Two Equally Charged Particles Are Held 3.2 ' 10$3 M Apart And Then Released From Rest. The Initial Acceleration

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When exploring the fascinating world of electrostatics, understanding how charged particles interact under Coulomb's law is fundamental. In this article, we analyze a specific scenario where two particles, carrying equal charges, are initially held a fixed distance apart and then released from rest. Our focus is on calculating the initial acceleration of each particle immediately after release, considering electrostatic forces and the principles of classical mechanics.

This detailed examination not only elucidates the underlying physics but also provides insights into related phenomena such as charge interactions, energy conservation, and acceleration dynamics in electrostatic systems.

Understanding the Scenario

Before delving into calculations, it is essential to understand the physical setup and the principles involved.

Initial Configuration

- Particles: Two particles with identical charges, say \(q \) and \(q \).

- Separation Distance: The particles are held 3.2×10^3 meters apart, i.e., 3,200 meters.

- Rest State: Both particles are initially at rest, meaning their initial velocities are zero.

- Release: They are simultaneously released from rest, allowing electrostatic forces to act upon them.

Key Assumptions

- The particles are point charges, meaning their size is negligible relative to the separation distance.

- The surrounding medium is vacuum or air, with permittivity ε_0.

- External forces other than electrostatic forces are negligible.

- The system is isolated, conserving energy and momentum.

Fundamental Principles Involved

To analyze the initial accelerations, we rely on Coulomb’s law and Newton’s second law.

Coulomb’s Law

Coulomb’s law describes the force between two point charges:

$$
F = \frac{1}{4 \pi \varepsilon_0} \cdot \frac{q_1 q_2}{r^2}
$$

where:

- F is the magnitude of the electrostatic force.

- q_1 and q_2 are the magnitudes of the charges.

- r is the separation distance between the charges.

- ε_0 is the permittivity of free space, approximately $8.854 \times 10^{-12} \, F/m$.

Since the particles are equally charged, $q_1 = q_2 = q$.

Newton’s Second Law

The acceleration a of a particle is related to the net force F acting on it and its mass m:

$$
a = \frac{F}{m}
$$

Calculating the Initial Force and Acceleration

To find the initial acceleration, we follow these steps:

1. Determine the electrostatic force magnitude based on Coulomb’s law.

2. Use Newton’s second law to find the acceleration for each particle.

Step 1: Calculating the Coulomb Force

Given data:

- $r = 3.2 \times 10^{3} \, m$

- q (unknown in the problem description; assuming a specific value or leaving as a variable)

Suppose each charge has magnitude q; then the force is:

$$
F = \frac{1}{4 \pi \varepsilon_0} \cdot \frac{q^2}{r^2}
$$

The Coulomb constant k is:

$$
k = \frac{1}{4 \pi \varepsilon_0} \approx 8.988 \times 10^{9} \, Nm^2/C^2
$$

Thus:

$$
F = k \cdot \frac{q^2}{r^2}
$$

Without specific charge values, the force remains expressed in terms of q.

Step 2: Determining the Initial Acceleration

Assuming:

- Mass of each particle: m (value needed for exact calculation; if not given, we leave as a variable)

Then, the initial acceleration a for each particle:

$$
a = \frac{F}{m} = \frac{k \cdot q^2}{m \cdot r^2}
$$

This expression indicates that the initial acceleration depends directly on the charge magnitude and inversely on the mass and the square of the separation distance.

Numerical Example

To provide a concrete understanding, consider an example with specific values:

- Charge: $q = 1 \times 10^{-6} \, C$ (1 microcoulomb)

- Mass of each particle: $m = 1 \times 10^{-3} \, kg$ (1 gram)

Calculations:

$$
F = 8.988 \times 10^{9} \times \frac{(1 \times 10^{-6})^2}{(3.2 \times 10^{3})^2}
$$

$$
F = 8.988 \times 10^{9} \times \frac{1 \times 10^{-12}}{1.024 \times 10^{7}}
$$

$$
F \approx 8.988 \times 10^{9} \times 9.77 \times 10^{-20}
$$

$$
F \approx 8.78 \times 10^{-10} \, N
$$

Then, the initial acceleration:

$$
a = \frac{F}{m} = \frac{8.78 \times 10^{-10}}{1 \times 10^{-3}} = 8.78 \times 10^{-7} \, m/s^2
$$

This small acceleration indicates that, for these values, the particles start to repel each other with a very gentle initial acceleration.

Factors Affecting Initial Acceleration

Several factors influence the magnitude of the initial acceleration of the particles:

1. Magnitude of Charges (q)

- Larger charges produce stronger electrostatic forces, resulting in higher acceleration.

- The force scales with q^2, so doubling the charge quadruples the force.

2. Mass of Particles (m)

- Heavier particles experience lower acceleration for the same force.

- Acceleration is inversely proportional to mass.

3. Separation Distance (r)

- Force decreases with the square of the distance.

- Increasing r significantly reduces the force and thus the acceleration.

4. Medium Properties

- The presence of a medium other than vacuum (e.g., air, dielectric) can affect force calculations if polarization effects are considered.

Implications and Extensions

Understanding the initial acceleration provides insights into several physical phenomena and practical applications.

1. Motion Dynamics

- The particles will accelerate away from each other, increasing their kinetic energy while decreasing potential energy, in accordance with conservation of energy.

2. Time to Reach Certain Speeds

- Using initial acceleration, one can estimate how long it takes for the particles to reach specific velocities.

3. Electric Field and Potential Energy

- The initial electric field at the position of each particle is:

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

- The potential energy stored in their configuration:

$$
U = \frac{k \cdot q^2}{r}
$$

4. Energy Conservation

- As particles move apart, potential energy converts into kinetic energy.

- The initial kinetic energy is zero, so the initial acceleration is critical in determining their subsequent motion.

Real-World Applications and Examples

Understanding the initial acceleration of charged particles is vital in various technological and scientific contexts:

- Particle Accelerators: The initial acceleration of particles is crucial for designing accelerators and understanding their motion.

- Electrostatic Precipitators: Particles are charged and accelerated to remove pollutants from gases.

- Electrostatic Discharge (ESD): The initial acceleration influences how charges transfer rapidly during ESD events, affecting electronic device safety.

- Space Physics: Charged particles in space environments experience Coulomb forces, influencing their acceleration and trajectories.

Summary of Key Points

- The initial acceleration of two equally charged particles depends on the magnitude of their charges, their masses, and the initial separation distance.

- Coulomb’s law provides the force magnitude, which, combined with Newton’s second law, yields the initial acceleration.

- Numerical examples illustrate that even with microcoulomb charges and small masses, the accelerations can be extremely small at large separations.

- Variations in charge, mass, or distance significantly impact the initial dynamics of the particles.

- The understanding of initial accelerations is foundational for analyzing subsequent motion, energy transfer, and potential applications in various fields.

Conclusion

Analyzing the initial acceleration of two equally charged particles released from rest reveals the intricate interplay between electrostat

Frequently Asked Questions

What is the initial acceleration of each charged particle when released from rest 3.2×10³ meters apart?

The initial acceleration can be calculated using Coulomb's law and Newton's second law. First, determine the electrostatic force using $F = k q_1 q_2 / r^2$, then divide by the mass of each particle to find acceleration $a = F / m$.

How does the distance between two equally charged particles affect their initial acceleration when released?

The initial acceleration is inversely proportional to the square of the distance (r^2). As the separation decreases, the electrostatic force increases, resulting in a higher initial acceleration.

If the particles are initially at rest and equally charged, what is the direction of their acceleration after release?

Both particles experience a repulsive force and accelerate away from each other along the line connecting their centers.

How does the charge magnitude influence the initial acceleration of the particles?

Larger charges increase the electrostatic force, leading to greater initial acceleration of each particle when released.

What assumptions are typically made to simplify calculations of initial acceleration in this scenario?

Assumptions often include point charges, no external forces or fields, particles having known masses and charges, and neglecting effects like air resistance or other interactions.

Additional Resources

Initial Acceleration of Two Equally Charged Particles Held 3.2×10^3 m Apart and Then Released From Rest

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Introduction

The dynamics of electrostatic interactions between charged particles have long served as a fundamental cornerstone in physics, underpinning phenomena from atomic structures to macroscopic electromagnetic systems. A classic problem involves two point charges, identical in magnitude and sign, initially held at rest at a fixed separation, and then released to move under their mutual Coulomb repulsion. The initial acceleration of these particles provides vital insights into the foundational principles of electrostatics, energy conservation, and classical mechanics.

This investigation explores the initial acceleration of two equally charged particles initially separated by a distance of 3.2×10^3 meters, which are then released simultaneously from rest. Analyzing such a scenario involves applying Coulomb's law, Newtonian mechanics, and energy conservation principles to derive quantitative measures of their initial accelerations. This problem not only offers a rich theoretical framework but also underscores the importance of precise calculations and physical understanding in complex systems.

Physical Setup and Assumptions

To establish a rigorous analysis, the problem is characterized by the following assumptions and conditions:

- Particles: Two point charges, each with charge magnitude \(q \), both of equal magnitude and sign (e.g., both positive for specificity).
- Initial Separation: \(r_0 = 3.2 \times 10^3 \, \text{m} \).
- Initial State: Both particles are initially at rest; thus, initial velocities \(v_1 = v_2 = 0 \).
- Environment: The particles are isolated in vacuum, with no external forces or fields influencing their motion.
- Objective: To determine the initial acceleration of each particle immediately after release, considering the mutual electrostatic repulsion.

Fundamental Principles and Equations

The core physical principles involved are Coulomb’s law, Newton’s second law, and conservation of energy:

Coulomb's Law

The electrostatic force \(F \) between two point charges \(q_1 \) and \(q_2 \), separated by a distance \(r \), is given by:

$$
F = \frac{1}{4\pi \varepsilon_0} \frac{q_1 q_2}{r^2}
$$

For two identical charges q:

$$
F = \frac{1}{4\pi \varepsilon_0} \frac{q^2}{r^2}
$$

where:

- ε_0 is the permittivity of free space ($\varepsilon_0 \approx 8.854 \times 10^{-12} \, \text{F/m}$).

Newton's Second Law

Each particle experiences a force F and thus has an acceleration:

$$
a = \frac{F}{m}
$$

where m is the mass of the particle.

Deriving the Initial Acceleration

Since the particles are identical and initially at rest, they will accelerate away from each other symmetrically. The force on each particle is equal in magnitude but opposite in direction, and the initial acceleration a_0 can be expressed as:

$$
a_0 = \frac{F}{m}
$$

Substituting Coulomb's law:

$$
a_0 = \frac{1}{4\pi \varepsilon_0} \frac{q^2}{m r_0^2}
$$

This formula directly relates the initial acceleration to the charge magnitude, mass, and initial separation.

Practical Calculation: Estimating Parameters

To obtain meaningful numerical results, specific values for q and m are necessary. Typical choices for such a problem are:

- Charge magnitude q: For example, one elementary charge $e = 1.602 \times 10^{-19} \, \text{C}$, or a larger charge depending on context.
- Mass m: For a proton, $m_p \approx 1.673 \times 10^{-27} \, \text{kg}$; for an electron, $m_e \approx 9.109 \times 10^{-31} \, \text{kg}$. Alternatively, macroscopic particles could be considered.

Given the vast separation distance ($3.2 \times 10^3 \, \text{m}$), the forces involved are extremely weak unless the charges are extraordinarily large. For illustrative purposes, consider the case where each particle carries a single elementary charge.

Example Calculation with Elementary Charges

- $q = e = 1.602 \times 10^{-19} \, \text{C}$
- $m = m_p = 1.673 \times 10^{-27} \, \text{kg}$
- $r_0 = 3.2 \times 10^3 \, \text{m}$

Compute the force:

$$
F = \frac{1}{4\pi \varepsilon_0} \frac{q^2}{r_0^2} = \left(9 \times 10^9 \, \text{Nm}^2/\text{C}^2\right) \times \frac{(1.602 \times 10^{-19})^2}{(3.2 \times 10^3)^2}
$$

Calculating numerator:

$$
(1.602 \times 10^{-19})^2 = 2.566 \times 10^{-38}
$$

Calculating denominator:

$$
(3.2 \times 10^3)^2 = 1.024 \times 10^7
$$

Therefore:

$$
F = 9 \times 10^9 \times \frac{2.566 \times 10^{-38}}{1.024 \times 10^7} \approx 9 \times 10^9 \times 2.505 \times 10^{-45} \approx 2.254 \times 10^{-35} \, \text{N}
$$

The initial acceleration:

\[

$$
a_0 = \frac{F}{m} = \frac{2.254 \times 10^{-35}}{1.673 \times 10^{-27}} \approx 1.347 \times 10^{-8} \, \text{m/s}^2
$$

This extremely small acceleration underscores the weak nature of electrostatic interactions at macroscopic distances with elementary charges.

Significance of Initial Acceleration

The calculated initial acceleration, although tiny, reflects the fundamental physics governing charge interactions. It also emphasizes the importance of scale:

- For microscopic particles with large charges (e.g., ions or artificially charged small spheres), accelerations can be more substantial.
- For macroscopic objects with typical charges, the forces and accelerations are negligible at such large separations, requiring either very large charges or smaller distances to observe meaningful effects.

Factors Affecting Initial Acceleration

Several parameters influence the initial acceleration:

Parameter	Effect on a_0
Charge magnitude q	$a_0 \propto q^2$
Particle mass m	$a_0 \propto 1/m$
Initial separation r_0	$a_0 \propto 1/r_0^2$

Understanding these dependencies allows for tailored experimental or theoretical investigations.

Implications and Broader Context

Energy Conservation and Kinetics

At the moment of release, the initial potential energy stored in the electrostatic configuration begins converting into kinetic energy as the particles accelerate away from each other. The initial acceleration provides a glimpse into the early stages of this energy transformation.

Relevance to Atomic and Molecular Phenomena

While the scale of the problem is macroscopic, analogous principles govern atomic interactions—such as the repulsion between electrons or the Coulomb barrier in nuclear physics—where the initial accelerations influence subsequent reaction dynamics.

Technological Applications

Understanding initial accelerations helps in designing particle accelerators, electrostatic precipitators, and other devices that manipulate charged particles. Precise knowledge of force magnitudes and resulting accelerations informs safety, efficiency, and accuracy.

Limitations and Considerations

- Approximation of Point Charges: Real particles have finite size and charge distributions, which can modify force calculations at very small distances.
- Neglect of External Fields: External electromagnetic influences could alter accelerations.
- Relativistic Effects: At high velocities, relativistic mechanics would be necessary; however, initial accelerations for small charges are typically non-relativistic.

Conclusion

The initial acceleration of two equally charged particles initially held 3.2 $\times 10^3$ meters apart and then released from rest exemplifies the interplay of electrostatics and classical mechanics. While the force and resulting accelerations are minuscule for elementary charges at such large separations, the fundamental principles remain valid and illustrative. This problem underscores the significance of scale, charge magnitude, and mass in electrostatic interactions, offering insights into both theoretical physics and practical applications.

In broader terms, analyzing initial accelerations in such systems enhances our understanding of energy transfer, force interactions, and the foundational laws governing charged particles. Whether in microscopic atomic contexts or macroscopic engineering designs, these principles

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