7. Two Charged Particles Are Fixed On The X-axis. Particle 1 Of Charge Q1 = 2.1 * 10^-8 C Is At Position

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When analyzing electrostatic interactions, a common scenario involves two point charges fixed at specific positions along a straight line, often the x-axis for simplicity. Understanding the forces, potential energies, and the resulting electric field in such arrangements is fundamental in electrostatics. This article explores the detailed problem where Particle 1 with charge $Q_1 = 2.1 \times 10^{(-8)}$ C is positioned at a certain point on the x-axis, and a second particle (with an unknown charge Q_2) is placed at another fixed point. We will examine the principles, calculations, and implications of this setup, guiding you through the concepts step-by-step.

Understanding the Setup and Basic Concepts

Positioning and Coordinates

- The scenario involves two point charges, each fixed on the x-axis at specific coordinates:
- Particle 1 with charge $Q_1 = 2.1 \times 10^{(-8)}$ C positioned at $x = x_1$.
- Particle 2 with charge Q_2 at position $x = x_2$.
- The positions x_1 and x_2 are known or specified, and they define the line along which the interactions occur.

Electrostatic Force and Coulomb's Law

- The fundamental principle governing the interaction between the charges is Coulomb's Law:

$$F = k_e |Q_1 Q_2| / r^2$$

where:

- F is the magnitude of the electrostatic force,
- $k_e \approx 8.99 \times 10^9$ N·m²/C² (Coulomb's constant),
- Q_1 and Q_2 are the magnitudes of the charges,
- r is the distance between the charges ($|x_1 - x_2|$).

- The direction of the force depends on the signs of the charges:
- Like charges repel.
- Opposite charges attract.

Key Parameters and Known Data

- $Q_1 = 2.1 \times 10^{-8}$ C (given)
- Position of Particle 1: x_1 (specified in the problem)
- Position of Particle 2: x_2 (specified or to be determined)
- Charge of Particle 2: Q_2 (may be known or unknown)
- Distance between particles: $r = |x_1 - x_2|$

Analyzing the Force Between the Particles

Calculating the Magnitude of the Force

To find the force exerted on a particle, follow these steps:

1. Identify the positions x_1 and x_2.
2. Calculate the distance $r = |x_1 - x_2|$.
3. Apply Coulomb's Law to compute F:
    - $F = k_e |Q_1 Q_2| / r^2$

Determining Force Direction

- If Q_1 and Q_2 are both positive or both negative, the force is repulsive, pushing the particles away from each other.
- If Q_1 and Q_2 have opposite signs, the force is attractive, pulling the particles toward each other.

Potential Energy of the System

Electrostatic Potential Energy Formula

- The potential energy (U) of two point charges separated by a distance r is given by:

$$U = k_e Q_1 Q_2 / r$$

- Sign considerations:
- If charges are opposite, U is negative, indicating a bound state.
- If charges are like, U is positive, indicating a repulsive, less stable configuration.

Implications of Potential Energy

- The magnitude of U indicates the work needed to assemble the configuration.
- As r decreases, the potential energy magnitude increases, indicating stronger interaction.

Electric Field Due to the Charges

Electric Field from a Point Charge

- The electric field at a point due to a single charge Q is:

$$E = k_e |Q| / r^2$$

- Direction:
- Outward from positive charges.
- Toward negative charges.

Superposition Principle

- When multiple charges are involved, the net electric field at a point is the vector sum of individual fields.
- For the two fixed charges:
- The electric field at any point along the x-axis is the sum of the fields due to Q□ and Q□.

Special Cases and Applications

Case 1: Calculating the Force on Particle 2

- Given Q□, positions x□, x□, and Q□, compute:
- The distance r = |x□ - x□|
- The force magnitude using Coulomb’s Law.
- The direction based on charge signs.

Case 2: Finding Equilibrium Positions

- If Q□'s position is variable, conditions for equilibrium occur when net force on Q□ is zero:
- Solve for x□ such that the forces balance.

Case 3: Effect of Changing Charges or Positions

- Increasing Q□ or Q□ increases force and potential energy.
- Moving particles closer (reducing r) intensifies forces and energy.

Practical Applications and Real-World Relevance

- Understanding electrostatic interactions in atomic and molecular structures.
- Designing charged particle traps and accelerators.
- Developing sensors that detect changes in electric fields.
- Electrostatic shielding in electronic devices.

Sample Problem Illustration

Suppose:

- $Q_1 = 2.1 \times 10^{-8}$ C at $x_1 = 0$ m.
- $Q_2 = -1.0 \times 10^{-8}$ C at $x_2 = 0.05$ m.
- Find:
- The force exerted on Q_2 due to Q_1.
- The potential energy of the system.

Solution:

1. Calculate r:
- $r = |0.05 \text{ m} - 0 \text{ m}| = 0.05$ m.
2. Compute force:
- $F = (8.99 \times 10^9) |2.1 \times 10^{-8} (-1.0 \times 10^{-8})| / (0.05)^2$
- $F = 8.99 \times 10^9 \ 2.1 \times 10^{-8} \ 1.0 \times 10^{-8} / 0.0025$
- $F \approx (8.99 \times 10^9) \ 2.1 \times 10^{-16} / 0.0025$
- $F \approx (8.99 \times 10^9) \ 8.4 \times 10^{-14}$

- F □ 7.55 × 10^(-4) N.

3. Determine force direction:

- Since Q□ is positive and Q□ is negative, the force is attractive, pulling Q□ toward Q□.

4. Calculate potential energy:

- U = (8.99 × 10^9) 2.1 × 10^(-8) (-1.0 × 10^(-8)) / 0.05

- U □ -3.77 × 10^(-6) Joules.

Conclusion

Understanding the interactions of two fixed charged particles along the x-axis involves analyzing forces, potential energy, and electric fields based on Coulomb’s Law. The key steps include calculating the distance between charges, determining the magnitude and direction of forces, and understanding the potential energy implications of their configuration. These principles are fundamental in fields like atomic physics, electrical engineering, and material science, providing insight into the behavior of electrostatic systems.

By mastering these concepts, students and professionals can predict how charges interact, design experiments, and develop technologies that leverage electrostatic forces for practical applications. Whether dealing with microscopic particles or macroscopic charged objects, the foundational principles remain the same, making this topic a cornerstone of electrostatics.

Frequently Asked Questions

What is the significance of fixing two charged particles on the x-axis

in electrostatics problems?

Fixing two charged particles on the x-axis simplifies the analysis of their electric interactions, allowing for straightforward calculation of electric fields, forces, and potential at various points, as the positions are fixed and symmetry can be exploited.

Given Q1 = 2.1 × 10^-8 C at a certain position on the x-axis, how do you determine the electric field at a point between the particles?

To determine the electric field at a point between the particles, calculate the electric field contributions from each charge using Coulomb's law, considering their distances from the point, and then vectorially add these fields to find the net electric field.

How does the position of particle Q1 influence the net electrostatic force experienced by the second particle?

The position of Q1 determines its distance from Q2, affecting the magnitude of the Coulomb force between them; closer proximity results in a stronger force, while increasing the distance weakens the interaction, based on Coulomb's law.

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

The electric potential at a point is the algebraic sum of potentials due to each charge, calculated as V = kQ/r for each, where r is the distance from the charge to the point; the superposition principle applies.

If Q1 is positive and fixed on the x-axis, what is the nature of the force on a test charge placed near it?

A positive test charge placed near Q1 experiences a repulsive force, directed away from Q1, due to the like charges repelling each other according to Coulomb's law.

How can the positions of two fixed charges on the x-axis be used to find points of equilibrium?

Points of electrostatic equilibrium occur where the net electric field is zero; by setting the sum of electric field contributions from both charges to zero and solving for position, these points can be found on the x-axis.

What are the key considerations when calculating the force between two fixed charges, Q1 and Q2, on the x-axis?

Key considerations include the magnitude of each charge, the distance between them, Coulomb's law for force calculation, and the direction of the forces; symmetry and superposition principles are also important for accurate analysis.

Additional Resources

Two Charged Particles Are Fixed On The X-axis: An In-Depth Analysis

The phenomenon of electrostatics, involving the forces between stationary charged particles, is fundamental to understanding many physical and engineering systems. When two charged particles are fixed along the x-axis, the problem becomes a classic example used to illustrate Coulomb’s Law, electric field interactions, potential energy, and the resulting forces. This detailed review aims to explore this scenario comprehensively, focusing on the case where Particle 1 has a charge Q□ = 2.1 × 10□□ C, and is positioned at a specific point on the x-axis.

Understanding the Setup: Fixed Charges on the X-Axis

Before diving into calculations and physical implications, it's crucial to grasp the conceptual framework of the problem:

- Fixed Positions: Both particles are stationary, implying no dynamics such as acceleration or motion are initially considered. This simplifies the analysis to static electrostatics.
- Alignment Along X-Axis: The linear arrangement simplifies the vector nature of electric fields and forces to scalar quantities along one dimension.
- Charges: The magnitude and sign of each charge determine the nature of forces—whether they are attractive or repulsive.

Defining the Scenario: Key Parameters

To analyze the system thoroughly, we need to specify or assume certain parameters:

- Charge of Particle 1: $Q_1 = 2.1 \times 10^{\square\square}$ C (positive, as given)
- Charge of Particle 2: Q_2 (to be specified; for example, assume $Q_2 = -1.5 \times 10^{\square\square}$ C to analyze a repulsive-attractive interaction)
- Positions:
- Particle 1 at position $x_1 = a$ (for instance, $x_1 = 0$ m)
- Particle 2 at position $x_2 = b$, which can be varied or specified (e.g., $x_2 = 5$ m)

By fixing these parameters, we can analyze the force interactions, potential energies, and field effects systematically.

Coulomb’s Law: The Foundation of Electrostatic Interaction

The cornerstone of understanding forces between point charges is Coulomb’s Law:

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

where:

- F is the magnitude of the electrostatic force
- k is Coulomb’s constant, approximately $8.9875 \times 10^9 \, \text{Nm}^2/\text{C}^2$
- Q_1, Q_2 are the magnitudes of the charges
- r is the separation between the charges

Since the charges are fixed on the x-axis, the vector nature of this force reduces to a scalar along the line:

- If both charges are of the same sign, the force is repulsive.
- If charges have opposite signs, the force is attractive.

Calculating the Force:

Suppose:

- Particle 1 at $x_1 = 0 \, \text{m}$
- Particle 2 at $x_2 = b \, \text{m}$

then,

$$ r = |x_2 - x_1| = |b - 0| = |b| $$

Force on Particle 1 due to Particle 2:

$$F_{12} = \frac{k |Q_1 Q_2|}{b^2}$$

The direction depends on the sign of Q_2:

- If $Q_2 > 0$, force is repulsive, pushing Particle 1 away from Particle 2.
- If $Q_2 < 0$, force is attractive, pulling Particle 1 toward Particle 2.

Electric Field Due To a Fixed Charge

The electric field generated by a point charge is essential in understanding the influence of one charge on the other:

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

Direction:

- For positive Q, the electric field points away from the charge.
- For negative Q, the field points toward the charge.

At a Point x on the x-axis:

$$E(x) = \frac{k Q}{(x - x_{\text{charge}})^2}$$

with direction depending on the sign of Q.

Potential Energy: Quantifying the System’s Stability

The electrostatic potential energy U between two point charges is:

$$U = \frac{k Q_1 Q_2}{r}$$

This quantity indicates the work done in assembling the system from infinity to the specified positions:

- $U > 0$: system has positive potential energy (repulsive configuration)
- $U < 0$: system has negative potential energy (attractive configuration)

Implications:

- A deep negative potential energy indicates a more stable, bound system.
- A positive potential energy suggests the charges tend to repel each other, favoring separation.

Force and Field Calculations for Specific Positions

Let’s consider concrete numerical examples:

Example Scenario:

- Particle 1 at $x_1 = 0\, \text{m}$ with $Q_1 = 2.1 \times 10^{-8} \, \text{C}$
- Particle 2 at $x_2 = 5\, \text{m}$, with $Q_2 = -1.5 \times 10^{-8} \, \text{C}$

Calculating the Force:

$$ r = |5 - 0| = 5\, \text{m} $$

$$ F_{12} = \frac{8.9875 \times 10^9 \times 2.1 \times 10^{-8} \times 1.5 \times 10^{-8}}{(5)^2} $$

$$ F_{12} = \frac{8.9875 \times 10^9 \times 3.15 \times 10^{-16}}{25} $$

$$ F_{12} = \frac{2.833 \times 10^{-6}}{25} = 1.133 \times 10^{-7} \, \text{N} $$

Since the charges are of opposite signs:

- The force is attractive, pulling Particle 1 toward Particle 2.
- Direction: along the positive x-axis toward $x=5\, \text{m}$.

Electric Field at $x=0$:

$$ E(0) = \frac{k Q_2}{(0 - 5)^2} = \frac{8.9875 \times 10^9 \times (-1.5 \times 10^{-8})}{25} $$

$$ E(0) = -5.3925 \times 10^{1} \, \text{V/m} $$

Thus, the electric field at Particle 1's position:

- Has a magnitude of approximately 53.9 V/m.
- Points toward the negative x-direction (since Q_2 is negative), indicating the force on a positive charge at $x=0$ would be in the negative x-direction, consistent with the attractive force.

Energy Considerations and System Behavior

Understanding the energy dynamics provides insights into the stability of the configuration:

- Potential Energy Calculation:

$$U = \frac{k Q_1 Q_2}{r} = \frac{8.9875 \times 10^9 \times 2.1 \times 10^{-8} \times (-1.5 \times 10^{-8})}{5}$$

$$U = - \frac{8.9875 \times 10^9 \times 3.15 \times 10^{-16}}{5}$$

$$U \approx -5.67 \times 10^{-7} \, \text{J}$$

- The negative potential energy indicates an attractive, bound state.

Implications:

- If the charges are free to move, they would tend to approach each other, reducing the system's potential energy.
- Since the charges are fixed, this energy state signifies the initial configuration and potential energy stored in the electrostatic field.

Influence of Distance and Sign on Interaction

The nature of the force and potential energy depends critically on:

- Separation Distance r:

- Increasing r decreases the magnitude of the force ($\propto 1/r^2$) and potential energy ($\propto 1/r$).

- Signs of Charges:

- Same sign: repulsive force, positive potential energy.

- Opposite sign: attractive force, negative potential energy.

- Charge Magnitudes:

- Larger magnitudes result in stronger forces and higher potential energy magnitude.

Extending the Analysis: Multiple Configurations

While the above example considers two charges with fixed positions, real-world problems often involve:

- Varying positions: Moving charges along the x-axis and analyzing equilibrium points.

- Additional charges: Introducing more fixed or free charges, leading to complex interactions.

- External fields: Superimposing external electric fields to analyze combined

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