A -4. 00 Nc Point Charge Is At The Origin, And A Second -6. 50 Nc Point Charge Is On The X -axis At X

A -4. 00 Nc Point Charge Is At The Origin, And A Second -6. 50 Nc Point Charge Is On The X-axis At X. Understanding the electrostatic interactions between point charges is fundamental in physics and electrical engineering. When dealing with two point charges positioned along the x-axis, such as a -4.00 nC charge at the origin and a -6.50 nC charge at a certain point on the x-axis, it becomes essential to analyze the electric field, potential, and the forces involved. This comprehensive guide aims to elucidate these concepts, providing a detailed understanding suitable for students, educators, and enthusiasts interested in electrostatics.

Introduction to Electric Charges and Coulomb's Law

What Are Electric Charges?

Electric charges are fundamental properties of matter that cause electromagnetic interactions. They come in two types: positive and negative. Like charges repel each other, while opposite charges attract. The magnitude of the electric force between two point charges depends on their magnitudes and the distance separating them.

The Coulomb’s Law Equation

Coulomb's Law quantifies the force between two point charges:

- $F = k_e \frac{|q_1 q_2|}{r^2}$

where:
- F is the magnitude of the electrostatic force,
- k_e is Coulomb's constant ($8.9875 \times 10^9 \, \mathrm{Nm^2/C^2}$),
- q_1 and q_2 are the charges,
- r is the distance between the charges.

This law indicates that the force is directly proportional to the product of the charges and inversely proportional to the square of the distance between them.

Scenario Description: Two Point Charges on the X-axis

Setup Details

In our case:
- Charge 1: $q_1 = -4.00 \, \mathrm{nC}$ located at the origin, $x=0$.
- Charge 2: $q_2 = -6.50 \, \mathrm{nC}$ located at $x = X$, where X is a specified position on the x-axis.

The negative signs indicate both charges are negatively charged, leading to certain interactions that influence the electric field and potential in the space around them.

Understanding the Coordinates and Distance

The position of the second charge along the x-axis determines the electric interactions:
- If $X > 0$, the second charge is to the right.
- If $X < 0$, it is to the left.
- The distance between the charges is simply $|X - 0| = |X|$.

Accurately calculating the electric field and potential at any point requires considering these positions and the superposition principle.

Electric Field Due to Point Charges

Electric Field Definition

The electric field at a point in space due to a point charge is a vector quantity representing the force per unit positive test charge placed at that point.

- The electric field $\vec{E}$ due to a point charge is given by:

  - $\vec{E} = k_e \frac{q}{r^2} \hat{r}$

where:
- q is the source charge,
- r is the distance from the charge to the point,
- $\hat{r}$ is the unit vector pointing from the charge to the point.

Superposition of Electric Fields

Since electric fields are vectors, the net electric field at any point is the vector sum of the fields due to each individual charge:

- $\vec{E}_{\text{net}} = \vec{E}_1 + \vec{E}_2$

This principle allows calculation of the resultant electric field at any point along the x-axis or elsewhere.

Calculating Electric Fields on the X-axis

Electric Field at a Point x Due to Each Charge

Suppose we want to determine the electric field at a point x on the x-axis:

- From the charge at the origin:

  - $E_1 = k_e \frac{|q_1|}{x^2}$, directed away from the charge if q_1 is positive, or toward it if negative.

- From the second charge at $x = X$:

  - $E_2 = k_e \frac{|q_2|}{(x - X)^2}$, with the direction depending on the sign of q_2.

The total electric field at x is then obtained by vector addition, considering the directions.

Example: Electric Field at a Point to the Right of Both Charges

Assuming both charges are negative, the electric fields due to each are directed toward the charges:

- To the right of both charges, the fields due to each charge point toward the charges, resulting in vector components pointing in different directions depending on the position.

Calculations involve:

- Determining the magnitude of each field,
- Assigning the correct directions,
- Summing the components to find the net electric field.

Electric Potential Due to Point Charges

Potential Definition

Electric potential at a point in space due to a point charge is a scalar quantity representing the work done in bringing a unit positive charge from infinity to that point.

- The potential V due to a point charge is:

  - $V = k_e \frac{q}{r}$

- For multiple charges, total potential is the algebraic sum:

  - $V_{\text{total}} = V_1 + V_2$

Calculating Potential at a Point on the X-axis

At a position x:

- Potential due to q_1:

  - $V_1 = k_e \frac{q_1}{|x|}$

- Potential due to q_2:

  - $V_2 = k_e \frac{q_2}{|x - X|}$

Total potential:

- $V_{\text{total}}(x) = V_1 + V_2$

Note that potential is scalar, so signs must be carefully considered based on the charges.

Force Between the Charges

Calculating the Force

The force between the two point charges is given by Coulomb's Law:

- $F = k_e \frac{|q_1 q_2|}{X^2}$

- Both charges are negative, so they repel each other with a force magnitude as above, directed along the line connecting them, away from each other.

Direction of Force

- Since both charges are negative, each experiences a force pushing it away from the other:
- The charge at the origin experiences a force to the left.
- The charge at X experiences a force to the right.

Understanding this interaction is critical when analyzing the stability of configurations or designing electrostatic devices.

Applications and Practical Considerations

Electrical Field Mapping

Knowing the electric fields generated by multiple point charges helps in:
- Designing capacitors,
- Analyzing charge distributions,
- Understanding electromagnetic interference.

Electrostatic Force Calculations in Engineering

- Microelectromechanical systems (MEMS),
- Particle accelerators,
- Charged particle traps.

Safety and Precautions

- High voltages and charges can cause electric shocks,
- Proper handling and insulation are vital in experimental setups involving point charges or charged conductors.

Summary and Key Takeaways

- Electric charges exert forces described by Coulomb's Law, which is fundamental in electrostatics.

- The electric field due to point charges can be superimposed vectorially to find the net field at any point.
- Electric potential is a scalar quantity, summing contributions from individual charges.
- The interactions between charges depend on their magnitudes, signs, and positions along the x-axis.
- Understanding these principles is essential for designing and analyzing electrical and electronic systems.

Conclusion

Analyzing the interactions between a -4.00 nC charge located at the origin and a -6.50 nC charge positioned along the x-axis at \(X \) involves calculating electric fields, potentials, and forces using Coulomb's Law and the superposition principle. Whether studying fundamental physics or applying these

Frequently Asked Questions

What is the significance of the charges being at the origin and on the x-axis in this problem?

The placement of the charges at specific points along the x-axis simplifies the calculation of the electric field and potential at various points, allowing for a straightforward analysis of their interactions based on Coulomb's law.

How do the magnitudes and signs of the charges (-4.00 nC and -6.50 nC) affect the electric field along the x-axis?

Since both charges are negative, they produce electric fields that point toward each charge. The larger magnitude (-6.50 nC) results in a stronger field, influencing the net electric field at any point along the x-axis depending on the position relative to the charges.

How can we determine the point along the x-axis where the electric field is zero?

To find the point where the electric field is zero, set the magnitudes of the electric fields due to both charges equal to each other and solve for x. This involves equating Coulomb’s law expressions for the electric field from each charge and solving the resulting equation.

What is the electric potential at a point on the x-axis due to these two point charges?

The electric potential at any point is the algebraic sum of the potentials due to each charge, calculated using V = k q / r, where r is the distance from the charge to the point. Since potentials are scalar quantities, they add directly.

How does the presence of two negative charges influence the electric field and potential in the region between and beyond the charges?

Between the charges, the electric fields from each charge oppose each other, potentially canceling at a specific point. Beyond the charges, the fields reinforce or oppose depending on the direction, affecting the net electric field and potential distribution accordingly.

What are common methods to analyze the electric field and potential for multiple point charges aligned along an axis?

Common methods include vector addition of electric fields, scalar addition of electric potentials, and solving for equilibrium points where the net field is zero. Using symmetry and Coulomb's law simplifies calculations for charges aligned along a straight line.

Additional Resources

A -4.00 nC Point Charge Is At The Origin, And A Second -6.50 nC Point Charge Is On The X-Axis At X

Investigating the Electrostatic Interaction Between Two Point Charges

The study of electrostatics, a fundamental branch of physics, explores the forces exerted between charged particles. In this context, understanding the behavior of point charges and their interactions is crucial, especially in applications spanning from atomic physics to electrical engineering. This article delves into a specific scenario: a -4.00 nanocoulomb (nC) point charge positioned at the origin, and a second -6.50 nC charge located along the x-axis at a certain position \(x\).

Our comprehensive analysis aims to clarify the electrostatic forces, potential energies, and field interactions in this configuration, providing insights relevant to academic research, practical engineering, and educational purposes.

Introduction to the Configuration

The Physical Setup

In the described scenario:

- Charge 1: $q_1 = -4.00\,\text{nC}$ located at the origin $(0, 0)$.
- Charge 2: $q_2 = -6.50\,\text{nC}$ positioned at $(x, 0)$, where x is a variable along the x-axis.

Both charges are negative, indicating they are like charges, which repel each other according to Coulomb's law. The magnitude of the charges suggests a relatively small but significant electrostatic interaction, relevant in micro- and nano-scale systems.

Objectives of the Analysis

This investigation aims to:

- Calculate the electric force exerted on each charge.
- Determine the electric potential energy of the system.
- Explore the electric field distribution.
- Analyze how the forces and potentials change as a function of x.
- Identify points of equilibrium where net forces vanish.

Coulomb's Law and Its Application

Fundamental Principles

Coulomb's law describes the electrostatic force between two point charges:

$$
F = \frac{k |q_1 q_2|}{r^2}
$$

where:

- F is the magnitude of the force.
- k is Coulomb’s constant, approximately $8.988 \times 10^9\, \text{N·m}^2/\text{C}^2$.
- q_1, q_2 are the magnitudes of the charges.
- r is the separation distance between the charges.

The direction of the force is along the line connecting the charges, with like charges repelling and opposite charges attracting.

Application to Our Charges

Given both charges are negative, the forces are repulsive. For two charges q_1 at $(0,0)$ and q_2 at $(x, 0)$:

- The force on q_1 due to q_2:

$$
F_{12} = \frac{k |q_1 q_2|}{x^2}
$$

- The force on q_2 due to q_1:

$$
F_{21} = \frac{k |q_1 q_2|}{x^2}
$$

By Newton's third law, these forces are equal in magnitude and opposite in direction.

Quantitative Analysis

Calculating the Force Magnitude

Using the given values:

- $q_1 = -4.00\,\text{nC} = -4.00 \times 10^{-9}\,\text{C}$,
- $q_2 = -6.50\,\text{nC} = -6.50 \times 10^{-9}\,\text{C}$,
- $k = 8.988 \times 10^9\, \text{N·m}^2/\text{C}^2$.

The product:

$$
|q_1 q_2| = (4.00 \times 10^{-9}) \times (6.50 \times 10^{-9}) = 26.0 \times 10^{-18}\, \text{C}^2
$$

Thus, the force as a function of x:

$$
F(x) = \frac{8.988 \times 10^9 \times 26.0 \times 10^{-18}}{x^2} = \frac{233.7 \times 10^{-9}}{x^2} = \frac{2.337 \times 10^{-7}}{x^2}\, \text{N}
$$

Force as a Function of Distance

- When $x = 1\, \text{m}$:

$$
F(1) = 2.337 \times 10^{-7}\, \text{N}
$$

- When $x = 0.1\, \text{m}$:

$$
F(0.1) = 2.337 \times 10^{-7} / 0.01 = 2.337 \times 10^{-5}\, \text{N}
$$

This inverse-square relationship indicates the force sharply increases as the charges approach each other.

Electric Potential Energy of the System

Definition and Calculation

The electric potential energy U between two point charges is:

$$
U = \frac{k q_1 q_2}{r}
$$

Given both charges are negative, their product is positive, so the potential energy is negative, indicating a bound or attractive potential well, although here, the like charges repel, making the system energetically less favorable at close distances.

Expression for Our Charges

$$
U(x) = \frac{8.988 \times 10^9 \times (-4.00 \times 10^{-9}) \times (-6.50 \times 10^{-9})}{x}
$$

Simplify numerator:

$$
(8.988 \times 10^9) \times (26.0 \times 10^{-18}) = 233.7 \times 10^{-9}
$$

Since both charges are negative, their product is positive:

$$
U(x) = \frac{233.7 \times 10^{-9}}{x} = \frac{2.337 \times 10^{-7}}{x}\, \text{J}
$$

At various x values:

- $x = 0.5\, \text{m}$:

$$
U(0.5) = 2.337 \times 10^{-7} / 0.5 = 4.674 \times 10^{-7}\, \text{J}
$$

- $x = 0.1\, \text{m}$:

$$
U(0.1) = 2.337 \times 10^{-7} / 0.1 = 2.337 \times 10^{-6}\, \text{J}
$$

The potential energy becomes more negative (or less positive) as x decreases, indicating a stronger electrostatic interaction at shorter distances.

Electric Field Distribution

Electric Field Due to a Single Point Charge

The electric field at a point in space due to a point charge is:

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

with direction pointing away from the charge if it is positive, and toward the charge if it is negative.

Electric Field at a Point Along the X-Axis

- Due to q_1:

$$
E_1(x) = \frac{8.988 \times 10^9 \times 4.00 \times 10^{-9}}{x^2} = \frac{35.95 \times 10^{0}}{x^2} = \frac{35.95}{x^2}\, \text{N/C}
$$

- Due to q_2:

$$
E_2(x) = \frac{8.988 \times 10^9 \times 6.50 \times 10^{-9}}{|x - x_2|^2}
$$

where x_2 is the position of q_2.

Since both charges are negative:

- The electric field points toward each charge.
- The total electric field at a point is the vector sum of the fields due to each charge.

Field at Various Points

- Between the charges: the fields point toward the negative charges, resulting in a combined field direction depending on the position.
- Far from the charges: the fields diminish rapidly with distance.

Understanding the field distribution is essential for applications where the influence of these charges extends into surrounding space, such as in the design of electrostatic shields or sensors.

Equilibrium Considerations

Points of Zero Force (Equilibrium Points)

Since both charges are like charges (negative), the net force experienced by each is repulsive. However, in a more complex arrangement, there might be points along the axis where the electric field cancels out, leading to equilibrium positions.

In this simple two-charge system:

- The only potential equilibrium points occur at infinity, where forces vanish.
- No finite point along the x-axis exists where the net force on either charge is zero unless other forces or charges are introduced.

Stability of the System

Given the repulsive nature of the same-signed charges, the system tends to

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