

A Small Sphere Of Mass 2.5×10^{-5} Kg Carries A Total Charge Of 6.0×10^{-8} C. The Sphere Hangs From A Silk

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Introduction to Electrostatics and Charged Spheres

A small sphere of mass 2.5×10^{-5} kg carries a total charge of 6.0×10^{-8} C. The sphere hangs from a silk thread, creating an interesting scenario to analyze electrostatic forces, tensions, and equilibrium conditions. This setup is commonly used in physics experiments to illustrate Coulomb's law, electric field interactions, and the principles of static equilibrium. Understanding the behavior of such charged objects provides insight into fundamental electrostatic phenomena and their real-world applications.

Fundamentals of Electrostatics

Coulomb's Law

Coulomb's law describes the force between two point charges. The magnitude of the electrostatic force (F) between two charges (q_1 and q_2) separated by a distance (r) is given by:

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

where k is Coulomb's constant, approximately $8.99 \times 10^9 \text{ N}\cdot\text{m}^2/\text{C}^2$.

Electric Field and Force

The electric field (E) created by a charge q at a distance r is:

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

This field exerts a force on other charges placed within it, leading to attraction or repulsion depending on the nature of the charges involved.

Analyzing the Charged Sphere Hanging from Silk

Scenario Overview

In this scenario, a small sphere with a significant charge is suspended from a silk thread, which is initially at rest. The system reaches an equilibrium where the electrostatic repulsive force between the sphere and another charge (or possibly an external charge) balances the tension in the silk and the gravitational force acting on the sphere.

Key forces involved:

1. Gravity (Weight): $W = m g$
2. Electrostatic Force: F_e
3. Tension in the Silk Thread: T

Calculating the Weight of the Sphere

The weight (W) of the sphere is calculated using:

- $W = m g$

Given:

- $m = 2.5 \times 10^5 \text{ kg}$
- $g \approx 9.8 \text{ m/s}^2$

Therefore:

$$W = 2.5 \times 10^5 \text{ kg} \times 9.8 \text{ m/s}^2 = 2.45 \times 10^6 \text{ N}$$

Electrostatic Force Between the Sphere and External Charges

Determining the Force

The electrostatic force depends on the magnitude of the charges and their

separation distance. If the sphere interacts with another charge or set of charges, Coulomb's law applies:

- $F_e = k |q_1 q_2| / r^2$

Example Calculation

Suppose there is an external point charge (Q) placed at a distance r from the sphere. The electrostatic force on the sphere is:

- $F_e = 8.99 \times 10^9 \text{ N}\cdot\text{m}^2/\text{C}^2 (6.0 \times 10^8 \text{ C } Q) / r^2$

Specific values of Q and r are needed to compute the exact force, but the general principle remains the same.

Balancing Forces: Conditions for Equilibrium

Conditions for Equilibrium

The sphere remains at rest when the following conditions are satisfied:

1. The net force in the vertical direction is zero:

- $T \cos \theta = W$

1. The net force in the horizontal direction is zero:

- $T \sin \theta = F_e$

Analyzing the Tension and Angles

From the above, we can derive the tension (T) and the angle (θ) that the silk makes with the vertical:

- $\tan \theta = F_e / W$

And tension T can be expressed as:

- $T = W / \cos \theta$

Calculating the Angle of Deviation

Using the known values:

- $F_e = k q^2 / r^2$ (assuming the external charge is equal to the sphere's charge for simplicity)
- $W = 2.45 \times 10^6 \text{ N}$

The angle θ is:

$$\theta = \arctangent (F_e / W)$$

This angle indicates how far the sphere swings from the vertical due to electrostatic repulsion.

Implications and Practical Applications

Electrostatic Experiments

This setup is often used in physics laboratories to demonstrate Coulomb's law and electrostatic forces. By adjusting the distance between charges and observing the sphere's angle, students can verify theoretical calculations and deepen their understanding of electrostatics.

Real-World Applications

- Designing electrostatic precipitators for pollution control
- Understanding charge interactions in atomic and molecular physics
- Developing sensors that rely on electrostatic forces
- Studying the behavior of charged particles in physics and engineering

Factors Affecting the Behavior of the Charged Sphere

Environmental Conditions

- Air currents and vibrations can disturb the equilibrium
- Humidity affects the charge retention on the silk and sphere

Material Properties

- The silk's tensile strength influences the maximum tension before snapping
- The sphere's conductivity affects how charges distribute over its surface

Safety Considerations When Handling High Charges

While the charges in this scenario are theoretical and extremely high, real-world applications must consider safety protocols, including:

- Proper insulation and grounding
- Avoiding direct contact with high-voltage equipment
- Using appropriate protective equipment in laboratory setups

Conclusion

The analysis of a small, highly charged sphere hanging from a silk thread provides a fascinating insight into electrostatics, force balance, and equilibrium conditions. By understanding the forces at play—gravitational, electrostatic, and tension—students and researchers can explore fundamental physics principles and their applications. Whether in educational demonstrations or advanced engineering systems, understanding these interactions is crucial for harnessing electrostatic forces effectively and

safely.

Frequently Asked Questions

What is the significance of the sphere's mass in analyzing its electrostatic behavior?

The mass (2.5×10^5 kg) helps determine the gravitational force acting on the sphere, which is essential when analyzing the balance of forces, especially if the sphere is suspended or in equilibrium under electrostatic forces. It also influences the sphere's response to external forces and its stability.

How does the total charge of 6.0×10^8 C affect the sphere's interactions?

The large charge results in strong electrostatic forces, which can cause the sphere to repel or attract other charges nearby, or experience significant forces if placed in an electric field. It also influences the electric potential and the force exerted on nearby objects.

What is the role of the silk thread in this setup?

The silk thread acts as a suspension medium, supporting the charged sphere while allowing it to respond freely to electrostatic forces. It also provides a pivot point, enabling the sphere to rotate or swing when subjected to electric forces.

How can one calculate the electric force acting on the sphere?

The electric force can be calculated using Coulomb's Law: $F = (k \times |q_1 \times q_2|) / r^2$, where q_1 and q_2 are charges and r is the distance between them. If the sphere interacts with external charges or electric fields, this formula helps determine the magnitude and direction of the force.

What is the significance of the sphere hanging from a silk thread in electrostatics experiments?

It allows the measurement of electrostatic forces through the deflection or angle of the sphere, enabling the study of Coulomb's law, electric fields, and charge interactions in a controlled manner.

How would the electrostatic force affect the position or angle of the hanging sphere?

Electrostatic forces can cause the sphere to deflect from its equilibrium position, creating an angle in the silk thread. The magnitude of this deflection is related to the electrostatic force acting on the sphere.

What safety precautions should be taken when working with such high charge levels?

Handling high charges requires proper insulation, avoiding direct contact, using grounded equipment, and working in controlled environments to prevent electrical shocks or damage from electrostatic discharges.

Can the electrostatic force overcome the weight of the sphere? Why or why not?

Given the extremely high charge ($6.0 \times 10^8 \text{ C}$), the electrostatic force could be significant; however, whether it overcomes the weight depends on the specific configuration, distance, and other forces. Typically, such a large charge would produce a force capable of causing noticeable motion or deflection.

How does the size and shape of the sphere influence its electrostatic properties?

The size and shape determine the distribution of charge on the sphere's surface and affect parameters like capacitance and electric field strength. A small, spherical shape ensures a uniform charge distribution, simplifying calculations and analysis.

What real-world applications involve charged spheres hanging from silk threads?

Applications include Coulomb's law demonstrations, electrostatic force experiments, calibration of electroscopes, and studies of charge interactions in physics education and research.

Additional Resources

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Introduction: The Fascinating World of Electrostatics and Their Real-World Manifestations

In the realm of physics, the interaction of electric charges and their associated forces form the backbone of countless phenomena that influence our daily lives, from lightning strikes to the operation of electronic devices. Among the fascinating experiments that illustrate fundamental electrostatic principles is the scenario of a small sphere suspended from a silk thread, carrying a significant electric charge. Such a setup not only exemplifies Coulomb's law and electrostatic forces but also offers insights into the delicate balance of forces acting upon charged objects. This article explores this intriguing scenario in depth, examining the physics behind the forces, the implications of the sphere's mass and charge, and the broader significance of electrostatics in scientific and practical contexts.

Understanding the Basic Setup: The Charged Sphere and Its Suspension

The core elements of this scenario are straightforward yet profound:

- A small sphere with a mass of 2.5×10^{-5} kg (which, notably, is quite large for a sphere in typical laboratory experiments but serves as an illustrative example).
- The sphere carries a total electric charge of 6.0×10^{-8} C.
- It is suspended from a silk thread, which acts as a support and influences the equilibrium of the system.

This configuration is a classic example used to demonstrate electrostatic forces and the principles of equilibrium. The key question often posed is: How does the electrostatic repulsion influence the position and stability of the sphere? To answer this, we need to analyze the forces acting on the sphere.

Fundamental Forces at Play

Several forces influence the behavior and position of the charged sphere:

1. Gravitational Force

- Definition: The force due to gravity acting downward on the sphere.
- Magnitude: $(F_g = mg)$
- where $(m = 2.5 \times 10^5 \text{ kg})$,
- and $(g \approx 9.81 \text{ m/s}^2)$ (acceleration due to gravity).
- Calculation:
$$F_g = 2.5 \times 10^5 \times 9.81 \approx 2.45 \times 10^6 \text{ N}$$
- Implication: This is an enormous force, indicating that the sphere's weight influences its vertical equilibrium.

2. Electrostatic (Coulomb) Force

- Definition: The repulsive force between charges, described by Coulomb's law.
- Coulomb's Law:
$$F_e = \frac{k |q_1 q_2|}{r^2}$$
- where:
 - $(k \approx 8.99 \times 10^9 \text{ Nm}^2/\text{C}^2)$,
 - (q_1) and (q_2) are the charges,
 - (r) is the separation between charges.
- In this scenario: Since the sphere carries a total charge $(q = 6.0 \times 10^8 \text{ C})$, and assuming the other charge is a similar sphere or a fixed charge, the electrostatic force acts horizontally when the sphere swings away from the vertical equilibrium position.

3. Tension in the Silk Thread

- The silk thread provides the tension force (T) , which balances the combined effects of gravity and electrostatic repulsion.
- Direction: The tension acts along the thread, which makes an angle (θ) with the vertical when the sphere is displaced.

Analyzing Equilibrium: Balancing Forces

When the sphere reaches equilibrium, the forces acting upon it are balanced. The key aspects involve:

- The vertical component of tension balancing gravity.
- The horizontal component balancing electrostatic repulsion.

Conditions for Equilibrium

- Vertical balance:

$$T \cos \theta = mg$$

- Horizontal balance:

$$T \sin \theta = F_e$$

Dividing the two equations:

$$\frac{T \sin \theta}{T \cos \theta} = \frac{F_e}{mg} \Rightarrow \tan \theta = \frac{F_e}{mg}$$

This relation allows us to determine the angle (θ) of deflection based on the known forces.

Estimating the Electrostatic Force and Sphere Separation

To proceed, we need to estimate the electrostatic force (F_e) . However, the problem statement does not specify whether the sphere interacts with another charged object or with an identical sphere. For the purpose of analysis, let's assume the sphere is repelling an identical charged sphere or interacts with a fixed charge at a known separation.

Suppose the sphere interacts with a static point charge (Q) , or with an identical sphere at a distance (r) . The force then depends on the magnitude of the charges and their separation.

Assuming the sphere's charge $(q = 6.0 \times 10^{-8} \text{ C})$, and that the other charge is similar or fixed, the Coulomb force becomes:

$$F_e = \frac{k q^2}{r^2}$$

Given the enormous charge, even a small separation results in a colossal force.

Example Calculation:

If the separation (r) is 1 meter:

$$F_e = \frac{8.99 \times 10^9 \times (6.0 \times 10^8)^2}{1^2}$$

$$F_e = 8.99 \times 10^9 \times 36 \times 10^{16} = 8.99 \times 36 \times 10^{25} \approx 323.6 \times 10^{25} \text{ N}$$

This force is astronomically large, exceeding any realistic scenario. Therefore, for the forces to be manageable, the charges or separations would need to be different in practice. Nonetheless, the proportionality illustrates the sensitivity of electrostatic forces to charge magnitude and distance.

Implications of the Sphere's Massive Charge

The specified charge of $(6.0 \times 10^8 \text{ C})$ is extraordinarily high—far beyond typical laboratory or natural charges. For context:

- The electric charge of a typical lightning bolt is on the order of 10 to 100 coulombs.
- The charge of a common static shock is in the microcoulomb range (10^{-6} C) .

Thus, the specified charge suggests a hypothetical or idealized scenario designed to explore theoretical principles rather than real-world conditions.

Potential Issues with Such High Charges:

- Electrostatic Breakdown: The air or surrounding medium would ionize at high electric fields, causing discharge.
- Material Limitations: The silk thread and sphere material would need extraordinary insulating properties to withstand such charges.

Real-World Applications and Significance

While the numbers are extreme, the principles underlying this scenario have

real-world applications:

- Electrostatic Precipitators: Devices that use electric fields to remove particles from exhaust gases.
- Electrostatic Levitation: Techniques in material science and physics experiments where objects are suspended using electric fields.
- Understanding Coulomb's Law: Fundamental in designing capacitors, sensors, and other electronic components.
- Electric Field Mapping: Studying how charges distribute and interact in complex systems.

This scenario also illustrates the importance of force balance, the influence of charge magnitude, and the role of supporting structures like silk threads in managing electrostatic forces.

Conclusion: Bridging Theory and Practical Reality

The examination of a small, heavily charged sphere hanging from a silk thread offers a compelling window into the principles of electrostatics, force equilibrium, and the delicate interplay of physical forces. Although the specific charges and masses described are largely theoretical—given their impractical magnitudes—the fundamental concepts remain vital in understanding natural phenomena and technological innovations. As we continue to explore the boundaries of electrostatic science, such thought experiments serve as invaluable tools for grasping the underlying laws that govern our universe, reinforcing the importance of Coulomb's law, force balance, and material considerations in both laboratory research and real-world applications.

Note: In practical scenarios, charges of this magnitude are impossible due to material limitations and environmental effects. Nonetheless, analyzing such a setup deepens our appreciation for the elegance and power of electrostatic principles.

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