A 4.4 - UC Point Charge Is Placed In An External Uniform Electric Field Of 1.5 X 10^4 N/C. At What Distance

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Understanding the behavior of electric charges in external electric fields is fundamental in electrostatics, a vital branch of physics. When a point charge is introduced into a uniform electric field, it experiences forces that influence its motion and potential energy. This article explores a specific scenario: a 4.4 microcoulomb (μC) point charge placed in an external uniform electric field of magnitude 1.5 x 10^4 N/C. The key question is: at what distance from a reference point or another charge does certain phenomena occur? We will analyze this problem step-by-step, providing insights into the underlying physics principles, relevant formulas, and practical applications.

Understanding the Problem Context

Before diving into calculations, it’s essential to clarify the problem's parameters and objectives.

Key Parameters

- **Charge (q):** 4.4 μC = 4.4 x 10^-6 C
- **Electric Field (E):** 1.5 x 10^4 N/C
- **Question:** Find the distance (r) at which certain conditions are met (e.g., potential energy, force balance, or specific electrostatic interactions).

Note: The exact nature of "at what distance" depends on the problem's context—whether it involves potential energy considerations, force balance, or electric potential. In this case, we interpret it as determining the distance where the electric potential energy equals a specified value or where the forces acting balance out.

Fundamental Concepts in Electrostatics

To solve such problems, understanding core electrostatic principles is crucial.

Electric Field and Force

- The electric field (E) created by a point charge q at a distance r is given by Coulomb's Law:

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

where k is Coulomb's constant ($8.9875 \times 10^9 \, \text{N}\cdot\text{m}^2/\text{C}^2$).

- The force (F) experienced by a charge q in an electric field E is:

$$
F = qE
$$

Potential Energy in an Electric Field

- The electric potential energy (U) of a charge q in an electric potential V is:

$$
U = qV
$$

- The electric potential (V) at a distance r from a point charge q' is:

$$
V = \frac{k q'}{r}
$$

Analyzing the Scenario

Suppose the problem involves the interaction between the point charge and the external electric field, and we need to find the distance where the potential energy or force reaches a specific value or condition.

Case 1: Equating Electric Force and External Field Force

If the question is to find the distance at which the electric force due to a point charge balances the force due to the external electric field, then:

\[
qE = \frac{k q q'}{r^2}
\]

However, since only one charge and a uniform external field are specified, a more typical scenario is:

- The point charge is placed in the external field.
- The question asks at what distance from a reference point (such as another charge or a point in space) the potential energy or electric potential reaches a certain value.

Case 2: Electric Potential Energy in External Field

Alternatively, the problem could involve calculating the potential energy of the charge in the external field at a specific distance.

Step-by-Step Solution Approach

Here's a systematic approach to solving the problem:

1. Clarify the exact condition to be met

- Is it the distance where the potential energy equals a specific value?
- Is it the distance where the force or electric potential reaches a certain magnitude?
- Or is it the equilibrium position where forces balance?

Assuming the problem asks: At what distance from a certain point or charge does the electric potential energy of the charge in the external field equal a given value?

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2. Calculate the Electric Potential due to the External Field

Since the external field is uniform, the electric potential at a distance r from some reference point is:

\[

V = E \times r
\]

Note: This formula applies along the direction of the field, assuming constant magnitude.

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3. Determine the Electric Potential Energy of the Charge

The potential energy of the charge q at this point is:

\[
U = qV = q \times E \times r
\]

Given:

\[
q = 4.4 \times 10^{-6} \, \text{C}
\]
\[
E = 1.5 \times 10^{4} \, \text{N/C}
\]

Therefore,

\[
U(r) = (4.4 \times 10^{-6}) \times (1.5 \times 10^{4}) \times r
\]

\[
U(r) = 6.6 \times 10^{-2} \times r \quad \text{(Joules)}
\]

---

4. Set the Desired Condition and Solve for r

Suppose the problem states that the potential energy should be equal to a specific value, say \(U_0 \). Then,

\[
U_0 = 6.6 \times 10^{-2} \times r
\]

\[

$$
r = \frac{U_0}{6.6 \times 10^{-2}}
$$

Example: If the desired potential energy is 0.1 Joules,

$$
r = \frac{0.1}{6.6 \times 10^{-2}} \approx 1.515 \, \text{meters}
$$

Additional Considerations and Practical Applications

Understanding these calculations has practical implications in various fields such as:

- Electrostatic shielding: Designing systems where charges are kept at specific distances to mitigate electric potential.
- Capacitor design: Determining electrode spacing based on desired electric potential and energy.
- Particle physics: Calculating the forces and energies involved in particle accelerators or detectors.

Common Challenges and Errors to Avoid

When solving problems involving electric fields and charges, consider the following pitfalls:

- Unit inconsistencies: Always convert microcoulombs to coulombs, and verify units throughout calculations.
- Incorrect assumptions: Clarify whether the electric field is due to a point charge or is externally applied.
- Sign conventions: Remember that electric potential energy depends on the sign of the charge and the direction of the electric field.
- Boundary conditions: Ensure that the reference points for potential calculations are correctly chosen.

Summary

In conclusion, determining the distance at which a 4.4 μC charge experiences specific electrostatic conditions in an external electric field involves understanding the relationships between electric field, potential, force, and energy. By applying Coulomb’s Law, the formula for electric potential, and energy considerations, one can calculate the required distance for various scenarios.

Key formulas:

- Electric potential due to a point charge: $V = \frac{k q'}{r}$
- Electric potential energy: $U = qV$
- Electric field magnitude: $E = \frac{k |q|}{r^2}$
- Force on a charge in an electric field: $F = qE$

Understanding these principles allows for precise calculations crucial in designing and analyzing electrostatic systems, ensuring safety, efficiency, and functionality across numerous scientific and engineering applications.

Meta Description:
Learn how to calculate the distance where a 4.4 μC point charge, placed in an external electric field of 1.5×10^4 N/C, reaches specific electrostatic conditions. Step-by-step explanations, formulas, and practical applications included.

Frequently Asked Questions

How do you determine the equilibrium position of a 4.4 μC point charge placed in an external electric field of 1.5×10^4 N/C?

The equilibrium position is found where the electric force on the charge equals zero or balances with other forces. Since a point charge in a uniform electric field experiences a force $F = qE$, the charge will move until it reaches a point where it is in equilibrium, which depends on other forces or constraints present. In the absence of other forces, the charge will accelerate in the direction of the field.

What is the force experienced by a 4.4 μC point charge in an external electric field of 1.5×10^4 N/C?

The force is given by $F = qE = 4.4 \times 10^{-6}\ \text{C} \times 1.5 \times 10^{4}\ \text{N/C} = 0.066\ \text{N}$.

Is the distance at which a point charge experiences a certain electric potential in an external field dependent on the charge magnitude?

Yes, the electric potential at a point depends on both the electric field and the position relative to the source charges. For a test charge in a uniform field, the potential varies linearly with distance, but the exact position depends on initial conditions and the presence of other charges.

How can the concept of electric potential energy help determine the position of a charge in an external electric field?

Electric potential energy $U = qV$, where V is the electric potential at a point. By analyzing the potential energy change as the charge moves, one can find the equilibrium or specific positions where forces balance, thereby determining the required distance.

What additional information is needed to calculate the exact distance at which the 4.4 μC charge is placed in the external electric field?

To determine the exact distance, we need details such as the initial position of the charge, boundary conditions, or the presence of other charges or constraints. Without this information, only the force experienced at a given point can be calculated.

Can the electric field strength of 1.5 × 10^4 N/C be considered uniform over any significant distance for practical calculations?

Yes, in many practical scenarios, electric fields of this magnitude are considered uniform over small regions, making calculations of force and potential straightforward. However, over large distances, field non-uniformities may need to be considered.

What is the significance of the 'UC Point' in the context of electric fields and point charges?

The 'UC Point' typically refers to a 'Unstable Equilibrium Point' where the net force on the charge is zero but small displacements cause the charge to move away from that point. Identifying such points helps understand potential energy landscapes and stability in electric fields.

Additional Resources

A 4.4 - UC Point Charge Is Placed In An External Uniform Electric Field Of 1.5 X 10^4 N/C. At What Distance?

Introduction

The interaction of electric charges with external electric fields is a foundational concept in electromagnetism, providing insights into phenomena ranging from atomic scales to large-scale electrical systems. In this investigation, we explore a classic problem: determining the specific distance at which a point charge of 4.4 microcoulombs (μC) experiences a particular force when placed in a uniform external electric field of 1.5×10^4 N/C.

This scenario encapsulates core principles, including Coulomb's law, the behavior of electric fields, and the superposition of fields. Not only does it serve as an illustrative example for students and practitioners, but it also underpins practical applications such as particle manipulation, sensor calibration, and electric field mapping.

Theoretical Foundations

Coulomb's Law and Electric Fields

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

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

where:
- k is Coulomb's constant ($8.9875 \times 10^9 \, \mathrm{N\,m^2/C^2}$),
- q_1 and q_2 are the magnitudes of the charges,
- r is the separation between the charges.

The electric field E produced by a point charge q at a distance r is:

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

The external electric field E_{ext}, assumed uniform, exerts a force F_{ext} on the charge q:

$$
F_{ext} = q E_{ext}
$$

The superposition principle states that the net electric field at a point is the vector sum of all individual fields. When a point charge is placed in an external uniform field, the total field is the sum of the external field and the field due to the charge itself.

Problem Statement and Objective

Given:
- Point charge: $q = 4.4\, \mu C = 4.4 \times 10^{-6} \, C$,
- External electric field: $E_{ext} = 1.5 \times 10^4 \, N/C$.

Question: At what distance r from the charge does the external electric field produce a certain force or influence?

While the problem statement initially appears to ask for the distance where the external field acts, it is most instructive to interpret it as determining the distance at which the electric field from the point charge influences or balances the external field, or when the total force or field interactions reach a specific value.

Analytical Approach

Case 1: Finding the distance where the field from the charge equals the external field

One natural approach is to find the distance r where the electric field due to the point charge equals the magnitude of the external electric field. This yields a characteristic length scale relevant to the problem.

Set:

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

Solving for r:

$$
r = \sqrt{\frac{k|q|}{E_{ext}}}
$$

Substituting known values:

$$
r = \sqrt{\frac{8.9875 \times 10^9 \times 4.4 \times 10^{-6}}{1.5 \times 10^4}}
$$

Calculating numerator:

$$
8.9875 \times 10^9 \times 4.4 \times 10^{-6} = 8.9875 \times 4.4 \times 10^{3} = (8.9875 \times 4.4) \times 10^{3}
$$

$$
8.9875 \times 4.4 \approx 39.55
$$

Thus,

$$
r = \sqrt{\frac{39.55 \times 10^{3}}{1.5 \times 10^{4}}} =
$$

$$
\sqrt{\frac{39,550}{15,000}}
$$

Simplify:

$$
\frac{39,550}{15,000} \approx 2.637
$$

Finally:

$$
r \approx \sqrt{2.637} \approx 1.624\, \text{meters}
$$

Result: At approximately 1.62 meters, the electric field generated by the point charge equals the external uniform field of $1.5 \times 10^{4} \, N/C$.

Deep Dive: Physical Interpretation and Implications

Significance of the 1.62 m Distance

This distance marks the boundary where the point charge's influence on the electric field is comparable to the external field. Closer than this, the charge's own field dominates; farther away, the external field's influence prevails.

This balance point is essential in various applications:

- Electrostatic shielding: Understanding at what distances a charge's influence diminishes allows engineers to design effective shielding.

- Sensor calibration: Knowing the spatial influence helps calibrate devices sensitive to electric fields, such as field mills or particle detectors.

- Particle manipulation: In fields like electrophoresis or plasma physics, controlling the distance relative to charges allows for precise control of particle trajectories.

Additional Considerations

Force on the Charge

The force exerted by the external field on the charge:

$$
F_{ext} = q E_{ext} = 4.4 \times 10^{-6} \times 1.5 \times 10^{4} = 0.066\, \text{N}
$$

This force is significant enough to cause noticeable movement of a small particle or charge in a controlled environment.

Superposition of Fields

If an object or medium exists between the charge and the external field, superposition must be considered to analyze net forces and fields accurately.

Practical Applications and Experimental Design

Understanding the interplay between a point charge and an external electric field is critical in designing experiments and devices. For instance:

- Electrostatic probes: To measure electric fields, probes are placed at distances where the local field dominates.
- Electric field mapping: Calculating the influence zones helps generate accurate field maps.
- Charged particle accelerators: Knowing the influence zones helps in controlling particle paths with precision.

Limitations and Assumptions

The calculation assumes:

- The external field is perfectly uniform over the region of interest.
- The point charge is isolated, with no other nearby charges influencing the field.
- The medium is vacuum or air, with permittivity corresponding to free space.

Real-world complexities such as dielectric materials, charge distributions, and environmental factors may alter the actual distances and forces.

Conclusion

This investigation demonstrates that a point charge of 4.4 μC placed in an external uniform electric field of 1.5×10^4 N/C experiences a field from its own charge that equals the external field at approximately 1.62 meters. This key distance underscores the spatial extent of electrostatic influence and provides valuable insights into experimental design, device calibration, and fundamental physics.

Understanding these principles allows scientists and engineers to predict charge behavior in complex environments, optimize apparatuses, and develop new technologies harnessing electrostatic phenomena. The interplay of local and external fields remains a rich area of study, with ongoing research expanding its applications across multiple domains.

References

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Note: The calculations and interpretations above are based on ideal conditions; actual measurements may vary due to environmental factors and material properties.

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