A Charge Q Is At The Origin. A Charge -2q Is At X = 2.30 M On The X Axis. (a) For What Finite Value Of

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Understanding electrostatics and the behavior of point charges along a line is fundamental in physics, especially in the study of electric fields and potentials. The problem involving two point charges placed along the x-axis offers insight into the principles of Coulomb's law, electric potential, and the conditions for equilibrium. In this article, we will analyze a specific scenario where a charge Q is positioned at the origin, and a charge $-2q$ is located at $x = 2.30\, \text{m}$. Our goal is to determine the finite value of a third charge placed somewhere along the x-axis such that it experiences a particular condition, often equilibrium, or zero net force, as dictated by the context of the problem.

Understanding the Setup: Charges and Their Positions

The Configuration of Charges

The problem involves two primary point charges:
- Charge Q located at the origin $(x=0)$.
- Charge $-2q$ located at $x = 2.30\, \text{m}$.

These charges create an electric field along the x-axis, influencing any other charge placed at some position x. The key is to understand the nature of the forces exerted by these charges and how a third charge behaves in this field.

Significance of the Charges' Signs and Magnitudes

- The charge Q at the origin could be positive or negative, but typically in such problems, the sign is specified or implied.
- The charge $-2q$ is negative, indicating an attractive or repulsive force depending on the sign of the third charge.
- The magnitudes Q and $2q$ influence the strength of the electric forces, governed by Coulomb's law.

Fundamentals of Coulomb's Law and Electric Fields

Coulomb's Law

Coulomb's law provides the magnitude of the electrostatic force between two point charges:
$$ F = k \frac{|q_1 q_2|}{r^2} $$
where:
- k is Coulomb's constant ($8.99 \times 10^9\, \text{Nm}^2/\text{C}^2$),
- q_1 and q_2 are the magnitudes of the charges,
- r is the distance between the charges.

Electric Field Due to a Point Charge

The electric field E created by a point charge q at a distance r is:
$$ E = k \frac{|q|}{r^2} $$
The direction of the field is away from the positive charge and toward the negative charge.

Superposition Principle

The net electric field at any point is the vector sum of the fields due to individual charges.

Determining the Position of the Third Charge

Suppose we seek the position x along the x-axis where a third charge q_0 must be placed such that the net force on it is zero (equilibrium condition). The specific question might be: At what position x is the net electrostatic force on the third charge zero?

Typical Approach:
1. Identify the forces acting on the third charge at a general position x.
2. Write expressions for forces due to both charges Q and $-2q$.
3. Set the net force to zero and solve for x.

Calculating the Position for Equilibrium

Assumptions and Sign Conventions

- Assume the third charge q_0 is positive.
- The charges Q and $-2q$ are fixed.
- The third charge is placed somewhere along the x-axis, say at position x.

Force from Charge Q at the Origin
- Distance: x.
- Force magnitude:
$$F_Q = k \frac{|Q q_0|}{x^2}$$
- Direction: away from Q if Q and q_0 have the same sign; toward Q if opposite.

Force from Charge $-2q$ at $x=2.30\, \text{m}$
- Distance: $|x - 2.30|$.
- Force magnitude:
$$F_{-2q} = k \frac{2q \, |q_0|}{(x - 2.30)^2}$$
- Direction: toward or away based on the signs.

Equilibrium Condition
For the net force on q_0 to be zero:
$$F_Q \text{ and } F_{-2q} \text{ must balance in magnitude and direction}$$

Depending on the position x, the forces may act in the same or opposite directions, leading to different cases to analyze.

Solving for the Specific Finite Value of x

Suppose the problem asks: Find the finite position x along the x-axis where the net force on the third charge q_0 is zero.

Case 1: $0 < x < 2.30\, \text{m}$
- The third charge is between the origin and the $-2q$ charge.
- Forces due to both charges act along the x-axis, with directions depending on signs.

Case 2: $x > 2.30\, \text{m}$
- The third charge is beyond the $-2q$ charge.
- Similar analysis applies.

Case 3: $x < 0$
- The third charge is to the left of the origin.
- Again, forces are to be considered accordingly.

Setting Up the Equation
For equilibrium, the magnitudes of forces must satisfy:
$$k \frac{|Q q_0|}{x^2} = k \frac{2q |q_0|}{(x - 2.30)^2}$$
which simplifies to:

$$ \frac{|Q|}{x^2} = \frac{2q}{(x - 2.30)^2} $$

Rearranged:
$$ \frac{|Q|}{2q} = \frac{x^2}{(x - 2.30)^2} $$

Define $A = \frac{|Q|}{2q}$, then:
$$ \frac{x}{x - 2.30} = \pm \sqrt{A} $$

From this, solve for x:
$$ x = \pm \sqrt{A} (x - 2.30) $$

Leading to quadratic equations in x, whose solutions give potential equilibrium points.

Interpreting the Solutions and Physical Significance

The solutions for x derived from the quadratic equations represent the positions where the third charge experiences zero net force, i.e., equilibrium points.

Types of Equilibrium:
- Stable equilibrium: Small displacements produce forces that restore the charge to equilibrium.
- Unstable equilibrium: Small displacements cause the charge to move away from equilibrium.

In electrostatics, equilibrium points are often unstable unless specific conditions are met. The physical feasibility depends on the sign of the charges and the location of the third charge.

Additional Considerations and Practical Applications

Impact of Charge Magnitudes

- Increasing Q or q shifts the position of equilibrium.
- The ratio $\frac{|Q|}{2q}$ influences the solutions for x.

Real-World Applications

- Electrostatic shielding: understanding charge distributions helps design shielding devices.
- Particle trapping: positioning charges to create stable equilibrium points.
- Electric field mapping: analyzing potential points along a line.

Limitations and Assumptions

- Point charges are idealized; real charges have size and distribution.
- Coulomb's law applies in vacuum; media with different permittivities alter the forces.
- The problem assumes static charges and neglects other forces like gravity.

Summary

In conclusion, determining the finite value of x for which a charge experiences zero net force in the presence of other fixed charges involves applying Coulomb's law, superposition principle, and algebraic solutions of quadratic equations. The critical steps include:
- Recognizing the positions of fixed charges.
- Setting up force balance equations.
- Solving for x to find points of equilibrium.
- Interpreting the solutions to understand the stability and physical plausibility.

Understanding these principles not only aids in solving theoretical physics problems but also enhances the comprehension of electrostatic phenomena relevant in various technological applications. Whether designing sensors, understanding atomic interactions, or developing electronic devices, mastery of charge interactions along a line is fundamental.

Note: To fully solve the specific problem, additional information such as the value of Q, \(

Frequently Asked Questions

What is the significance of the charges' positions in calculating the electric potential at a point on the x-axis?

The positions of the charges determine their distances from the point where the potential is calculated, which directly affects the magnitude of each charge's contribution to the total electric potential at that point.

How do you determine the finite value of x where the net electric potential is zero due to two point charges?

You set the algebraic sum of the electric potentials from both charges equal to zero and solve for x, considering the distances of the point from each charge and their magnitudes.

What is the formula for electric potential at a point due to a point charge?

The electric potential V at a distance r from a point charge Q is given by V = k Q / r, where k is Coulomb's constant.

In the given scenario, why is it necessary to consider the signs of the charges when calculating the potential?

Because electric potential is scalar and depends on the magnitude and sign of the charges; positive and negative charges contribute with opposite signs, affecting where the net potential becomes zero.

How does the distance between the charges and the point of interest influence the position where the net potential is zero?

The distances determine the relative contributions of each charge to the potential at that point; adjusting the position changes these distances, and thus the point where their potentials cancel out, resulting in a finite solution for x.

Additional Resources

Electrostatics: An In-Depth Analysis of Charge Interactions on the X-Axis

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Introduction

Electrostatics, a fundamental branch of physics, deals with the study of stationary electric charges and the forces they exert on each other. Understanding the behavior of point charges and their potential energies forms the backbone of many practical applications, from designing electronic components to understanding natural phenomena like lightning.

In this article, we will delve into a classic electrostatics problem: a charge Q located at the origin and a charge $-2q$ placed at a position $x = 2.30\, \text{m}$ along the x-axis. Our goal is to determine the finite value of Q such that the net electrostatic force on the charge $-2q$ is zero. This problem encapsulates key principles of Coulomb's law, force equilibrium, and charge interactions, providing an excellent case study for both students and professionals interested in electrostatics.

Fundamental Concepts and Theoretical Background

Before tackling the problem, it's essential to understand the core principles involved.

Coulomb's Law

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

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

where:
- $k \approx 9.0 \times 10^9\, \text{Nm}^2/\text{C}^2$ (Coulomb's constant),
- q_1, q_2 are the magnitudes of the charges,
- r is the distance between the charges.

The force is attractive if the charges are of opposite signs and repulsive if they are of the same sign.

Force Direction and Significance

- The force exerted by Q on $-2q$ depends on their relative positions and signs.
- To find equilibrium, the net force on the $-2q$ charge must be zero, meaning the forces exerted by Q and any other charges must balance each other.

Problem Statement and Setup

Let's restate the problem:

- A charge Q is fixed at the origin $(x = 0)$.
- A charge $-2q$ is fixed at $x = 2.30\, \text{m}$.
- The task is to find the finite value of Q such that the net electrostatic force on the $-2q$ charge is zero.

Key considerations:

- The charge Q can be placed anywhere along the x-axis to achieve equilibrium.
- The charges involved are point charges.
- The value of $-2q$ is given, but the value of q is not specified; it can be considered as a known quantity or set to unity for ratio-based calculations.

Step-by-Step Approach

Step 1: Identify Possible Positions for Q

The position of Q relative to $-2q$ determines the nature of the forces:

- Case A: Q placed between the origin and $x=2.30\, \text{m}$ (i.e., $0 < x_Q < 2.30\, \text{m}$)
- Case B: Q placed to the left of the origin ($x_Q < 0$)
- Case C: Q placed to the right of the $-2q$ charge ($x_Q > 2.30\, \text{m}$)

Analyzing each case allows us to understand where equilibrium might occur.

Step 2: Establish the Force Equations

Suppose Q is at position x_Q. The forces on $-2q$ are:

- Force due to Q:

$$
F_Q = k \frac{|Q \times -2q|}{(x_{-2q} - x_Q)^2}
$$

- Force due to the $-2q$ charge itself, which is not relevant since it is fixed.

Note: Since we are looking for the force exerted by Q on $-2q$, the direction depends on the signs of Q and $-2q$.

Detailed Solution: Finding the Position of Q for Equilibrium

Let's analyze the case where Q is positioned to the left of the origin ($x_Q < 0$).

Reasoning:

- Since $-2q$ is at $x=2.30\, \text{m}$, if Q is at $x_Q<0$, the forces on $-2q$ are:

- The force due to Q (located at $x_Q<0$)
- The force due to the other charge (if any) at the origin (which is Q)

But in our problem, only two charges are involved: Q at origin and $-2q$ at $2.30\, \text{m}$. The problem implies that the force on $-2q$ due to Q and possibly other considerations (like the nature of the charges) determine equilibrium.

Step 3: Constructing the Force Balance Equation

Assuming Q is positioned at $x = x_Q$:

- The force exerted by Q on $-2q$:

$$
F_{Q \rightarrow -2q} = k \frac{|Q \times -2q|}{(x_{-2q} - x_Q)^2}
$$

- The force exerted by the fixed charge at the origin (which is Q at $x=0$):

- If Q is at $x=0$, the force on $-2q$ is:

$$
F_{Q \text{ at origin}} = k \frac{|Q \times -2q|}{(2.30)^2}
$$

- The direction of forces:

- Since both charges are negative (if Q is negative), the force is attractive, pulling $-2q$ toward Q.
- If Q is positive, the force on $-2q$ is repulsive, pushing $-2q$ away.

Assuming the goal is to find Q and its position so that the net force on $-2q$ is zero, the forces must cancel each other:

$$
F_{Q} \text{ (due to } Q \text{ at } x_Q) + F_{origin} \text{ (if applicable) } = 0
$$

But since the problem specifies Q at the origin, the initial setup is:

- Q at $x=0$
- $-2q$ at $x=2.30\, \text{m}$

Therefore, the only relevant force on $-2q$ is due to Q at the origin:

$$
F = k \frac{|Q \times -2q|}{(2.30)^2}
$$

But this force is always attractive or repulsive depending on the sign of Q. For equilibrium, the net force must be zero; however, since only one other charge exerts a force, unless there are other charges, the force can only be zero if the force itself is zero, which only occurs if $Q=0$. But this trivial solution isn't meaningful.

Step 4: Introducing Additional Charges or Locations for Q

Since the problem hints at a finite value of Q, and the force due to Q at the origin alone cannot be zero unless $Q=0$, the more meaningful interpretation is that Q is placed along the x-axis at some position \(x\), not necessarily at the origin.

Thus, the problem seems to be:

> Given the fixed charges: \(Q\) at an arbitrary position \(x\) and \(-2q\) at \(x=2.30\, \text{m}\), find the position \(x\) of \(Q\) such that the force on \(-2q\) is zero.

Step 5: Solving for \(Q\) and Its Position

Suppose:

- \(Q\) is at position \(x\),
- The charge \(-2q\) is at \(x=2.30\, \text{m}\),
- The goal: Find the finite value of \(Q\) that results in zero net force on \(-2q\).

Force from \(Q\) on \(-2q\):

\[
F_Q = k \frac{|Q \times -2q|}{(2.30 - x)^2}
\]

Force from the other \(Q\):

- If \(Q\) is at position \(x\), the force on \(-2q\) depends on the sign of \(Q\):

- If \(Q\) is positive: the force is repulsive, pushing \(-2q\) away.
- If \(Q\) is negative: the force is attractive, pulling \(-2q

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