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Understanding the behavior of electric charges in a coordinate system is fundamental to mastering electrostatics. When two point charges are positioned along the same axis, their interactions are governed by Coulomb's Law, which describes the force between them. This article explores the scenario where two point charges are placed on the negative x-axis, specifically focusing on a charge Q_1 with a magnitude of 1.0 nanocoulomb (NC) located at $x = +2.0$ centimeters, and the implications of this setup. We will analyze the electric fields, forces, potential energies, and the resulting behaviors in such a configuration.

Setting Up the Problem: Coordinates and Charge Arrangement

Coordinate System and Charge Placement

In this scenario, the coordinate system is a standard Cartesian plane with an x-axis extending in both positive and negative directions. The key details are:

- $Q_1 = 1.0$ NC (nanocoulomb), located at $x = +2.0$ cm
- The second charge, Q_2 , is positioned somewhere along the negative x-axis, i.e., at $x = -a$, where a is a positive distance measured in centimeters.

Assumptions for the Analysis

- Both charges are point charges.
- The charges are stationary unless otherwise specified.
- The medium surrounding the charges is vacuum or air, with a dielectric constant close to 1.
- The values are converted into SI units for calculations: centimeters to meters, nanocoulombs to coulombs.

Conversion to SI Units

Before proceeding with calculations, we convert the given values:

Quantity	Value	Conversion	SI Units
Distance from origin to Q1	2.0 cm	1 cm = 0.01 m	0.02 m
Charge Q1	1.0 NC	1 NC = 1 x 10 ⁻⁹ C	1 x 10 ⁻⁹ C
Position of Q1	x = +2.0 cm	0.02 m	x = +0.02 m
Position of Q2	x = -a (unknown)	-	-

Electrostatic Fundamentals: Coulomb’s Law

Understanding Coulomb’s Law

Coulomb’s Law quantifies the electrostatic force between two point charges:

$$F = k_e \frac{|Q_1 Q_2|}{r^2}$$

where:

- F is the magnitude of the force between the charges.
- k_e is Coulomb’s constant, approximately $8.988 \times 10^9 \text{ N}\cdot\text{m}^2/\text{C}^2$.
- Q_1 and Q_2 are the magnitudes of the charges.
- r is the distance between the charges.

Key Points to Remember

- Force magnitude depends on the product of charges and inversely on the square of their separation.
- The direction of the force is along the line connecting the charges.
- Like charges repel; unlike charges attract.

Analyzing the Electric Field and Potential

Electric Field Due to a Point Charge

The electric field (E) created by a point charge (Q) at a distance (r) is:

$$E = k_e \frac{|Q|}{r^2}$$

Direction:

- Radially outward from positive charges.
- Radially inward toward negative charges.

Calculating Electric Field at a Point

Suppose we are interested in the electric field at a point (P) located at some position (x) along the x-axis. The total electric field at (P) is the vector sum of the fields due to each charge:

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

where:

- $(\vec{E}_1)$ is due to (Q_1) .
- $(\vec{E}_2)$ is due to (Q_2) .

Potential Energy and Electric Potential

The electric potential (V) at a point due to a point charge is:

$$V = k_e \frac{Q}{r}$$

Total electric potential at a point is the algebraic sum of potentials due to all charges.

Calculating Forces Between the Charges

Suppose the second charge (Q_2) is placed at $(x = -a)$. The primary task is to determine:

- The magnitude of the force on each charge.
- The direction of these forces.
- The equilibrium position if (Q_2) is free to move.

Force Between the Two Charges

The distance between (Q_1) and (Q_2) :

$$r = |x_{Q1} - x_{Q2}| = |0.02 \text{ m} - (-a)| = |0.02 + a| \text{ m}$$

The force magnitude:

$$F = k_e \frac{|Q_1 Q_2|}{(a + 0.02)^2}$$

- If (Q_2) is positive, the force on (Q_1) is repulsive.
- If (Q_2) is negative, the force is attractive.

Determining Equilibrium Positions

If (Q_2) is free to move along the x-axis, the point where net force is zero is of particular interest. This involves setting the forces due to both charges equal in magnitude but opposite in direction, leading to potential equilibrium points.

Conditions for Equilibrium

- Stable equilibrium: Small displacements result in forces restoring the charge to equilibrium.
- Unstable equilibrium: Small displacements lead to forces pushing the charge away.

The positions of equilibrium depend on the magnitudes and signs of (Q_1) and (Q_2) .

Numerical Examples and Calculations

Case 1: Q_2 is positive, placed at $x = -a$

Suppose $Q_2 = 1.0 \text{ nC}$ and is located at $x = -4.0 \text{ cm}$ (i.e., $a = 2 \text{ cm}$).

- Distance between Q_1 and Q_2 :

$$r = 0.02 \text{ m} + 0.04 \text{ m} = 0.06 \text{ m}$$

- Force magnitude:

$$F = (8.988 \times 10^9) \times \frac{(1 \times 10^{-9})(1 \times 10^{-9})}{(0.06)^2} \approx 2.5 \times 10^{-4} \text{ N}$$

- Force direction: repulsive from Q_1 to Q_2 .

Case 2: Effect of Different Charge Magnitudes

If Q_2 has a different magnitude, say 2.0 nC , the force scales proportionally:

$$F' = 2 \times F$$

which would be approximately $5.0 \times 10^{-4} \text{ N}$.

Applications and Implications in Real-World Physics

Understanding Electric Field Interactions

- Electric fields from point charges are foundational for understanding phenomena such as electrostatic shielding, capacitor design, and particle interactions.
- Knowledge of forces between charges aids in designing microelectronic components and understanding atomic-scale interactions.

Electrostatics in Engineering and Technology

- Precise control of charge interactions enhances the development of sensors and electronic circuits.
- Electrostatic forces are exploited in printing technologies, air purifiers, and particle accelerators.

Educational Significance

- Thought experiments with point charges help students grasp abstract concepts in electrostatics.
- Visualizing the electric field lines and force vectors enhances comprehension.

Summary and Key Takeaways

- Point charges on the x-axis influence each other's electric fields and forces depending on their magnitudes and positions.
- Coulomb's Law provides a quantitative framework for calculating forces.
- The configuration where one charge is at $(x=+2, \text{cm})$ and another at an arbitrary negative x-position offers insights into electric field behavior, force interactions, and potential equilibrium points.
- Understanding such fundamental setups is essential for more complex electrostatic problems and practical applications in physics and engineering.

Conclusion

The analysis of two point charges positioned along the x-axis of a coordinate system reveals the intricate dance of electric forces and fields. By applying Coulomb's Law, converting units appropriately, and considering the signs and

positions of charges

Frequently Asked Questions

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

The electric potential at a point on the x-axis 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.

How do you determine the electric field at a point on the x-axis caused by two point charges?

The electric field is a vector sum of the fields due to each charge, calculated as $E = k |q| / r^2$, with directions determined by the sign of each charge and their positions relative to the point.

What is the significance of the sign of a point charge in calculating electric potential and field?

The sign determines the direction of the electric field and whether the potential adds or subtracts at a given point. Positive charges produce fields and potentials directed away from the charge, negative charges toward it.

How can I find the point on the x-axis where the electric potential due to two charges is zero?

Set the sum of potentials from both charges equal to zero: $kq_1/r_1 + kq_2/r_2 = 0$, and solve for the position x . This often involves considering the distances from each charge to the point.

Given $Q_1 = 1.0 \text{ nC}$ at $x = +2.0 \text{ cm}$, how does the electric field change along the x-axis?

The electric field varies depending on the distance from Q_1 and any other charges present. It decreases with distance from the charge and is directed away from positive charges.

What is the role of Coulomb's law in calculating the interactions between two point charges on the x-

axis?

Coulomb's law quantifies the force between two point charges, given by $F = k |q_1 q_2| / r^2$, which helps determine the electric field and potential at various points.

How does the distance between the two charges affect the electric potential and field at a point on the x-axis?

Both potential and electric field decrease with increasing distance from the charges. The closer the point is to a charge, the greater its contribution to the total potential and field.

If $Q_1 = 1.0 \text{ nC}$ is at $x = +2.0 \text{ cm}$, and Q_2 is at some position on the x-axis, how can I find the net electric potential at a specific point?

Calculate the potential due to each charge at that point using $V = k q / r$, then sum algebraically. The total potential is the sum of both contributions.

What are the key assumptions when analyzing electric fields and potentials of point charges on the x-axis?

Assumptions include point charges having no size, static conditions (charges not moving), and the superposition principle being valid for electric fields and potentials.

How can I visualize the electric field produced by two point charges on the x-axis?

Draw electric field lines originating from positive charges and terminating at negative charges, with their density indicating field strength. The lines' directions show the field direction at various points.

Additional Resources

Two Point Charges Are Located On The x -axis Of A Coordinate System: $Q_1 = 1.0 \text{ nC}$ Is At $x = +2.0 \text{ cm}$, And

Understanding the behavior of electric charges and their interactions is fundamental to the study of electromagnetism. When dealing with point charges positioned along a coordinate axis, it becomes essential to analyze how their electric fields influence each other and the surrounding space. In this

article, we delve into a classic scenario involving two point charges aligned on the negative x-axis: a charge $(Q_1 = 1.0 \text{ nC})$ located at $(x = +2.0, \text{cm})$, and a second charge (Q_2) positioned somewhere along the same axis. We explore the principles governing their interactions, the calculation of electric fields and potentials, and the implications of their arrangement.

Introduction to Point Charges and Coulomb's Law

What Are Point Charges?

Point charges are idealized charges that are considered to have negligible size, meaning all of their charge is concentrated at a single point in space. This simplification allows physicists and engineers to analyze electrostatic interactions without the complexities introduced by extended charge distributions.

The Fundamental Law: Coulomb's Law

The force between two point charges (Q_1) and (Q_2) separated by a distance (r) is described by Coulomb's law:

$$F = k_e \frac{|Q_1 Q_2|}{r^2}$$

where:

- (F) is the magnitude of the electrostatic force,
- $(k_e \approx 8.988 \times 10^9, \text{Nm}^2/\text{C}^2)$ is Coulomb's constant,
- (Q_1) and (Q_2) are the magnitudes of the charges,
- (r) is the separation distance between the charges.

This force acts along the line connecting the two charges and can be attractive or repulsive depending on the signs of the charges.

Setting Up the Scenario: Coordinates and Known Values

In our scenario:

- The first charge, $(Q_1 = 1.0, \text{nC} = 1.0 \times 10^{-9}, \text{C})$, is placed at coordinate $(x = +2.0, \text{cm})$.

- The second charge, (Q_2) , has an unknown magnitude and position along the x-axis; for simplicity, assume it is located at some coordinate $(x = x_2)$.

The negative x-axis extends from the origin towards negative infinity, but in this case, our charges are located on the positive side of the origin, along the +x direction.

Analyzing Electric Fields and Potentials Along the Axis

Electric Field Due to a Point Charge

The electric field (E) produced by a point charge (Q) at a point (P) located on the x-axis at a distance (r) from the charge is given by:

$$E = k_e \frac{|Q|}{r^2}$$

The direction of this field depends on the sign of (Q) :

- If (Q) is positive, the field points away from the charge.
- If (Q) is negative, the field points toward the charge.

For a charge (Q_1) at $(x = +2.0, \text{cm})$, the electric field at any point (x) on the axis is:

$$E_1(x) = k_e \frac{Q_1}{(x - 2.0, \text{cm})^2}$$

with the sign of the field depending on the relative positions and charge sign.

Similarly, the field due to (Q_2) at position (x_2) is:

$$E_2(x) = k_e \frac{Q_2}{(x - x_2)^2}$$

with its direction determined by the sign of (Q_2) .

Superposition Principle

The net electric field at any point along the axis is the vector sum of the individual fields:

$$E_{\text{net}}(x) = E_1(x) + E_2(x)$$

Because the electric field is a vector quantity, the signs and directions are crucial in determining whether the fields reinforce or oppose each other.

Calculating Electric Potential Along the Axis

Definition of Electric Potential

Electric potential (V) at a point due to a point charge is:

$$V = k_e \frac{Q}{r}$$

where (r) is the distance from the charge to the point of interest.

The total potential at a point on the axis is the algebraic sum of potentials from all charges:

$$V_{\text{total}}(x) = V_1(x) + V_2(x) = k_e \left(\frac{Q_1}{|x - 2.0|} + \frac{Q_2}{|x - x_2|} \right)$$

Determining the Influence of Charges at Various Points

Electric Field and Potential at Specific Locations

To understand the behavior of the system, consider the electric field and potential at different regions:

- At a point to the right of both charges ($(x > 2.0, \text{cm})$):
 - Both charges exert fields pointing away or toward the point, depending on their signs.
 - The net field is influenced by the relative magnitudes and distances.
- At the midpoint between charges:
 - The fields from each charge can partially cancel or reinforce, leading to points of equilibrium where the net force on a test charge would be zero.
- At points far from both charges (as $(x \rightarrow \pm \infty)$):
 - The combined effect diminishes, and the potential approaches zero.

Electric Field Zero Points

One significant question in electrostatics involves locating points along the axis where the net electric field is zero. These points are solutions to:

$$\begin{aligned} & \backslash[\\ & E_1(x) + E_2(x) = 0 \\ & \backslash] \end{aligned}$$

which can be solved algebraically when the charges are known.

Practical Applications and Implications

Electrostatic Shielding and Control

Understanding how point charges influence each other allows engineers to design shielding mechanisms, where certain regions are protected from electric fields by strategic placement of charges or conductive materials.

Designing Electric Field Configurations

In devices like particle accelerators or sensors, precise knowledge of electric fields generated by charge distributions enables the control of particle trajectories and sensitivity.

Fundamental Physics and Education

This scenario offers a foundational example for students learning about Coulomb's law, electric field superposition, and potential energy in electrostatics.

Advanced Considerations: Mutual Interactions and Dynamics

Force on Each Charge

Each charge experiences a force due to the other:

$$\begin{aligned} & \backslash[\\ & F_{12} = k_e \frac{|Q_1 Q_2|}{r_{12}^2} \\ & \backslash] \end{aligned}$$

where $(r_{12} = |x_2 - 2.0\text{ cm}|)$.

This force can cause acceleration if the charges are free to move, leading to dynamic behavior governed by Newton's second law.

Energy of the System

The potential energy stored in the configuration of two point charges is:

$$U = k_e \frac{Q_1 Q_2}{r_{12}}$$

which indicates that the energy depends on the magnitude of the charges and their separation.

Conclusion: Interplay of Charges on the Axis

Analyzing the behavior of two point charges positioned along the negative x-axis reveals rich physical phenomena rooted in fundamental electrostatics principles. From calculating electric fields and potentials to understanding equilibrium points, this scenario exemplifies the interplay of forces and fields that govern many practical and theoretical applications. Whether in designing electronic components, understanding atomic interactions, or exploring fundamental physics, the principles discussed here serve as essential tools for scientists and engineers alike.

Understanding the specific influences of point charges not only deepens our grasp of electromagnetism but also paves the way for innovations across multiple technological fields. As we continue to explore and manipulate electric fields, the insights gained from such fundamental scenarios remain invaluable.

Note: For specific calculations involving the unknown (Q_2) or its position (x_2) , additional boundary conditions or data are required. This article provides a comprehensive framework for approaching such problems and understanding the core concepts involved.

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