4) Two Point Charges, Q1 = -1.0 C And Q2 = 4.0 C, Are Placed As Shown In The Figure. (k = 1/40 = 8.99

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Introduction

Understanding the behavior of electric charges and their interactions is fundamental in physics and electrical engineering. When dealing with point charges—idealized particles with electric charge concentrated at a single point—the principles of Coulomb's Law allow us to analyze the forces and electric fields they produce. In this article, we'll explore the scenario involving two point charges: Q1 = -1.0 C and Q2 = 4.0 C, placed in a specific configuration. Using Coulomb's Law with the electrostatic constant $k = \frac{1}{4\pi\varepsilon_0} \approx 8.99 \times 10^9\, \text{N·m}^2/\text{C}^2$, we'll examine the forces between these charges, the electric field at various points, and the potential energy of the system.

This detailed discussion aims to clarify the fundamental concepts and provide step-by-step calculations relevant for students, educators, and professionals interested in electrostatics.

Understanding Coulomb's Law and its Significance

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

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

where:
- F is the magnitude of the force between the charges,
- $k \approx 8.99 \times 10^9\, \text{N·m}^2/\text{C}^2$ (Coulomb's constant),
- Q_1 and Q_2 are the magnitudes of the two charges,
- r is the distance between the charges.

The law states:
- Like charges repel each other.
- Opposite charges attract each other.
- The force magnitude decreases with the square of the distance.

Understanding this law is crucial to analyzing the behavior of charge configurations, as it helps determine forces, electric fields, and potential energies.

The Configuration of the Two Charges

In this specific scenario:
- $Q_1 = -1.0\, \text{C}$,
- $Q_2 = 4.0\, \text{C}$,
- The charges are placed at certain positions as shown in the figure (not provided here, but typically with a known separation).

Assuming a common setup:
- Q_1 is located at position $x=0$,
- Q_2 is placed at position $x=d$,

the exact distance d between the charges influences the magnitude of forces and fields.

Calculating the Force Between the Charges

Given:
- $Q_1 = -1.0\, \text{C}$,
- $Q_2 = 4.0\, \text{C}$,
- Distance d (for example, assume $d = 2\, \text{m}$ for calculation purposes),

The magnitude of the force is:

$$ F = 8.99 \times 10^9 \times \frac{|(-1.0)(4.0)|}{(2)^2} = 8.99 \times 10^9 \times \frac{4.0}{4} = 8.99 \times 10^9\, \text{N} $$

Since the product of charges is negative, the force is attractive, meaning the charges will tend to move toward each other.

Key points:
- The force magnitude is directly proportional to the product of the charges.
- The force’s direction depends on the signs of the charges:
- Opposite signs: attraction.
- Same signs: repulsion.

Electric Field Produced by Each Charge

Electric field (E) at a point in space due to a point charge is:

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

The direction of the electric field:
- Radiates outward from positive charges.
- Points inward toward negative charges.

For each charge:
- The electric field at a point depends on the distance from that charge.
- The total electric field at a point is the vector sum of the fields due to each charge.

Calculating Electric Field at a Point

Suppose we want to find the electric field at a point P located between the two charges:

1. Calculate the electric field due to Q_1:

$$ E_{Q_1} = 8.99 \times 10^9 \times \frac{1.0}{r_1^2} $$

2. Calculate the electric field due to Q_2:

$$ E_{Q_2} = 8.99 \times 10^9 \times \frac{4.0}{r_2^2} $$

3. Determine the direction of each field:

- Q_1 is negative, so its field points toward Q_1.
- Q_2 is positive, so its field points away from Q_2.

4. Sum the components considering their directions to find the net electric field at P.

Electric Potential Energy of the System

The potential energy (U) stored in the system of two point charges is:

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

For the given charges and distance:

$$ U = 8.99 \times 10^9 \times \frac{(-1.0)(4.0)}{d} = -8.99 \times 10^9 \times \frac{4.0}{d} $$

- A negative U indicates a bound, stable system where the charges are attracted.
- The potential energy depends inversely on the separation distance d.

Work Done in Assembling the Charges

The work required to assemble the system from infinitely separated charges is equal to the potential energy:

$$ W = U $$

- For charges of opposite signs, energy is released when they come together.
- For like charges, energy must be supplied to bring them together.

In this case, since the charges are opposite, the system is energetically favorable.

Applications and Practical Implications

Understanding the interactions between two point charges has numerous real-world applications, including:

- Design of electric sensors.
- Electrostatic precipitators in pollution control.
- Capacitor design in electronic circuits.
- Particle physics experiments involving charged particles.

Accurate calculations of forces, electric fields, and potential energy are essential for optimizing these applications.

Summary of Key Concepts

- Coulomb's Law governs the force between two point charges.
- Electric field due to a charge is a vector quantity pointing away from positive charges and toward negative charges.
- The potential energy of a charge system depends on the magnitude of charges and their separation.
- The nature of the force (attractive or repulsive) depends on the signs of the charges.
- Distance plays a crucial role: as r increases, forces and fields decrease proportionally to $1/r^2$.

Final Remarks

Analyzing the interaction between two point charges like $Q_1 = -1.0\, \text{C}$ and $Q_2 = 4.0\, \text{C}$ provides foundational insight into electrostatics. By applying Coulomb's Law and understanding electric fields and potential energy, one can predict the behavior of charged particles in various configurations. Mastery of these principles is vital for students and professionals working in physics, electrical engineering, and related fields.

For further exploration, consider varying the distance, charges, or adding more charges to observe how the system's behavior changes. Such exercises deepen understanding of electrostatic principles and their practical applications.

Keywords: Coulomb's Law, electric force, electric field, potential energy, point charges, electrostatics, charge interaction, electric potential, charge configuration, electrostatics applications

Frequently Asked Questions

What is the magnitude and direction of the electric force between two point charges Q1 = -1.0 C and Q2 = 4.0 C separated by a certain distance?

The magnitude of the electric force is given by Coulomb's Law: $F = k |Q1 Q2| / r^2$. Since Q1 is negative and Q2 is positive, the force is attractive, pulling Q1 towards Q2. The specific force depends on the separation distance r, which should be provided or measured.

How does the sign of the charges Q1 and Q2 affect the direction of the electric force between them?

Since Q1 is negative and Q2 is positive, the electric force between them is attractive, meaning each charge experiences a force pulling it toward the other. If both charges were of the same sign, the force would be repulsive, pushing them away from each other.

If Q1 is fixed and Q2 is moved closer, how does the electric force change?

As Q2 is moved closer to Q1, the separation distance r decreases, leading to an increase in the magnitude of the electric force, since F is inversely proportional to r^2. Therefore, closer proximity results in a stronger force.

What is the significance of the Coulomb constant $k = 8.99 \times 10^9\ N\cdot m^2/C^2$ in calculating electric forces?

The Coulomb constant k quantifies the strength of the electrostatic force between point charges. It appears in Coulomb's Law and ensures the units and magnitude of the calculated force are correct, based on the charges and their separation.

In the given setup, how would the electric potential energy between Q_1 and Q_2 be calculated?

The electric potential energy U is given by $U = k Q_1 Q_2 / r$. Since Q_1 and Q_2 have opposite signs, the potential energy is negative, indicating a bound, attractive interaction between the charges.

Can the electric force between Q_1 and Q_2 cause acceleration of the charges, and how would you calculate it?

Yes, the electric force exerts a force on each charge, causing acceleration according to Newton's second law: $F = m a$. To find acceleration, divide the force by the mass of each charge. If the charges are fixed in place, they won't accelerate; otherwise, the acceleration can be calculated using the force value obtained from Coulomb's Law.

Additional Resources

Two Point Charges, $Q_1 = -1.0$ C And $Q_2 = 4.0$ C, Are Placed As Shown In The Figure

In the realm of electrostatics, understanding the interactions between point charges forms the foundation of many advanced concepts in physics and engineering. This article delves deeply into the behavior and characteristics of a system comprising two point charges—$Q_1 = -1.0$ C and $Q_2 = 4.0$ C—placed in a specific configuration. We explore the electric fields they generate, the forces they exert on each other, the potential energy involved, and the implications of their placement, all within the context of Coulomb’s law and electrostatic principles.

Introduction to Electrostatic Interactions

Electrostatics deals with stationary electric charges and the forces they exert on each other. The fundamental law governing these interactions is Coulomb's Law, which quantifies the magnitude and direction of the electrostatic force between two point charges.

Coulomb's Law Equation:

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

Where:
- F is the magnitude of the force between the charges,
- k is Coulomb's constant ($8.99 \times 10^9\, \text{N·m}^2/\text{C}^2$),
- Q_1 and Q_2 are the magnitudes of the charges,
- r is the distance between the charges.

In this context, the charges are $Q_1 = -1.0\, \text{C}$ and $Q_2 = 4.0\, \text{C}$. The signs of the charges determine the nature of the force—whether it is attractive or repulsive—and influence the electric field distribution.

Configuration and Assumptions

Suppose the two charges are placed along a straight line, with Q1 at position $x=0$ and Q2 at position $x=d$. For illustrative purposes, let's assume the following:

- The charges are fixed in their positions.
- The distance d between the charges is known or can be varied.
- The medium surrounding the charges is vacuum or air (permittivity ε_0).
- No other charges or external fields are present.

Understanding the system's behavior involves calculating:

- The electric field at any point in space.
- The force each charge exerts on the other.
- The potential energy stored in the configuration.
- The influence of the charges' magnitudes and positions on the system's stability.

Electric Field Due to Point Charges

The electric field generated by a point charge at a point in space is given by:

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

where:

- Q is the charge,
- r is the distance from the charge to the point,
- $\hat{\mathbf{r}}$ is the unit vector pointing from the charge to the point.

Superposition Principle:
The total electric field at any point is the vector sum of the fields due to each charge.

Electric Field at a Point Between or Outside the Charges

- Between the charges: The electric field results from both charges, with directions depending on their signs.
- Outside the charges: The field may be dominated by the closer or larger magnitude charge.

Example Calculation:
Suppose we want to find the electric field at the midpoint $x = d/2$. The contributions from both charges are:

$$
E_{Q_1} = k \frac{|Q_1|}{(d/2)^2}
$$

$$
E_{Q_2} = k \frac{|Q_2|}{(d/2)^2}
$$

The directions depend on the signs:
- Since Q_1 is negative, its field points toward it.
- Q_2 is positive, its field points away from it.

The resultant field at the midpoint results from vector addition, considering these directions.

Force Between the Charges

Applying Coulomb's law, the magnitude of the force F between Q1 and Q2 separated by distance d is:

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

Calculations:

\[

$$
F = 8.99 \times 10^9\, \frac{(1.0)(4.0)}{d^2} = 3.596 \times 10^{10} \frac{1}{d^2}
$$

Where d is in meters, F in Newtons.

Direction and Nature of Force:

- Since Q1 is negative and Q2 positive, the force is attractive; each charge experiences a force pulling it toward the other.
- The negative charge (Q1) experiences a force directed toward Q2, and vice versa.

Potential Energy of the System

The electrostatic potential energy U stored in the configuration is given by:

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

Note that since Q_1 is negative, the energy will be negative, indicating a bound state with potential for energy release if the charges are separated.

Calculating U:

$$
U = 8.99 \times 10^9\, \frac{(-1.0)(4.0)}{d} = -\frac{3.596 \times 10^{10}}{d}
$$

The negative potential energy signifies a bound system, with energy required to separate the charges to infinity.

Influence of Charge Magnitudes and Positions

Effect of Charge Signs and Magnitudes

- The positive and negative charges attract, leading to a stable configuration if unconstrained.
- The magnitude of the charges determines the strength of the interaction;

larger magnitudes generate stronger forces and higher energy.

Effect of Distance \(d\)

- Increasing \(d\) reduces the magnitude of force and potential energy, asymptotically approaching zero.
- Decreasing \(d\) increases the force and energy, potentially leading to high stresses or breakdown in physical systems.

Stability and Equilibrium

- For fixed charges, the system is inherently unstable if free to move—forces would accelerate charges toward each other.
- In practical applications, charges are often held in place by external forces or constraints.

Electric Field and Force Diagrams

Visual representations clarify how the charges interact:

- Field lines:
- From Q2 (positive), lines radiate outward.
- Toward Q1 (negative), lines converge inward.
- Force vectors:
- Both charges experience forces directed toward each other, aligned along the line connecting them.

These diagrams help in understanding potential points of zero electric field, equilibrium positions, and force directions.

Implications and Applications

Understanding two-point charge systems is fundamental in various fields:

- Electrostatic shielding: design of containers or enclosures to prevent electric field penetration.
- Capacitors: modeling charge storage with point charges.
- Particle physics: interactions between charged particles.
- Electrostatic precipitators: removing particles from exhaust gases via charge interactions.

Advanced Considerations

Effect of Medium Permittivity

If the charges are in a medium other than vacuum, the Coulomb constant k is replaced by:

$$
k' = \frac{1}{4\pi \varepsilon}
$$

where ε is the permittivity of the medium, affecting the force and energy calculations proportionally.

Dynamic Situations

- If charges are free to move, they will accelerate due to the force.
- Conservation of energy principles govern their motion, leading to potential oscillations or collisions depending on initial conditions.

Conclusion

The interaction between point charges $Q_1 = -1.0\, \text{C}$ and $Q_2 = 4.0\, \text{C}$ exemplifies fundamental electrostatic principles. Their magnitudes, signs, and spatial arrangement dictate the forces they exert, the electric fields they produce, and the potential energy stored in the system. Such analyses underpin much of modern electromagnetism and are essential for designing devices and understanding natural phenomena involving electric charges.

In practical applications, careful consideration of charge placement and magnitude is crucial to control electrostatic forces, prevent unintended discharges, and harness electrostatic energy effectively. As research progresses, the principles governing two-point charges continue to inform innovations in energy storage, particle manipulation, and electromagnetic compatibility.

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University Press.

Note: The specific placement of charges, the value of \(d\), and the physical context significantly influence the detailed behavior of the system.

4 Two Point Charges Q1 1 0 C And Q2 4 0 C Are Placed As Shown In The Figure K 1 40 8 99

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