What Must The Charge (sign And Magnitude) Of A Particle Of Mass 1.44 G Be For It To Remain Stationary

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Understanding the conditions under which a charged particle remains stationary in an electric or magnetic field is fundamental in physics. In particular, determining the magnitude and sign of the charge necessary for a particle of a given mass to stay stationary involves analyzing the interplay of electromagnetic forces and gravitational effects. This article explores this intriguing question in detail, providing a comprehensive overview suitable for students, educators, and enthusiasts interested in electromagnetism and classical mechanics.

Fundamental Concepts Involved

Before delving into the calculations and specifics, it's essential to understand the core principles that govern the motion of charged particles in electromagnetic fields.

Newton's Laws and Forces on a Particle

A particle's motion is determined by Newton's second law:

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

where:
- $\mathbf{F}$ is the net force,
- m is the mass,
- $\mathbf{a}$ is the acceleration.

For the particle to remain stationary, its acceleration must be zero:

$$
\mathbf{a} = 0 \Rightarrow \mathbf{F}_{\text{net}} = 0
$$

This means the forces acting on the particle must balance each other out.

Electromagnetic Forces

Two primary electromagnetic forces can act on a charged particle:

- Electric Force ($\mathbf{F}_E$): caused by electric fields $\mathbf{E}$, given by:

$$
\mathbf{F}_E = q \mathbf{E}
$$

- Magnetic Force ($\mathbf{F}_B$): caused by magnetic fields $\mathbf{B}$, given by:

$$
\mathbf{F}_B = q \mathbf{v} \times \mathbf{B}
$$

where:
- q is the charge,
- $\mathbf{v}$ is the velocity of the particle,
- $\times$ denotes the vector cross product.

Since the particle is stationary, the magnetic force $\mathbf{F}_B$ is zero because it depends on velocity.

Gravitational Force

Gravity exerts a force:

$$
\mathbf{F}_g = m \mathbf{g}
$$

where:
- m is the mass,
- $\mathbf{g}$ is the acceleration due to gravity (approximately $9.8\, \mathrm{m/s^2}$ downward).

In many practical scenarios, gravitational forces are negligible compared to electromagnetic forces, especially for small charges in strong fields, but it's essential to consider all forces for completeness.

Given Data and Assumptions

Let's specify the problem parameters:

- Mass of particle, m: 1.44 grams = 0.00144 kg
- Goal: Find the charge q (both magnitude and sign) such that the particle remains stationary.

Additional assumptions:

- The particle is placed in a uniform electric field $\mathbf{E}$ and/or magnetic field $\mathbf{B}$.
- The fields are configured such that the net force can be balanced.
- No other forces (like friction or air resistance) are considered.
- The environment is ideal, with fields of known magnitude.

Note: Since the problem does not specify the external fields, we will analyze the general conditions necessary for the particle to remain stationary, considering both electric and magnetic fields.

Conditions for the Particle to Remain Stationary

To keep the particle stationary, the sum of all forces must be zero:

$$
\mathbf{F}_{\text{total}} = 0
$$

Depending on the environment, this can be achieved via:

- Electric forces balancing gravity (electric levitation),
- Magnetic forces counteracting gravity,
- A combination of electric and magnetic forces.

Scenario 1: Balancing Gravitational Force with Electric Force

If a uniform electric field $\mathbf{E}$ acts vertically (say, upward), then the electric force on the particle is:

$$
\mathbf{F}_E = q \mathbf{E}
$$

To balance gravity:

$$
q E = m g
$$

Assuming $\mathbf{E}$ is directed upward, the charge q must have a sign opposite to gravity's direction to produce an upward force.

Calculating q:

$$
q = \frac{m g}{E}
$$

- Magnitude of q: depends on the electric field strength E.

- Sign of q: opposite to the direction of gravity.
- If gravity pulls downward, then a positive charge would need an electric field directed upward to levitate, or vice versa.

Scenario 2: Balancing Gravitational Force with Magnetic Force

Magnetic forces act perpendicular to both the magnetic field $\mathbf{B}$ and the particle's velocity $\mathbf{v}$. Since the particle is stationary:

$$
\mathbf{F}_B = 0
$$

Thus, magnetic fields alone cannot exert a force on a stationary particle, unless the particle is moving.

Scenario 3: Combined Electric and Magnetic Fields (Lorentz Force)

In the presence of both fields, the Lorentz force is:

$$
\mathbf{F} = q (\mathbf{E} + \mathbf{v} \times \mathbf{B})
$$

For a stationary particle ($\mathbf{v} = 0$), the magnetic component vanishes, leaving only the electric force.

Conclusion:

To keep a stationary particle suspended, an electric field can be employed to counteract gravity, provided the particle's charge and the field strength are appropriately chosen.

Calculating the Charge Magnitude and Sign

Given the context, let's proceed with the most straightforward scenario: balancing gravity with an electric field.

Step 1: Determine the Weight of the Particle

The weight W:

$$
W = m g
$$

Using:

$$
m = 0.00144\, \text{kg}
$$
$$
g = 9.8\, \mathrm{m/s^2}
$$

Calculates to:

$$
W = 0.00144 \times 9.8 \approx 0.014112\, \mathrm{N}
$$

Step 2: Establish the Electric Field Needed

Suppose the electric field E is known or set to a practical value based on the environment. For illustration, assume:

$$
E = 10^4\, \mathrm{V/m}
$$

This is a high but achievable electric field in controlled laboratory conditions.

Step 3: Calculate the Required Charge q

$$
q = \frac{W}{E} = \frac{0.014112}{10^4} = 1.4112 \times 10^{-6}\, \mathrm{C}
$$

which is approximately 1.41 mC (microcoulombs).

Step 4: Determine the Sign of q

- To levitate the particle against gravity, the electric force must act upward.
- Since gravity pulls downward, the electric force must be upward:

$$
F_E = q E \Rightarrow q > 0
$$

if E is directed upward.

- Sign of charge: positive if electric field is upward; negative if electric field is downward.

Practical Considerations and Constraints

While the calculations above provide a theoretical estimate, several practical factors influence the actual charge and field requirements.

Charge Stability and Particle Material

- The particle's material determines how much charge it can hold without discharging or disintegrating.
- Materials like dust particles or small beads can be charged via triboelectric methods or corona discharge.

Field Strength Limitations

- High electric fields can lead to electrical breakdown of the medium (air or vacuum), limiting achievable field strengths.
- The dielectric strength of air at standard conditions is roughly $3 \times 10^6\, \mathrm{V/m}$, so fields of $10^4\, \mathrm{V/m}$ are well within safe limits.

Environmental Factors

- External disturbances, such as air currents or vibrations, can cause movement.
- Conductive or insulating properties of the particle affect how it charges and responds to fields.

Summary of Key Findings

- To keep a 1.44 g particle stationary in an electric field of $10^4\, \mathrm{V/m}$, it requires a charge of approximately 1.41 mC.
- The sign of the charge depends on the direction of the electric field relative to gravity:
- If the field is upward, the charge should be positive.
- If downward, the charge should be negative for levitation.
- In the absence of magnetic fields, magnetic forces do not contribute to balancing the weight unless the particle is moving.

Additional Insights and Advanced Topics

Beyond the basic scenario, several advanced considerations can influence the charge and force balance.

Electrodynamics in Different Environments

Frequently Asked Questions

What is the condition for a particle to remain stationary in a magnetic field?

The magnetic force on the particle must be zero, which occurs if the particle's charge is zero or if the particle is at rest and the magnetic field exerts no force when the velocity component perpendicular to the field is zero.

Given a particle of mass 1.44 g, what is its mass in kilograms?

The mass in kilograms is $1.44 \text{ g} = 1.44 \times 10^{-3} \text{ kg}$.

Can a charged particle remain stationary in a magnetic field if the magnetic field is uniform?

Yes, if the particle's charge is zero, it will remain stationary regardless of the magnetic field, since magnetic forces act only on moving charges.

Is it possible for a particle with a non-zero charge to remain stationary in a magnetic field?

No, if the particle has a non-zero charge and is initially at rest, the magnetic force is zero because magnetic force depends on velocity; thus, it remains stationary unless other forces act on it.

What is the significance of the charge's sign (positive or negative) for a stationary particle?

The sign of the charge determines the direction of the force if the particle moves; however, for a stationary particle, the sign does not affect its stationary state, as no magnetic force acts on it when at rest.

What magnitude of charge is needed for a particle of mass 1.44 g to remain stationary in a magnetic field?

If the particle is at rest, no magnetic charge magnitude is required for it to stay stationary; it remains so regardless of charge, provided no other forces act on it.

If an external electric field is present, what charge must the particle have to stay stationary?

The particle must have a charge such that the electric force balances other forces acting on it; otherwise, in the absence of electric fields, magnetic forces do not affect stationary particles.

How does the magnitude of the charge relate to the magnetic force experienced by a moving particle?

The magnetic force is proportional to the magnitude of the charge and the velocity of the particle; zero velocity results in zero magnetic force regardless of charge magnitude.

In the absence of other forces, can a non-zero charge particle of mass 1.44 g stay stationary in a magnetic field?

Yes, but only if the particle is initially at rest and no other forces act upon it; magnetic forces do not influence stationary charges.

Additional Resources

Understanding the Charge and Sign Required for a 1.44 g Particle to Remain Stationary: An In-depth Analysis

In the fascinating realm of electromagnetism, the behavior of charged particles under the influence of electric and magnetic fields has long captivated physicists and students alike. One intriguing question that often arises pertains to the specific conditions—particularly the magnitude and sign of charge—that a particle must possess to remain stationary within a given electromagnetic environment. When considering a particle with a mass of 1.44 grams, this question becomes especially interesting due to the interplay of gravitational and electromagnetic forces. This article aims to explore, in comprehensive detail, what charge (both in magnitude and sign) a particle of this mass must have to remain perfectly stationary, analyzing the physical principles, equations, and conditions involved.

Fundamental Principles Underpinning the Particle's Stationary State

Before delving into the calculations, it is essential to understand the fundamental forces at play when considering a charged particle in an electromagnetic field.

1. Gravitational Force

Every mass experiences a force due to gravity, which on Earth manifests as its weight:

$$F_g = mg$$

where:

- m is the mass of the particle,
- g is the acceleration due to gravity (~9.81 m/s²).

For our particle:

$$ m = 1.44\, \text{g} = 1.44 \times 10^{-3}\, \text{kg} $$

Thus:

$$ F_g = (1.44 \times 10^{-3}\, \text{kg}) \times 9.81\, \text{m/s}^2 \approx 1.414 \times 10^{-2}\, \text{N} $$

Electromagnetic Forces and Their Role in Stationarity

The electromagnetic forces that can counteract gravity are primarily the Lorentz force, which combines electric and magnetic effects.

2. The Lorentz Force Equation

The total electromagnetic force $\vec{F}_e$ on a particle with charge q, moving with velocity $\vec{v}$, in electric $\vec{E}$ and magnetic $\vec{B}$ fields is:

$$ \vec{F}_e = q (\vec{E} + \vec{v} \times \vec{B}) $$

For the particle to be stationary, its net force must be zero:

$$ \vec{F}_{net} = \vec{F}_g + \vec{F}_e = 0 $$

Since gravity acts downward, the electromagnetic force must balance this exactly.

Conditions for the Particle to Remain Stationary

Achieving a stationary state involves balancing gravitational and electromagnetic forces. This balance depends on the configuration of the electric and magnetic fields, the sign of the charge, and the particle's potential velocity.

3. Case 1: No Magnetic Field, Only Electric Field

Suppose the environment contains only a uniform electric field $\vec{E}$, oriented vertically. To keep the particle stationary, the electric force must oppose gravity:

$$q \vec{E} = - m g \hat{y}$$

- If $q > 0$, then $\vec{E}$ must be directed downward.
- If $q < 0$, then $\vec{E}$ must be directed upward.

The magnitude of the charge is then:

$$|q| = \frac{F_g}{E} = \frac{1.414 \times 10^{-2}\, \text{N}}{E}$$

Implication:
- The electric field must be sufficiently strong in the appropriate direction to balance the weight.
- The sign of q depends on the electric field direction.

4. Case 2: Presence of Magnetic Field and Particle Velocity

If the particle is moving with velocity $\vec{v}$, magnetic fields come into play.

- For the particle to be stationary, the magnetic component of the Lorentz force must also contribute to balancing gravity:

$$q \left(\vec{E} + \vec{v} \times \vec{B} \right) = - m g \hat{y}$$

In many practical scenarios, a magnetic field alone cannot produce a force component in the vertical direction unless the particle has a non-zero velocity component perpendicular to the magnetic field.

Note: For simplicity, assume $\vec{E} = 0$, and the magnetic field $\vec{B}$ is directed horizontally, say along the x-axis.

Then, the magnetic force becomes:
$$ \vec{F}_B = q \vec{v} \times \vec{B} $$

Choosing $\vec{v}$ perpendicular to $\vec{B}$ ensures a force perpendicular to both.

Numerical Calculations and Significance of Charge Magnitude

Let's analyze specific scenarios to determine the charge magnitude and sign needed.

5. Scenario: Electric Field Only

Suppose an electric field E of 1000 V/m directed downward.

- Electric force magnitude:
$$ F_E = q E $$
- To balance gravity:
$$ q E = m g $$
$$ q = \frac{m g}{E} = \frac{1.414 \times 10^{-2}}{1000} = 1.414 \times 10^{-5}\, \text{C} $$

Sign of q:

- Since the force must oppose gravity (which acts downward), if E is downward (positive direction), then:

- For $q > 0$:
$$ \vec{F}_E \text{ points downward, reinforcing gravity} $$
- Not helpful; the particle would accelerate downward.

- For $q < 0$:
$$ \vec{F}_E \text{ points upward} $$

- Exactly cancels gravity if magnitude matches.

Conclusion:

- To keep the particle stationary in a downward electric field of 1000 V/m, the particle must carry a negative charge of approximately $1.414 \times 10^{-5} \, \text{C}$.

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6. Scenario: Magnetic Field with Particle Moving

Suppose a magnetic field $B = 1\, \text{T}$ is applied horizontally along the x-axis, and the particle moves with velocity v along the y-axis.

- Magnetic force:
$$F_B = q v B$$
- To balance gravity:
$$q v B = m g$$
$$q v = \frac{m g}{B} \approx \frac{1.414 \times 10^{-2}}{1} = 1.414 \times 10^{-2}\, \text{C} \cdot \text{m/s}$$

If the particle is moving at $v = 1\, \text{m/s}$:
$$q = \frac{1.414 \times 10^{-2}}{1} = 1.414 \times 10^{-2}\, \text{C}$$

Sign of q:

- The magnetic force will be:

$$\vec{F}_B = q \vec{v} \times \vec{B}$$

- For v along y and B along x, $\vec{v} \times \vec{B}$ points along the z-axis.

- To produce a vertical (upward or downward) force, more complex arrangements are needed, such as combining electric and magnetic fields or adjusting the directions.

In practice, magnetic fields alone cannot produce a vertical force unless the particle has an appropriate velocity vector or additional electric fields are involved.

Practical Considerations and Real-World Implications

The theoretical calculations provide insight into the conditions required for a particle to remain stationary, but real-world applications introduce complexities.

7. Constraints on Charge Magnitude and Sign

- The magnitude of charge necessary to counteract gravity depends inversely on the field strength. Extremely high electric fields (on the order of 10^6 V/m) are challenging to sustain without dielectric breakdown.

- The sign of the charge determines the direction of the force relative to the field. For balancing downward gravity:
- Negative charge in a downward electric field, or
- Positive charge in an upward electric field.

8. Stability of the Stationary Condition

Achieving a fine balance is one thing; maintaining it is another. Small perturbations can cause the particle to drift:

- Variations in field strength
- External disturbances
- Particle charge fluctuations

Therefore, in practical scenarios, additional stabilization mechanisms might be necessary, such as electromagnetic traps (e.g., Penning or Paul traps).

9. Role of Particle Size and Material

- The particle's physical properties influence how it interacts with fields:
- Dielectric properties
- Surface charge accumulation
- Possible polarization effects

Concluding Remarks: The Sign and Magnitude of

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