E_{net} is 90.0°.

Paraphrase

The net electric field at point P is 3.43×10^{12} N/C [90.0°].

2. ***Given***

$q_A = 4.00\ \text{C}$

$q_B = 4.00\ \text{C}$

$r_{q_A \text{ to P}} = 2.00\ \text{cm} = 2.00 \times 10^{-2}\ \text{m}$

$r_{q_B \text{ to P}} = 2.00\ \text{cm} = 2.00 \times 10^{-2}\ \text{m}$

$\theta_{q_A} = 60°$ to the horizontal

$\theta_{q_B} = 60°$ to the horizontal

Required

net electric field at the third vertex of the triangle, point P ($\vec{E}_{\text{net}}$)

Analysis and Solution

Since q_A is a positive charge, the electric field created by q_A at point P is directed away from q_A and away from point P along the imaginary line between q_A and P.
Since q_B is a positive charge, the electric field created by q_B at point P is directed away from q_B and away from point P along the imaginary line between q_B and P.
The distance between q_A and P is 2.00×10^{-2} m.
The distance between q_B and P is 2.00×10^{-2} m.
Determine the electric field created by q_A at point P:

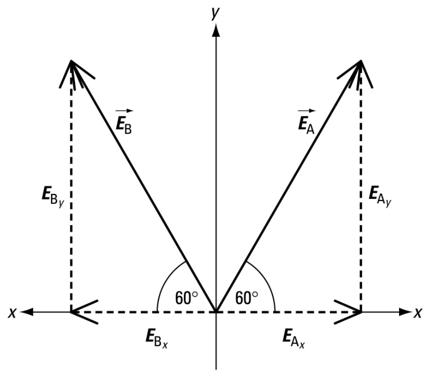
$$\left|\vec{E}_A\right| = \frac{kq_A}{r_{q_A \text{ to P}}^2}$$

$$= \frac{\left(8.99 \times 10^9\ \frac{\text{N}\cdot\text{m}^2}{\text{C}^{\not{2}}}\right)(4.00\ \not{\text{C}})}{(2.00 \times 10^{-2}\ \not{\text{m}})^2}$$

$$= 8.990 \times 10^{13}\ \text{N/C}$$

Since the charge and the distance to point P are the same, $\left|\vec{E}_B\right|$ also equals 8.990×10^{13} N/C.

The directions and *x* and *y* components of $\vec{E}_A$ and $\vec{E}_B$ are shown on the following page.



The components of $\vec{E}_B$ are:

$E_{A_x} = (8.990 \times 10^{13}\text{ N/C})(\cos 60°)$
$= 4.495 \times 10^{13}\text{ N/C}$

$E_{A_y} = (8.990 \times 10^{13}\text{ N/C})(\sin 60°)$
$= 7.786 \times 10^{13}\text{ N/C}$

Similarly, the components of $\vec{E}_B$ are:

$E_{B_x} = -(8.990 \times 10^{13}\text{ N/C})(\cos 60°)$
$= -4.495 \times 10^{13}\text{ N/C}$

$E_{B_y} = (8.990 \times 10^{13}\text{ N/C})(\sin 60°)$
$= 7.786 \times 10^{13}\text{ N/C}$

$$E_{\text{net}_x} = E_{A_x} + E_{B_x} = (4.495\times10^{13}\text{ N/C}) + (-4.495\times10^{13}\text{ N/C}) = 0\text{ N/C}$$

$$E_{\text{net}_y} = E_{A_y} + E_{B_y} = (7.786\times10^{13}\text{ N/C}) + (7.786\times10^{13}\text{ N/C}) = 1.56\times10^{14}\text{ N/C}$$

Since $E_{\text{net}_x} = 0$, $E_{\text{net}} = E_{\text{net}_y}$.

Since the angles with respect to the *x*-axis are the same, the direction of E_{net} is 90°.

Paraphrase

The net electric field at point P is 1.56×10^{14} N/C [90°].

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11.1 Check and Reflect

Knowledge

1. An electric field is a region of electrical influence surrounding a source charge, whereas an electric force is the electrical influence of the field on a test charge placed in the electric field. The force is only produced when another charge is placed in the field, whereas the field can exist without the presence of the test charge.

2. A field theory was necessary to explain "action at a distance."

3. The direction of an electric field at a point is defined by the direction of the electric force exerted by a test charge at that point. The electric field is directed toward a negative source charge and away from a positive source charge.
4. An electric field is a vector field because it has magnitude and direction.
5. The differing lengths of the vector arrows indicate differing magnitudes of the electric fields at different positions around charges. The different directions of the vector arrows indicate different directions of the electric fields.

6. Since $|\vec{E}| = \frac{kq_1}{r^2}$, then:

(a) If the magnitude of the source charge is halved, the magnitude of the electric field must be halved.

(b) If the sign of the charge is changed, only the direction of the electric field changes, not the magnitude.

(c) If the magnitude of the test charge is halved, there is no effect on the magnitude of the electric field produced by the source charge.

Applications

7. (a) To determine the electric field of the charge, use:

$$\begin{aligned}|\vec{E}| &= \frac{kq}{r^2} \\ &= \frac{\left(8.99\times10^9\ \frac{\text{N}\cdot\cancel{\text{m}^2}}{\cancel{\text{C}^2}}\right)(4.50\times10^{-6}\ \cancel{\text{C}})}{(0.300\ \cancel{\text{m}})^2} \\ &= 4.495\times10^5\ \text{N/C} \\ &= 4.50\times10^5\ \text{N/C}\end{aligned}$$

The electric field is 4.50×10^5 N/C [right].

(b) To determine the electric force on the charge, use:

$$\begin{aligned}\vec{E} &= \frac{\vec{F}_\text{e}}{q} \\ \vec{F}_\text{e} &= \vec{E}q \\ &= (+4.495\times10^5\ \text{N}/\cancel{\text{C}})(+2.00\times10^{-8}\ \cancel{\text{C}}) \\ &= +8.99\times10^{-3}\ \text{N}\end{aligned}$$

The electric force is 8.99×10^{-3} N [right].

8. (a) To determine the electric field of the charge, use:

$$\begin{aligned}|\vec{E}| &= \frac{|\vec{F}_\text{e}|}{q} \\ &= \frac{5.10\times10^{-2}\ \text{N}}{2.50\times10^{-6}\ \text{C}} \\ &= 2.04\times10^4\ \text{N/C}\end{aligned}$$

The electric field of the charge is 2.04×10^4 N/C [away from the larger sphere].

(b) To determine magnitude of the charge, use:

$$\left|\vec{E}\right| = \frac{kq}{r^2}$$

$$q = \frac{\left|\vec{E}\right| r^2}{k}$$

$$= \frac{\left(2.04 \times 10^4 \ \frac{\cancel{\text{N}}}{\text{C}}\right)(0.0400 \ \cancel{\text{m}})^2}{8.99 \times 10^9 \ \frac{\cancel{\text{N}} \cdot \cancel{\text{m}^2}}{\text{C}^{\cancel{2}}}}$$

$$= 3.63 \times 10^{-9} \text{ C}$$

Since the force is attractive, the larger charge is $+3.63 \times 10^{-9}$ C.

9. ***Given***

$q_1 = -3.00 \times 10^{-3}$ C

$q_2 = -2.00 \times 10^{-3}$ C

$r_{q_1 \text{ to } q_2} = 1.20$ m

Required

(a) net electric field at point P, midway between the two charges ($\vec{E}_{\text{net}}$)

(b) point between the two charges where the net electric field is zero ($r_{q_1 \text{ to P}}$)

Analysis and Solution

(a) The electric field at point P created by q_1 is to the right.
The electric field at point P created by q_2 is to the left.
Use vector addition to determine the net electric field at point P:

$$\vec{E}_{\text{net}} = \vec{E}_{q_1} + \vec{E}_{q_2}$$

The distance midway between the two charges is:

$$r = \frac{1.20 \text{ m}}{2}$$

$$= 0.600 \text{ m}$$

Consider right to be positive.

$$E_{\text{net}} = E_{q_1} + E_{q_2}$$

$$= \left(\frac{kq_1}{r^2_{\text{P to } q_1}}\right) + \left(-\frac{kq_2}{r^2_{\text{P to } q_2}}\right)$$

$$= \frac{\left(8.99 \times 10^9 \ \frac{\text{N} \cdot \cancel{\text{m}^2}}{\cancel{\text{C}^2}}\right)(3.00 \times 10^{-3} \ \cancel{\text{C}})}{(0.600 \ \cancel{\text{m}})^2} - \frac{\left(8.99 \times 10^9 \ \frac{\text{N} \cdot \cancel{\text{m}^2}}{\cancel{\text{C}^2}}\right)(2.00 \times 10^{-3} \ \cancel{\text{C}})}{(0.600 \ \cancel{\text{m}})^2}$$

$$= 7.492 \times 10^7 \text{ N/C} - 4.994 \times 10^7 \text{ N/C}$$

$$= 2.50 \times 10^7 \text{ N/C}$$

(b) The electric field at point P created by q_1 is to the right.
The electric field at point P created by q_2 is to the left.
The distance between q_1 and point P is:

$r_{q_1 \text{ to P}}$

The distance between q_2 and point P is:

$r_{q_2 \text{ to P}} = 1.20 \text{ m} - r_{q_1 \text{ to P}}$

Since the net electric field between the two charges is zero, at point P,

$$\left|\vec{E}_{q_1}\right| = \left|E_{q_2}\right|$$

$$\left(\frac{kq_1}{r^2_{\text{P to } q_1}}\right) = \left(\frac{kq_2}{r^2_{\text{P to } q_2}}\right)$$

$$\frac{\left(8.99\times10^9\ \frac{\text{N}\cdot\text{m}^2}{\text{C}^2}\right)(3.00\times10^{-3}\ \text{C})}{(r_{q_1 \text{ to P}}\ \text{m})^2} = \frac{\left(8.99\times10^9\ \frac{\text{N}\cdot\text{m}^2}{\text{C}^2}\right)(2.00\times10^{-3}\ \text{C})}{(1.20 - r_{q_1 \text{ to P}}\ \text{m})^2}$$

$$r_{q_1 \text{ to P}} = 0.661 \text{ m}$$

Paraphrase

(a) The net electric field at point P is 2.50×10^7 N/C [right] or toward the −3.00 mC charge.

(b) The net electric field is zero, 0.661 m [left of the −3.00 mC charge].

Extension

10. Since the electric fields produced by the charges are all equal at the intersection of the diagonals and in opposite directions, then all the fields cancel each other out, and the net electric field at the intersection of the two diagonals is zero.

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Example 11.5 Practice Problems

1. The work done against the electrostatic forces is W. The electric potential energy gain is ΔE_p. In a conservative system, $\Delta E_p = W$, so

$$\begin{aligned} W &= \Delta E_p \\ &= 1.60\times10^{-19} \text{ J} \end{aligned}$$

The work done on the charge is 1.60×10^{-19} J.

2. The work done against the electrostatic forces is W. The change in electric potential energy is ΔE_p. In a conservative system, $\Delta E_p = W$, so

$$\begin{aligned} W &= \Delta E_p \\ &= E_{p_f} - E_{p_i} \\ &= 8.00 \times 10^{-19} \text{ J} - 6.40 \times 10^{-19} \text{ J} \\ &= 1.60 \times 10^{-19} \text{ J} \end{aligned}$$

The work done on the charge is 1.60×10^{-19} J.

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Example 11.6 Practice Problem

1. The work done against the electrostatic forces is W. In a conservative system, $\Delta E_p = W$, so

$$W = \Delta E_p$$
$$= 4.00 \times 10^5 \text{ J}$$

The work done on the charge was 4.00×10^5 J.

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Concept Check

The charge would possess twice as much electric potential energy. However, the electric potential remains the same.

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Example 11.7 Practice Problems

1. To calculate the potential difference, use:

$$\Delta V = \frac{\Delta E_p}{q}$$
$$= \frac{60 \text{ J}}{5.0 \text{ C}}$$
$$= 12 \text{ V}$$

The potential difference is 12 V.

2. To calculate the energy, use:

$$\Delta V = \frac{\Delta E_p}{q}$$
$$\Delta E_p = \Delta V q$$
$$= (500 \text{ V})(2.00 \times 10^{-2} \text{ C})$$
$$= 10.0 \text{ J}$$

The energy gain is 10.0 J.

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Example 11.8 Practice Problems

1. ***Given***

$\Delta E_p = 160$ J

$q = 2.00$ C

Required

potential difference between the two positions (ΔV)

Analysis and Solution

To calculate the electric potential difference, use $\Delta V = \dfrac{\Delta E_p}{q}$.

$$\Delta V = \frac{\Delta E_p}{q}$$
$$= \frac{160 \text{ J}}{2.00 \text{ C}}$$
$$= 80.0 \text{ V}$$

Paraphrase

The potential difference between the two positions is 80.0 V.

2. ***Given***

$\Delta V = 4.00 \times 10^4$ V

$q = 1.60 \times 10^{-19}$ C

Required

electric potential energy gained by the charge (ΔE_p) in joules (J) and electron volts (eV)

Analysis and Solution

The electric potential difference between two positions can be determined as:

$$V = \Delta V$$
$$= 4.00 \times 10^4 \text{ V}$$
$$V = \frac{\Delta E_p}{q}$$
$$\Delta E_p = Vq$$
$$= \left(4.00 \times 10^4 \text{ V}\right)\left(1.60 \times 10^{-19} \text{ C}\right)$$
$$= 6.40 \times 10^{-15} \text{ J}$$

Convert to electron volts:

$$\Delta E_p = (6.40 \times 10^{-15} \not{\text{J}})\left(\frac{1 \text{ eV}}{1.60 \times 10^{-19} \not{\text{J}}}\right)$$
$$= 4.00 \times 10^4 \text{ eV}$$

Paraphrase

The electric potential energy gained by moving the charge between the two positions is 6.40×10^{-15} J or 4.00×10^4 eV.

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Example 11.9 Practice Problems

1. ***Given***

$|\vec{E}| = 2.2 \times 10^4$ V/m

$\Delta d = 5.0 \times 10^{-4}$ m

Required

potential difference between the plates (ΔV)

Analysis and Solution

The potential difference between the plates is the electric potential difference, $V = \Delta V$.

To calculate the potential difference between the plates, use:

$$\left|\vec{E}\right| = \frac{\Delta V}{\Delta d}$$

$$\begin{aligned}\Delta V &= \left|\vec{E}\right|\Delta d \\ &= \left(2.2 \times 10^4 \ \frac{\text{V}}{\cancel{\text{m}}}\right)(5.0 \times 10^{-4} \ \cancel{\text{m}}) \\ &= 11 \text{ V}\end{aligned}$$

Paraphrase

The potential difference between the plates is 11 V.

2. ***Given***

$\left|\vec{E}\right| = 3.00 \times 10^6$ V/m

$\Delta d = 5.00 \times 10^{-3}$ m

Required

potential difference between the electrode faces (ΔV)

Analysis and Solution

The electric potential difference between the electrode faces is:

$$\left|\vec{E}\right| = \frac{\Delta V}{\Delta d}$$

$$\begin{aligned}\Delta V &= \left|\vec{E}\right|\Delta d \\ &= \left(3.00 \times 10^6 \ \frac{\text{V}}{\cancel{\text{m}}}\right)(5.00 \times 10^{-3} \ \cancel{\text{m}}) \\ &= 1.50 \times 10^4 \text{ V}\end{aligned}$$

Paraphrase

The potential difference between the electrode faces is 1.50×10^4 V.

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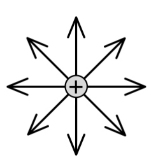
11.2 Check and Reflect

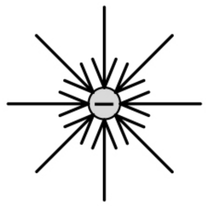
Knowledge

1. An electric field vector is an arrow indicating the magnitude and direction at a particular point of the electric field surrounding a charged object. An electric field line is a line drawn from the charged object to infinity or from infinity to the charged object. It shows only the direction of the electric field. The density of the electric field lines indicates the magnitude of the electric field.

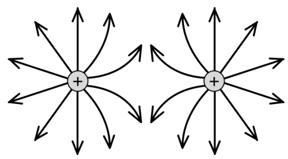
2. (a)



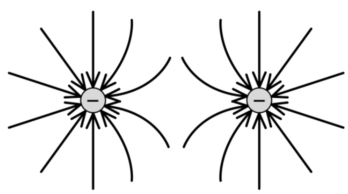
(b)



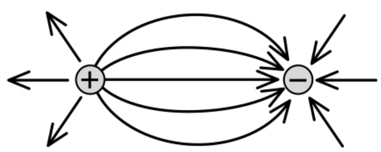
(c)



(d)



(e)



3. Electric potential is the change in the amount of electric potential energy stored per unit of charge, whereas electric potential energy is the total amount of electric energy at a point.

Applications

4. (a) To calculate the electric force on the proton, use:

$$|\vec{E}| = \frac{|\vec{F}_e|}{q}$$

$$\begin{aligned} |\vec{F}_e| &= |\vec{E}|q \\ &= \left(150 \frac{\text{N}}{\cancel{\text{C}}}\right)(1.60 \times 10^{-19} \cancel{\text{C}}) \\ &= 2.40 \times 10^{-17} \text{ N} \end{aligned}$$

The electric force on the proton is 2.40×10^{-17} N [downward].

(b) To calculate the gravitational force on the proton, use:

$$g = \frac{F_g}{m}$$

$$F_g = gm$$

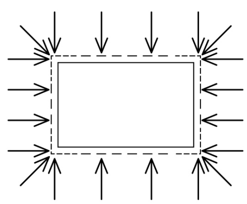
$$= \left(9.80 \frac{\text{N}}{\cancel{\text{kg}}}\right)(1.67 \times 10^{-27}\ \cancel{\text{kg}})$$

$$= 1.64 \times 10^{-26}\ \text{N}$$

The gravitational force on the proton is 1.64×10^{-26} N [downward].

5. (a) Since charges accumulate at points or corners, the charge will be more concentrated at the corners of the box than on the faces.

(b)



Note that there are no electric field lines inside the box.

6. To calculate the magnitude of the electric field, use:

$$|\vec{E}| = \frac{kq}{r^2}$$

$$= \frac{\left(8.99 \times 10^9 \frac{\text{N} \cdot \cancel{\text{m}^2}}{\text{C}^{\cancel{2}}}\right)(1.60 \times 10^{-8}\ \cancel{\text{C}})}{(0.300\ \cancel{\text{m}})^2}$$

$$= 1.60 \times 10^3\ \text{N/C}$$

The magnitude of the electric field is 1.60×10^3 N/C.

7. ***Given***

$q_1 = -3.2 \times 10^{-6}$ C

$q_2 = -6.4 \times 10^{-6}$ C

$r_{q_1 \text{ to } q_2} = 0.40$ m

Required

net electric field at point P, midway between the two charges ($\vec{E}_{\text{net}}$)

Analysis and Solution

The electric field created by q_1 at point P is to the left.

The electric field created by q_2 at point P is to the right.

The distance midway between the two charges is:

$$r = \frac{0.40\ \text{m}}{2}$$

$$= 0.20\ \text{m}$$

Since the two electric field vectors are along the same line, the net electric field can be determined by adding the individual field vectors.

$$\vec{E}_{\text{net}} = \vec{E}_{q_1} + \vec{E}_{q_2}$$

Consider toward the −6.4 μC charge to be positive.

$$E_{net} = E_{q_1} + E_{q_2}$$
$$= -\frac{kq_1}{r^2_{q_1 \text{ to P}}} + \frac{kq_2}{r^2_{q_2 \text{ to P}}}$$
$$= -\frac{\left(8.99\times10^9\ \frac{\text{N}\cdot\text{m}^2}{\text{C}^2}\right)(3.2\times10^{-6}\ \text{C})}{(0.20\ \text{m})^2} + \frac{\left(8.99\times10^9\ \frac{\text{N}\cdot\text{m}^2}{\text{C}^2}\right)(6.4\times10^{-6}\ \text{C})}{(0.20\ \text{m})^2}$$
$$= -7.19\times10^5\ \text{N/C} + 1.44\times10^6\ \text{N/C}$$
$$= 7.2\times10^5\ \text{N/C}$$

Paraphrase

The net electric field at point P is 7.2×10^5 N/C [toward the −6.4 μC charge].

8. To determine the energy gained by the charge, use:

$$V = \frac{\Delta E_p}{q}$$
$$\Delta E_p = Vq$$
$$= (1.00 \times 10^3\ \text{V})(2.00\ \text{C})$$
$$= 2.00 \times 10^3\ \text{J}$$

The energy gained by the charge is 2.00×10^3 J.

9. ***Given***

$q_1 = -1.0 \times 10^{-5}$ C

$q_2 = +5.0 \times 10^{-5}$ C

$r_{q_1 \text{ to P}} = 0.15$ m

$r_{q_2 \text{ to P}} = 0.45$ m

Required

net electric field at point P ($\vec{E}_{net}$)

Analysis and Solution

The electric field created by q_1 at point P is to the left.
The electric field created by q_2 at point P is to the right.
The distance between q_1 and point P is:

$r_{q_1 \text{ to P}} = 0.15$ m

The distance between q_2 and point P is:

$$r_{q_2 \text{ to P}} = 0.15\ \text{m} + 0.30\ \text{m}$$
$$= 0.45\ \text{m}$$

Since the two electric field vectors are along the same line, the net electric field can be determined by adding the individual field vectors.

$$\vec{E}_{net} = \vec{E}_{q_1} + \vec{E}_{q_2}$$

Consider right to be positive.

$$
\begin{aligned}
E_{net} &= E_{q_1} + E_{q_2} \\
&= -\frac{kq_1}{r^2_{\text{P to } q_1}} + \frac{kq_2}{r^2_{\text{P to } q_2}} \\
&= -\frac{\left(8.99\times10^9\ \frac{\text{N}\cdot\text{m}^2}{\text{C}^2}\right)(1.0\times10^{-5}\ \text{C})}{(0.15\ \text{m})^2} + \frac{\left(8.99\times10^9\ \frac{\text{N}\cdot\text{m}^2}{\text{C}^2}\right)(5.0\times10^{-5}\ \text{C})}{(0.45\ \text{m})^2} \\
&= -4.00\times10^6\ \text{N/C} + 2.22\times10^6\ \text{N/C} \\
&= -1.8\times10^6\ \text{N/C}
\end{aligned}
$$

Paraphrase

The net electric field at point P is 1.8×10^6 N/C [left].

10. (a) To determine the magnitude of the electric field between the plates, use:

$$
\begin{aligned}
\left|\vec{E}\right| &= \frac{\Delta V}{\Delta d} \\
&= \frac{12.0\ \text{V}}{6.00 \times 10^{-4}\ \text{m}} \\
&= 2.00 \times 10^4\ \text{V/m}
\end{aligned}
$$

The electric field between the plates has a magnitude of 2.00×10^4 V/m.

(b) To determine the change in electric potential energy of the charge, use:

$$
\begin{aligned}
\Delta V &= \frac{\Delta E_p}{q} \\
\Delta E_p &= \Delta V q \\
&= (12.0\ \text{V})(3.22 \times 10^{-6}\ \text{C}) \\
&= 3.86 \times 10^{-5}\ \text{J}
\end{aligned}
$$

The electric potential energy gained by the charge is 3.86×10^{-5} J.

Extensions

11. Charges accumulate on the outside surface of a hollow charged object, so the outside surface will be charged while the inside surface will not be charged. This effect protects the occupants inside a car if lightning strikes the car.

12. Charges accumulate on the outside surface, so only the electroscope connected to the outside surface will be affected.

13. No. Work is done only when there is a change in electric potential, similar to carrying an object parallel to the surface of Earth. No work is done on the object if it does not change its vertical position relative to the surface of Earth.

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Example 11.10 Practice Problems

1. ***Given***

$q = -3.00 \times 10^{-9}$ C

$E_{p_i} = 3.20 \times 10^{-12}$ J

Required

kinetic energy (E_{k_f})

Analysis and Solution
This system is conservative, so the loss of electric potential energy is converted to a gain of kinetic energy, according to the law of conservation of energy:
$E_{p_i} + E_{k_i} = E_{p_f} + E_{k_f}$
To determine the kinetic energy of the negative charge, calculate E_{k_f}.

$$E_{p_i} + E_{k_i} = E_{p_f} + E_{k_f}$$
$$3.20 \times 10^{-12}\ \text{J} + 0\ \text{J} = 0\ \text{J} + E_{k_f}$$
$$E_{k_f} = 3.20 \times 10^{-12}\ \text{J}$$

Paraphrase
The kinetic energy of the negative charge is 3.20×10^{-12} J.

2. ***Given***
$q = -2.00 \times 10^{-6}$ C
$v_f = 5.20 \times 10^{4}$ m/s
$m = 1.70 \times 10^{-3}$ kg
Required
electric potential energy lost by the charge (E_{p_i})
Analysis and Solution
This system is conservative, so a loss of electric potential energy is converted to a gain of kinetic energy, according to the law of conservation of energy:
$E_{p_i} + E_{k_i} = E_{p_f} + E_{k_f}$
Therefore, the initial potential energy of the negative charge was all converted to kinetic energy.
To determine the kinetic energy of the sphere just before it strikes the positive charge, use: $E_k = \frac{1}{2}mv^2$.

$$E_k = \frac{1}{2}mv^2$$
$$= \frac{1}{2}\left(1.70 \times 10^{-3}\ \text{kg}\right)\left(5.20 \times 10^{4}\ \text{m/s}\right)^2$$
$$= 2.30 \times 10^{6}\ \text{J}$$
$$E_{p_i} + E_{k_i} = E_{p_f} + E_{k_f}$$
$$E_{p_i} + 0\ \text{J} = 0\ \text{J} + 2.30 \times 10^{6}\ \text{J}$$
$$E_{p_i} = 2.30 \times 10^{6}\ \text{J}$$

Paraphrase
The electric potential energy lost is 2.30×10^{6} J.

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Concept Check

- When the initial motion of the charge is perpendicular to the plates, the charge will travel parallel to the electric field lines and perpendicular to the plates.
- When the initial motion of the charge is parallel to the plates, the charge will accelerate and travel in parabolic motion between the parallel plates.

Example 11.11 Practice Problems

1. *Given*

$q = +3.20 \times 10^{-19}$ C
$\Delta V = 4.00 \times 10^{4}$ V
$m = 6.65 \times 10^{-27}$ kg

Required

final speed of the alpha particle just before it strikes the negative plate (v)

Analysis and Solution

The initial electric potential energy of the alpha particle at the positive plate is:

$E_{p_i} = Vq$

Since it is at rest, its initial kinetic energy is:

$E_{k_i} = 0$ J

The final electric potential energy of the alpha particle at the negative plate is:

$E_{p_f} = 0$ J

This system is conservative, so a loss of electric potential energy is converted to a gain of kinetic energy, according to the law of conservation of energy:

$E_{p_i} + E_{k_i} = E_{p_f} + E_{k_f}$

To solve for the speed of the alpha particle, use $E_k = \frac{1}{2}mv^2$.

$$\begin{aligned}
E_{p_i} + E_{k_i} &= E_{p_f} + E_{k_f} \\
E_{p_i} + 0\text{ J} &= 0\text{ J} + E_{k_f} \\
Vq + 0\text{ J} &= 0\text{ J} + \frac{1}{2}mv^2 \\
Vq &= \frac{1}{2}mv^2 \\
v &= \sqrt{\frac{2Vq}{m}} \\
&= \sqrt{\frac{2\left(4.00\times10^{4}\text{ V}\right)\left(3.20\times10^{-19}\text{ C}\right)}{6.65\times10^{-27}\text{ kg}}} \\
&= 1.96\times10^{6}\text{ m/s}
\end{aligned}$$

Paraphrase

The final speed of the alpha particle just before it strikes the negative plate is 1.96×10^{6} m/s.

2. *Given*

$q = -6.00\times10^{-6}$ C

$\Delta E_k = 3.20\times10^{-4}$ J

Required

potential difference between the two parallel plates (ΔV)

Analysis and Solution

From the law of conservation of energy, potential energy lost is kinetic energy gained.

$$E_{p_i} + E_{k_i} = E_{p_f} + E_{k_f}$$
$$E_{p_i} + 0 \text{ J} = 0 \text{ J} + E_{k_f}$$

Therefore, the potential energy of the charge is 3.20×10^{-4} J.

To calculate the potential difference, use:

$$\begin{aligned}\Delta V &= \frac{\Delta E_p}{q} \\ &= \frac{3.20 \times 10^{-4} \text{ J}}{6.00 \times 10^{-6} \text{ C}} \\ &= 53.3 \text{ V}\end{aligned}$$

Paraphrase

The potential difference between the two parallel plates is 53.3 V.

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Example 11.12 Practice Problems

1. ***Given***

$\Delta d = 1.2 \times 10^{-2}$ m

$|\vec{E}| = 1.7 \times 10^{5}$ V/m

$m = 3.0 \times 10^{-15}$ kg

$q = 2.6 \times 10^{-12}$ C

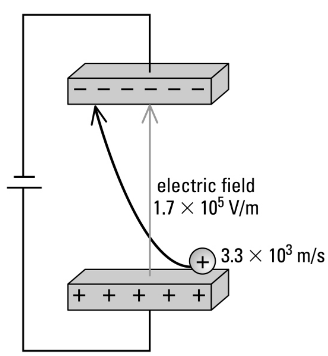
$\Delta t = 6.0 \times 10^{-6}$ s

Required

sketch of motion of charge between plates

distance positive charge moves toward negative plate (Δd)

Analysis and Solution



First find the electric force on the electron.

$$\begin{aligned}|\vec{F}_e| &= q|\vec{E}| \\ &= (2.6 \times 10^{-12} \text{ C})(1.7 \times 10^{5} \text{ V/m}) \\ &= 4.42 \times 10^{-7} \text{ N}\end{aligned}$$

Use the value for the electric force to calculate acceleration toward the negative plate.

$F = ma$

$a = \frac{F}{m}$

$= \frac{4.42 \times 10^{-7}\ \text{N}}{3.0 \times 10^{-15}\ \text{kg}}$

$= 1.473 \times 10^{8}\ \text{m/s}^2$

Calculate the distance the charge moves toward the negative plate using the equation $\Delta\vec{d} = \vec{v}_i\Delta t + \frac{1}{2}\vec{a}(\Delta t)^2$. Because there is no initial speed in the vertical direction,

$\Delta\vec{d} = \frac{1}{2}\vec{a}(\Delta t)^2$

$= \frac{1}{2}\left(1.473 \times 10^{8}\ \frac{\text{m}}{\text{s}^2}\right)\left(6.0 \times 10^{-6}\ \text{s}\right)^2$

$= 2.7 \times 10^{-3}\ \text{m}$

Paraphrase

The positive charge moves a distance of $2.7 \times 10^{-3}\ \text{m}$ toward the negative plate.

2. ***Given***

$q = 1.60 \times 10^{-19}$ C

$m = 9.11 \times 10^{-31}$ kg

$v = 2.3 \times 10^{3}$ m/s

$|\vec{E}| = 1.5 \times 10^{2}$ V/m

$\Delta d = 1.0 \times 10^{-2}$ m

Required

time taken for electron to fall 1.0×10^{-2} m (Δt)

Analysis and Solution

First find the electric force on the electron.

$|\vec{F}_e| = q|\vec{E}|$

$= \left(1.60 \times 10^{-19}\ \text{C}\right)\left(1.5 \times 10^{2}\ \text{V/m}\right)$

$= 2.4 \times 10^{-17}\ \text{N}$

Use the value for the electric force to calculate acceleration toward the positive plate.

$F = ma$

$a = \frac{F}{m}$

$= \frac{2.4 \times 10^{-17}\ \text{N}}{9.11 \times 10^{-31}\ \text{kg}}$

$= 2.634 \times 10^{13}\ \text{m/s}^2$

Calculate the time it takes the charge to move toward the positive plate using the equation $\Delta\vec{d} = \vec{v}_i\Delta t + \frac{1}{2}\vec{a}(\Delta t)^2$.

Because there is no initial speed in the vertical direction,

$$\Delta d = \frac{1}{2}a(\Delta t)^2$$

$$\begin{aligned}\Delta t &= \sqrt{\frac{2\Delta d}{a}} \\ &= \sqrt{\frac{2\left(1.0\times10^{-2}\ \cancel{\text{m}}\right)}{2.634\times10^{13}\ \frac{\cancel{\text{m}}}{\text{s}^2}}} \\ &= 2.7\times10^{-8}\ \text{s}\end{aligned}$$

Paraphrase

It takes the electron 2.7×10^{-8} s to fall 1.0×10^{-2} m toward the positive plate.

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11.3 Check and Reflect

Knowledge

1. A positively charged particle will accelerate toward a negative source charge and away from a positive source charge, parallel to the electric field.

2. No. A charge placed in the field is used only to determine the force of the electric field at a point in the electric field produced by the source charge.

3. Both charges have the same electric potential. The larger charge has more electric potential energy.

Applications

4. ***Given***

$q_{e^-} = -1.60\times10^{-19}$ C

$q_{p^+} = +1.60\times10^{-19}$ C

$V = 220$ V

$m_{e^-} = 9.11\times10^{-31}$ kg

$m_{p^+} = 1.67\times10^{-27}$ kg

Required

speeds of the charges (v)

Analysis and Solution

The initial electric potential energies of the charges are:

$E_{p_i} = Vq$

Since they are at rest, their initial kinetic energies are: $E_{k_i} = 0$ J

The final electric potential energies of the charges are: $E_{p_f} = 0$ J

This system is conservative system, so a loss of electric potential energy is converted to a gain of kinetic energy, according to the law of conservation of energy:

$$E_{p_i} + E_{k_i} = E_{p_f} + E_{k_f}$$

For the electron:

$$E_{p_i} + E_{k_i} = E_{p_f} + E_{k_f}$$
$$Vq + 0\text{ J} = 0\text{ J} + E_{k_f}$$
$$Vq = E_{k_f}$$
$$(220\text{ V})(1.60\times10^{-19}\text{ C}) = E_{k_f}$$
$$E_{k_f} = 3.52\times10^{-17}\text{ J}$$

To determine the speeds of the charges, use $E_k = \frac{1}{2}mv^2$.

For the electron:

$$E_k = \frac{1}{2}mv^2$$
$$v = \sqrt{\frac{2E_k}{m}}$$
$$= \sqrt{\frac{2(3.52\times10^{-17}\text{ J})}{9.11\times10^{-31}\text{ kg}}}$$
$$= 8.79\times10^{6}\text{ m/s}$$

For the proton:

$$E_{p_i} + E_{k_i} = E_{p_f} + E_{k_f}$$
$$Vq + 0\text{ J} = 0\text{ J} + E_{k_f}$$
$$Vq = E_{k_f}$$
$$(220\text{ V})(1.60\times10^{-19}\text{ C}) = E_{k_f}$$
$$E_{k_f} = 3.52\times10^{-17}\text{ J}$$

$$E_k = \frac{1}{2}mv^2$$
$$v = \sqrt{\frac{2E_k}{m}}$$
$$= \sqrt{\frac{2(3.52\times10^{-17}\text{ J})}{1.67\times10^{-27}\text{ kg}}}$$
$$= 2.05\times10^{5}\text{ m/s}$$

Paraphrase

The speed of the electron is 8.79×10^{6} m/s and the speed of the proton is 2.05×10^{5} m/s.

5. ***Given***

$q_{e^-} = -1.60\times10^{-19}$ C

$\Delta V = 25$ kV $= 2.5\times10^{4}$ V

$m_{e^-} = 9.11\times10^{-31}$ kg

Required

speed of the electrons (v)

Analysis and Solution

The initial electric potential energy of the electrons is: $E_{p_i} = Vq$

Since they are at rest, their initial kinetic energy is: $E_{k_i} = 0$ J

The final electric potential energy of the electrons is: $E_{p_f} = 0$ J

This system is conservative, so a loss of electric potential energy is converted to a gain of kinetic energy, according to the law of conservation of energy:

$$E_{p_i} + E_{k_i} = E_{p_f} + E_{k_f}$$
$$Vq + 0 \text{ J} = 0 \text{ J} + E_{k_f}$$
$$Vq = E_{k_f}$$
$$\left(2.5 \times 10^4 \text{ V}\right)\left(1.60 \times 10^{-19} \text{ C}\right) = E_{k_f}$$
$$E_{k_f} = 4.0 \times 10^{-15} \text{ J}$$

To determine the speed of the electrons, use $E_k = \frac{1}{2}mv^2$.

$$\begin{aligned} v &= \sqrt{\frac{2E_k}{m}} \\ &= \sqrt{\frac{2(4.0 \times 10^{-15} \text{ J})}{9.11 \times 10^{-31} \text{ kg}}} \\ &= 9.4 \times 10^7 \text{ m/s} \end{aligned}$$

Paraphrase

The maximum speed of the electrons is 9.4×10^7 m/s.

6. To determine the magnitude of the charge, use:

$$V = \frac{\Delta E_p}{q}$$

$$\begin{aligned} q &= \frac{\Delta E_p}{V} \\ &= \frac{1.92 \times 10^{-14} \text{ J}}{3.20 \times 10^4 \text{ V}} \\ &= 6.00 \times 10^{-19} \text{ C} \end{aligned}$$

The magnitude of the charge is 6.00×10^{-19} C.

7. To determine the work done on the charge, use:

$$V = \frac{\Delta E_p}{q}$$

$$V = \frac{W}{q}$$

$$\begin{aligned} W &= Vq \\ &= (120 \text{ V})(2.00 \times 10^{-6} \text{ C}) \\ &= 2.40 \times 10^{-4} \text{ J} \end{aligned}$$

The work done on the charge is 2.40×10^{-4} J.

8. ***Given***

$q_{e^-} = 1.60 \times 10^{-19}$ C

$V = 2.00 \times 10^4$ V

$m_{e^-} = 3.34 \times 10^{-27}$ kg

Required
(a) speed of the ion at the positive plate (v)
(b) speed of the ion midway between the two plates (v)
Analysis and Solution
(a) The initial electric potential energy of the ion is: $E_{p_i} = Vq$

Since it is at rest, its initial kinetic energy is: $E_{k_i} = 0$ J

The final electric potential energy of the ion is: $E_{p_f} = 0$ J

This system is conservative, so a loss of electric potential energy is converted to a gain of kinetic energy, according to the law of conservation of energy:

$$\begin{aligned} E_{p_i} + E_{k_i} &= E_{p_f} + E_{k_f} \\ Vq + 0\text{ J} &= 0\text{ J} + E_{k_f} \\ Vq &= E_{k_f} \\ (2.00 \times 10^4\text{ V})(1.60 \times 10^{-19}\text{ C}) &= E_{k_f} \\ E_{k_f} &= 3.20 \times 10^{-15}\text{ J} \end{aligned}$$

To solve for the speed of the ion, use $E_k = \frac{1}{2}mv^2$.

$$\begin{aligned} v &= \sqrt{\frac{2E_k}{m}} \\ &= \sqrt{\frac{2(3.20 \times 10^{-15}\text{ J})}{3.34 \times 10^{-27}\text{ kg}}} \\ &= 1.38 \times 10^6\text{ m/s} \end{aligned}$$

(b) Midway between the plates, the ion will gain half the kinetic energy, so $E_k = 1.60 \times 10^{-15}$ J:

$$\begin{aligned} E_k &= \frac{1}{2}mv^2 \\ v &= \sqrt{\frac{2E_k}{m}} \\ &= \sqrt{\frac{2(1.60 \times 10^{-15}\text{ J})}{3.34 \times 10^{-27}\text{ kg}}} \\ &= 9.79 \times 10^5\text{ m/s} \end{aligned}$$

Paraphrase
(a) The speed of the ion at the positive plate is 1.38×10^6 m/s.
(b) The speed of the ion midway between the plates is 9.79×10^5 m/s.

9. (a) In a conservative system,

$$\begin{aligned} W &= \Delta E_p \\ &= Vq \\ &= (6.0 \times 10^2\text{ V})(3.0 \times 10^{-8}\text{ C}) \\ &= 1.8 \times 10^{-5}\text{ J} \end{aligned}$$

The work done on the charge is 1.8×10^{-5} J.

(b) ***Given***

$q = +3.0 \times 10^{-8}$ C

$V = 6.0 \times 10^{2}$ V

$m = 3.0 \times 10^{-5}$ kg

Required

maximum kinetic energy of the returning charge (E_{k_f})

Analysis and Solution

The initial electric potential energy of the charge is: $E_{p_i} = Vq$.

Since the charge is at rest, its initial kinetic energy is: $E_{k_i} = 0$ J.

The final electric potential energy of the charge is: $E_{p_f} = 0$ J.

This system is conservative, so a loss of electric potential energy is converted to a gain of kinetic energy, according to the law of conservation of energy:

$$\begin{aligned} E_{p_i} + E_{k_i} &= E_{p_f} + E_{k_f} \\ Vq + 0 \text{ J} &= 0 \text{ J} + E_{k_f} \\ Vq &= E_{k_f} \\ \left(6.0 \times 10^{2} \text{ V}\right)\left(3.0 \times 10^{-8} \text{ C}\right) &= E_{k_f} \\ E_{k_f} &= 1.8 \times 10^{-5} \text{ J} \end{aligned}$$

Paraphrase

The maximum kinetic energy of the returning charge is 1.8×10^{-5} J.

(c) To solve for the final speed of the returning charge, use:

$$\begin{aligned} E_k &= \frac{1}{2}mv^2 \\ v &= \sqrt{\frac{2E_k}{m}} \\ &= \sqrt{\frac{2(1.8 \times 10^{-5} \text{ J})}{3.0 \times 10^{-5} \text{ kg}}} \\ &= 1.1 \text{ m/s} \end{aligned}$$

The final speed of the returning charge is 1.1 m/s.

10. ***Given***

$v = 5.45 \times 10^{6}$ m/s

$\left|\vec{E}\right| = 125$ N/C

$\Delta d = 6.20 \times 10^{-3}$ m

Required

(a) **(i)** sketch of electric field lines between plates

(ii) sketch of the motion of the electron through the capacitor

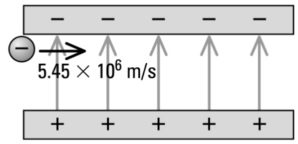
(b) electric force $\left(\vec{F}_e\right)$

(c) acceleration of the electron ($\vec{a}$)

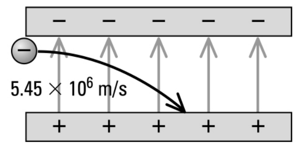
(d) horizontal distance electron travels (Δd)

Analysis and Solution

(a) (i)



(ii)



(b) The electric force on the electron is given by

$$\vec{E} = \frac{\vec{F}_e}{q}$$

$$\vec{F}_e = \vec{E}q$$

$$= \left(125\ \frac{\text{N}}{\cancel{\text{C}}}\right)\left(-1.60\times10^{-19}\ \cancel{\text{C}}\right)$$

$$= -2.00\times10^{-17}\ \text{N}$$

The electron moves toward the positive plate, or down.

(c) The acceleration of the electron is given by

$$\vec{F} = m\vec{a}$$

$$\vec{a} = \frac{\vec{F}}{m}$$

$$= \frac{-2.00\times10^{-17}\ \text{N}}{9.11\times10^{-31}\ \text{kg}}$$

$$= -2.195\times10^{13}\ \text{m/s}^2$$

$$= -2.20\times10^{13}\ \text{m/s}^2$$

The electron moves toward the positive plate, or down.

(d) Find the time it takes the electron to fall a distance of 6.20×10^{-3} m using the scalar form of the equation $\Delta\vec{d} = \vec{v}_i\Delta t + \frac{1}{2}\vec{a}(\Delta t)^2$, where $\vec{v}_i = 0$.

$$\Delta t = \sqrt{\frac{2\Delta d}{a}}$$

$$= \sqrt{\frac{2(6.20\times10^{-3}\ \cancel{\text{m}})}{2.195\times10^{13}\ \frac{\cancel{\text{m}}}{\text{s}^2}}}$$

$$= 2.30\times10^{-8}\ \text{s}$$

The time taken to travel horizontally equals the time taken to travel vertically. Since motion in the horizontal direction is uniform, use the scalar form of the equation $\vec{v} = \frac{\Delta\vec{d}}{\Delta t}$.

$$\begin{aligned}\Delta d &= v\Delta t\\ &= \left(5.45\times10^{6}\ \frac{\text{m}}{\not\text{s}}\right)\left(2.30\times10^{-8}\ \not\text{s}\right)\\ &= 0.130\ \text{m}\end{aligned}$$

Paraphrase

(b) The force due to the electric field on the electron is 2.00×10^{-17} N [down].

(c) The acceleration of the electron is 2.20×10^{13} m/s^2 [down].

(d) The electron will travel a horizontal distance of 0.130 m.

Extensions

11. Since each charge will gain the same amount of kinetic energy, the same amount of work is done on each charge. Since the magnitude of the charges are the same, $\vec{F}_e = \vec{E}_q$. From Newton's third law: $\vec{F}_{e^-} = \vec{F}_{p^+}$. If $\vec{F} = m\vec{a}$, then $m_{e^-}a_{e^-} = m_{p^+}a_{p^+}$.

The mass of the electron is smaller than that of the proton, so the electron must have a greater acceleration and will reach the plate sooner.

12. Since $V = \dfrac{\Delta E_p}{q}$, a high electric potential and a low electric potential energy mean that a small charge must be present.

13. The electron undergoes uniform motion in the horizontal direction but uniformly accelerated motion in the vertical direction. Therefore, its path between the charged plates is parabolic rather than circular.

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Chapter 11 Review

Knowledge

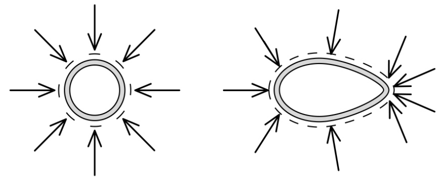
1. Three theories that attempt to explain "action at a distance" are the historical effluvium theory, the current field theory, and the modern string theory.

2. A charge placed near a charged object will experience a force. It will not experience a force near an uncharged object.

3. The arrow points in the direction of the field, and the length of the arrow indicates the magnitude of the quantity.

4. An electric field vector has a definite length determined by the magnitude of the quantity. An electric field line is a line drawn from the charged object to infinity or from infinity to the charged object. It shows only the direction of the electric field. The density of the electric field lines indicates the magnitude of the electric field.

5.



6. The density of the electric field lines indicates the magnitude of the electric field.

7. (a) Electric field lines for a negative charge originate at infinity.

(b) Electric field lines for a positive charge originate at the centre of the charge and extend to infinity.

8. $\vec{E} = \frac{\vec{F}_e}{q}$ and $|\vec{E}| = \frac{kq}{r^2}$

9. Electric charges achieve static equilibrium when all the electrostatic forces acting on the charged object are balanced.

10. At the pointed surface, electrostatic forces between charges on the surface do not run parallel to the surface because they have a tangential component. As a result, the tangential component of the force of repulsion is greater toward the pointed surface than in the other direction, with the result that the charges will accumulate at the pointed surface.

11. (a) A convenient zero reference point around a point charge is at infinity.

(b) A convenient zero reference point between two oppositely charged parallel plates is at either inside surface of the plates.

12. $E_p = W$ (to move the charge to the point around the charge)

13. The electric field around a point charge is non-uniform so the electric force on a charge in that field would vary with position. The electric force on a charge between charged plates would be uniform because the electric field between oppositely charged plates is uniform.

14. (a) Work done equals potential energy gain.

(b) Potential energy is converted to kinetic energy and vice versa without loss.

Applications

15. The potential energy at A would be higher than that at B because the zero reference point is chosen at infinity.

16. The leaves of the electroscope that is touched to the outside surface would diverge, indicating the presence of a charge. The electroscope touched to the inside surface would not be affected because there is no charge accumulation on this surface.

17. (a) To calculate the electric field at a point, use:

$$\begin{aligned} |\vec{E}| &= \frac{kq}{r^2} \\ &= \frac{\left(8.99 \times 10^9 \frac{\text{N} \cdot \cancel{\text{m}^2}}{\text{C}^{\cancel{2}}}\right)(2.30 \times 10^{-6} \cancel{\text{C}})}{(2.00 \cancel{\text{m}})^2} \\ &= 5.17 \times 10^3 \text{ N/C} \end{aligned}$$

The electric field is 5.17×10^3 N/C [away from the positive charge].

(b) To calculate the electric force on the charge, use:

$$\begin{aligned} |\vec{E}| &= \frac{|\vec{F}_e|}{q} \\ |\vec{F}_e| &= |\vec{E}|q \\ &= \left(5.17 \times 10^3 \frac{\text{N}}{\cancel{\text{C}}}\right)(2.00 \times 10^{-6} \cancel{\text{C}}) \\ &= 1.03 \times 10^{-2} \text{ N} \end{aligned}$$

The electric force is 1.03×10^{-2} N [toward the positive charge].

18. ***Given***

$q_1 = -5.00\ \text{C}$

$q_2 = -2.00\ \text{C}$

$r = 1.20\ \text{m}$

Required

(a) net electric field midway between the two charges ($\vec{E}_{\text{net}}$)

(b) point between the two charges where the net electric field is zero ($r_{q_1\ \text{to P}}$)

Analysis and Solution

(a) The electric field created by q_1 at point P is to the left and is a negative vector quantity.

The electric field created by q_2 at point P is to the right and is a positive vector quantity.

The distance midway between the two charges is:

$$\begin{aligned} r &= \frac{1.20\ \text{m}}{2} \\ &= 0.600\ \text{m} \end{aligned}$$

Since the two electric field vectors are along the same line, the net electric field can be determined by adding the individual field vectors.

$$\vec{E}_{\text{net}} = \vec{E}_{q_1} + \vec{E}_{q_2}$$

Consider right to be positive.

$$\begin{aligned} E_{\text{net}} &= E_{q_1} + E_{q_2} \\ &= -\frac{kq_1}{r^2_{\text{P to } q_1}} + \frac{kq_2}{r^2_{\text{P to } q_2}} \\ &= -\frac{\left(8.99 \times 10^9\ \frac{\text{N} \cdot \text{m}^2}{\text{C}^2}\right)(5.00\ \text{C})}{(0.600\ \text{m})^2} + \frac{\left(8.99 \times 10^9\ \frac{\text{N} \cdot \text{m}^2}{\text{C}^2}\right)(2.00\ \text{C})}{(0.600\ \text{m})^2} \\ &= -1.249 \times 10^{11}\ \text{N/C} + 4.994 \times 10^{10}\ \text{N/C} \\ &= -7.49 \times 10^{10}\ \text{N/C} \end{aligned}$$

(b) The electric field created by q_1 at point P is to the left and is a negative vector quantity.

The electric field created by q_2 at point P is to the right and is a positive vector quantity.

The distance between q_1 and point P is $r_{q_1\ \text{to P}}$

The distance between q_2 and point P is: $r_{q_2\ \text{to P}} = (1.20\ \text{m} - r_{q_1\ \text{to P}})$

Since the net electric field between the two charges is zero, then at point P:

$$\left|\vec{E}_{q_1}\right| = \left|\vec{E}_{q_2}\right|$$

$$\left(\frac{kq_1}{r^2_{\text{P to } q_1}}\right) = \left(\frac{kq_2}{r^2_{\text{P to } q_2}}\right)$$

$$\frac{\left(8.99\times10^9\ \frac{\text{N}\cdot\text{m}^2}{\text{C}^2}\right)(5.00\ \text{C})}{(r_{q_1\text{ to P}}\ \text{m})^2} = \frac{\left(8.99\times10^9\ \frac{\text{N}\cdot\text{m}^2}{\text{C}^2}\right)(2.00\ \text{C})}{(1.20 - r_{q_1\text{ to P}}\ \text{m})^2}$$

$$r_{q_1\text{ to P}} = 0.735\ \text{m}$$

Paraphrase

(a) The net electric field midway between the two charges is 7.49×10^{10} N/C [toward the −5.00 C charge].

(b) The position between the two charges where the net electric field is zero is 0.735 m from the −5.00 C charge.

19. ***Given***

$q_{\text{A}} = 2.0\times10^{-6}\ \text{C}$

$q_{\text{B}} = 2.0\times10^{-6}\ \text{C}$

Required

net electric field at point C ($\vec{E}_{\text{net}}$)

Analysis and Solution

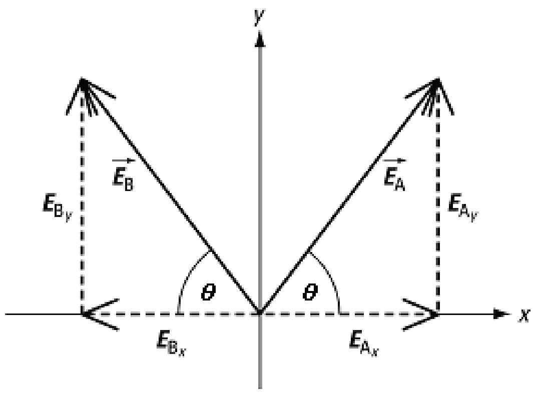
Since q_{A} is a positive charge, the electric field created by q_{A} at point C is directed away from q_{A} and away from point P along an imaginary line joining q_{A} and C.
Since q_{B} is a positive charge, the electric field created by q_{B} at point C is directed away from q_{B} and away from point P along an imaginary line joining q_{B} and C.
The distance between q_{A} and C and q_{B} and C is:

$$\begin{aligned} r_{q_{\text{A}}\text{ to C}} &= \sqrt{(0.040\ \text{m})^2 + (0.030\ \text{m})^2} \\ &= 0.050\ \text{m} \\ &= 5.0\times10^{-2}\ \text{m} \end{aligned}$$

Determine the electric field created by q_{A} at point C:

$$\begin{aligned} \left|\vec{E}_{\text{A}}\right| &= \frac{kq_{\text{A}}}{r^2_{q_{\text{A}}\text{ to C}}} \\ &= \frac{\left(8.99\times10^9\ \frac{\text{N}\cdot\text{m}^2}{\text{C}^2}\right)(2.0\times10^{-6}\ \text{C})}{(5.0\times10^{-2}\ \text{m})^2} \\ &= 7.19\times10^6\ \text{N/C} \end{aligned}$$

Similarly, the electric field created by q_{B} at point C is 7.19×10^6 N/C .
Solve the net electric field using the component method.



$$\tan\theta = \frac{\text{opposite}}{\text{adjacent}}$$

$$\theta = \tan^{-1}\left(\frac{0.040\text{ m}}{0.030\text{ m}}\right)$$
$$= 53.1°$$

$$E_{A_x} = (7.19 \times 10^6\text{ N/C})(\cos 53.1°)$$
$$= 4.32 \times 10^6\text{ N/C}$$

$$E_{A_y} = (7.19 \times 10^6\text{ N/C})(\sin 53.1°)$$
$$= 5.75 \times 10^6\text{ N/C}$$

Similarly,

$$E_{B_x} = -(7.19 \times 10^6\text{ N/C})(\cos 53.1°)$$
$$= -4.32 \times 10^6\text{ N/C}$$

$$E_{B_y} = (7.19 \times 10^6\text{ N/C})(\sin 53.1°)$$
$$= 5.75 \times 10^6\text{ N/C}$$

The vector sum of all the x components is:

$$E_{net_x} = \left(4.32\times10^6\text{ N/C}\right) + \left(-4.32\times10^6\text{ N/C}\right)$$
$$= 0\text{ N/C}$$

$$E_{net_y} = \left(5.75\times10^6\text{ N/C}\right) + \left(5.75\times10^6\text{ N/C}\right)$$
$$= 1.2\times10^7\text{ N/C}$$

Since $E_{net_x} = 0$, $E_{net} = E_{net_y}$. Since E_{net_y} is directed upward, the angle is 90.0°.

Paraphrase

The net electric field at point C is 1.2×10^7 N/C [90.0°].

20. (a) To calculate the work done on the charge, use:

$$W = \left|\vec{F}\right| \Delta d$$
$$= (15.0\text{ N})(0.20\text{ m})$$
$$= 3.0\text{ J}$$

The work done is 3.0 J.

(b) The work done against the electrostatic force is W.

The electric potential energy gain is ΔE_p.

In a conservative system:

$$\Delta E_p = W$$
$$= 3.0 \text{ J}$$

The electric potential energy gain is 3.0 J.

21. The electric potential energy of the charge equals the work done moving the charge a distance of 1.20 m. Determine the work done using the equation $\Delta E_p = W = |\vec{F}|\Delta d$, where $|\vec{F}| = |\vec{F}_e|$.

$$\begin{aligned}\Delta E_p &= |\vec{F}_e|\Delta d \\ &= k\frac{q_1 q_2}{r^{\not 2}} \times \not r \\ &= k\frac{q_1 q_2}{r} \\ &= \frac{\left(8.99 \times 10^9 \frac{\text{N}\cdot\text{m}^{\not 2}}{\not \text{C}^{\not 2}}\right)(2.50 \times 10^{-6} \not\text{C})(3.00 \not\text{C})}{1.20 \not\text{m}} \\ &= 5.62 \times 10^4 \text{ J}\end{aligned}$$

The potential energy of the smaller charge at this point is 5.62×10^4 J.

22. (a) ***Given***

$\Delta V = 6.00$ V

$\Delta d = 1.10$ cm = 0.0110 m

Required

magnitude of the electric field between the plates ($|\vec{E}|$)

Analysis and Solution

The magnitude of the electric field between the plates is:

$$\begin{aligned}|\vec{E}| &= \frac{\Delta V}{\Delta d} \\ &= \frac{6.00 \text{ V}}{0.0110 \text{ m}} \\ &= 545.5 \text{ V/m}\end{aligned}$$

Paraphrase

The electric field between the plates is 545 V/m.

(b) To determine the electric potential between the plates, use:

$$\begin{aligned}\Delta V &= |\vec{E}|\Delta d \\ &= \left(545.5 \frac{\text{V}}{\not\text{m}}\right)(3.75 \times 10^{-2} \not\text{m}) \\ &= 20.5 \text{ V}\end{aligned}$$

The electric potential between the plates is 20.5 V.

23. No work is done when a charge is moved perpendicular to a uniform electric field.

24. To calculate the electric field, use:

$$\begin{aligned}\left|\vec{E}\right| &= \frac{\Delta V}{\Delta d} \\ &= \frac{0.070\ \text{V}}{1.0 \times 10^{-7}\ \text{m}} \\ &= 7.0 \times 10^{5}\ \text{V/m}\end{aligned}$$

The electric field within the membrane is 7.0×10^{5} V/m.

25. ***Given***

$q = 4.80 \times 10^{-19}$ C

$\Delta V = 6.00 \times 10^{5}$ V

Required

electric potential energy gained by the charge (ΔE_{p})

Analysis and Solution

To calculate the electric potential energy, use:

$$\Delta V = \frac{\Delta E_{\text{p}}}{q}$$

$$\begin{aligned}\Delta E_{\text{p}} &= \Delta V q \\ &= \left(6.00 \times 10^{5}\ \text{V}\right)\left(4.80 \times 10^{-19}\ \text{C}\right) \\ &= 2.88 \times 10^{-13}\ \text{J} \\ &= \left(2.88 \times 10^{-13}\ \cancel{\text{J}}\right)\left(\frac{1\ \text{eV}}{1.60 \times 10^{-19}\ \cancel{\text{J}}}\right) \\ &= 1.80 \times 10^{6}\ \text{eV}\end{aligned}$$

Paraphrase

The energy gained by moving the nucleus between the two positions is 2.88×10^{-13} J or 1.80×10^{6} eV.

26. ***Given***

$q = 3.20 \times 10^{-19}$ C

$V = 2.00 \times 10^{4}$ V

Required

electric potential energy (ΔE_{p}) gained by the alpha particle, in joules (J) and electron volts (eV)

Analysis and Solution
To calculate the electric potential energy, use:

$$V = \frac{\Delta E_p}{q}$$

$$\begin{aligned}\Delta E_p &= Vq \\ &= \left(2.00 \times 10^4 \text{ V}\right)\left(3.20 \times 10^{-19} \text{ C}\right) \\ &= 6.40 \times 10^{-15} \text{ J} \\ &= \left(6.40 \times 10^{-15} \not{\text{J}}\right)\left(\frac{1 \text{ eV}}{1.60 \times 10^{-19} \not{\text{J}}}\right) \\ &= 4.00 \times 10^4 \text{ eV}\end{aligned}$$

Paraphrase
The energy gained by moving the alpha particle between the two positions is 6.40×10^{-15} J or 4.00×10^4 eV.

27. Measure the force on the known (test) charge, and then determine the strength of the electric field at that point by using $\vec{E} = \frac{\vec{F}_e}{q}$, where q is the known charge placed in the field.

(a) If the magnitude of the test charge were doubled, there would be no effect on the field produced by the primary charge.

(b) If the magnitude of the source charge were doubled, the magnitude of the electric field would double.

(c) If the sign of the charge producing the field were changed, the electric field would change to the opposite direction.

Extensions

28. If electric field lines crossed at a point, the point would have a different magnitude relative to other points that are the same distance from the charge causing the field.

29. It depends on the structure of the bird cage and on how much energy the lightning bolt carries. A conductive metal birdcage will act as a Faraday shield. This shield will protect the bird somewhat. However, the birdcage is not a continuous conductive surface, so it will not shield the interior of the cage completely. The smaller the gaps between the bars of the cage, the better the shielding. Another key variable is how much current flows through the metal bars of the cage. If the cage is well insulated from the ground, the bird might be fine. However, the voltage in lightning is great enough to ionize the air around the cage. The current flow through the metal bars of the cage might be great enough to vaporize them.
So, the bird might be unscathed if the lightning bolt is weak and the cage has closely spaced metal bars that are good conductors. A direct hit by a powerful lightning bolt could harm the bird.

30. The redistribution of charges on the outside surfaces results from the electrostatic forces of repulsion. For a spherical object, the repulsive forces are equal along the surface so that charge distributes equally. On an irregular object, the components of the repulsive forces are tangential to the surface and increase toward the point, so charges accumulate at a point.

31. Electrostatic repulsive forces will cause charges to move as far away from each other as possible, so they will accumulate on the outside surface.

32. If you held an electroscope inside a hollow charged sphere, there would be no effect on the electroscope.

33. A lightning rod uses the principle that charges accumulate at a point. This effect creates a larger electric field at the tip of the lightning rod, so the lightning strikes the rod rather than the building itself.

