An Electron With An Initial Speed Of 460,000 M/s Is Brought To Rest By An Electric Field. What Was The

An Electron With An Initial Speed Of 460,000 M/s Is Brought To Rest By An Electric Field. What Was The purpose of this article is to explore the physics behind this phenomenon, analyze the forces involved, and provide a comprehensive understanding of the underlying principles. This scenario is a classic example in electromagnetism and particle physics, illustrating how electric fields influence charged particles such as electrons.

Introduction to Electron Dynamics in Electric Fields

Electrons are fundamental particles with a negative electric charge. Their behavior under the influence of electric fields is central to many technological applications, including cathode ray tubes, electron microscopes, and particle accelerators. When an electron moves in an electric field, it experiences a force that can accelerate or decelerate it depending on the field's direction.

In our scenario, an electron initially travels at a high speed of 460,000 meters per second (m/s). The electron is then subjected to an electric field designed to bring it to rest. Understanding what occurs during this process involves concepts from classical mechanics, electromagnetism, and energy conservation principles.

Fundamental Concepts Involved

1. Electric Force on an Electron

The force exerted on an electron by an electric field is described by Coulomb's law:

- $F = qE$

Where:
- F is the force (in newtons, N),
- q is the charge of the electron (approximately -1.602 × 10-19 C),

- E is the electric field strength (in volts per meter, V/m).

Since electrons have a negative charge, their force direction is opposite to the electric field direction.

2. Work Done by the Electric Field

The electric field does work on the electron when it moves through the field:

- Work (W) = Force × displacement = qE × displacement

This work results in a change in the electron's kinetic energy.

3. Kinetic Energy and its Change

The kinetic energy (KE) of an electron is given by:

- KE = (1/2)mv^2

Where:
- m is the mass of the electron (~9.109 × 10-31 kg),
- v is the velocity of the electron.

Bringing the electron to rest involves reducing its kinetic energy to zero.

Calculating the Electric Field Required to Stop the Electron

The primary goal is to determine the electric field strength necessary to bring the electron from its initial velocity of 460,000 m/s to rest.

Step 1: Calculate the Initial Kinetic Energy of the Electron

Using the kinetic energy formula:

$$KE\_initial = (1/2) \times m \times v^2$$

Substituting known values:

$$KE\_initial = 0.5 \times 9.109 \times 10^{-31}\ kg \times (460{,}000\ m/s)^2$$

Calculating:

$$(460{,}000)^{\wedge}2 = 2.116 \times 10^{11}\ m^2/s^2$$

Therefore:

$$KE\_initial \approx 0.5 \times 9.109 \times 10^{-31} \times 2.116 \times 10^{11} \approx 9.65 \times 10^{-20}\ Joules$$

This is the initial kinetic energy that must be fully dissipated by the electric field.

Step 2: Determine the Electric Field Strength

The work done by the electric field to stop the electron equals its initial kinetic energy:

$$Work = Force \times displacement = qE \times displacement$$

Assuming the electric field acts over a certain distance \(d \), the work is:

$$W = qE \times d$$

Since the work must equal the initial kinetic energy:

$$qE \times d = KE\_initial$$

If the displacement \(d \) over which the electron is stopped is known, we can find the electric field \(E

\). Alternatively, if we want to find the electric field required to stop the electron within a specific distance, we can solve for \(E \):

```
E = KE_initial / (q × d)
```

Example: Suppose the electron is stopped over a distance of 1 millimeter (0.001 m):

$$E = 9.65 \times 10^{-20} / (1.602 \times 10^{-19} \times 0.001) \approx 0.602 \text{ V/m}$$

This indicates that an electric field of approximately 0.6 volts per meter over 1 mm would be sufficient to bring the electron to rest.

Note: The actual electric field depends on the distance over which the stopping occurs.

Energy Considerations and Real-World Implications

1. Energy Dissipation and Heat

The energy lost by the electron is transferred to the electric field's environment, often resulting in heat or electromagnetic radiation. In practical devices, this energy dissipation must be managed to prevent damage or interference.

2. Practical Limitations

- Achieving such high initial speeds requires acceleration mechanisms like particle accelerators.
- Generating uniform electric fields strong enough to stop electrons over short distances can be technologically challenging.
- The presence of magnetic fields can influence electron trajectories, complicating the stopping process.

Applications of Electron Deceleration by Electric Fields

Understanding how electrons are slowed or brought to rest by electric fields is crucial across various scientific and technological domains:

- **Electron Beam Devices:** Used in cathode ray tubes, electron microscopes, and TV tubes to manipulate electron trajectories.
- **Particle Accelerators:** Precise control of electron energies is essential for collision experiments and medical therapies.
- **Electrostatic Precipitators:** Use electric fields to remove particles from exhaust gases.
- **Radiation Therapy:** Electron beams are decelerated and stopped in tissues for cancer treatment.

Summary and Key Takeaways

- An electron moving at 460,000 m/s possesses significant kinetic energy, which can be calculated using classical mechanics.
- To bring the electron to rest using an electric field, the field must perform work equal to its initial kinetic energy.
- The required electric field strength depends on the distance over which the electron is decelerated.
- Practical implementation involves considerations of energy transfer, heat dissipation, and device engineering.
- The principles involved are foundational in many fields, including electronics, medical physics, and materials science.

Conclusion

The process of bringing an electron moving at high speed to rest via an electric field exemplifies fundamental physics principles. By calculating the initial kinetic energy and understanding the work done by the electric field, we can determine the necessary field strength and the energy transfer involved. These insights are not only academically interesting but also critically important for designing devices and systems that manipulate charged particles with precision. Whether in scientific research or everyday technology, the controlled use of electric fields to influence electron motion remains a cornerstone of modern physics and engineering.

Frequently Asked Questions

What is the initial kinetic energy of an electron moving at 460,000 m/s?

The initial kinetic energy can be calculated using KE = ½ mv^2, where m is the electron mass (~9.11×10^{-31} kg). Substituting values gives KE ≈ 9.11×10^{-31} kg × $(460{,}000\ \text{m/s})^2$ / 2 ≈ $9.11\times10^{-31} \times 2.116\times10^{11}$ / 2 ≈ 9.66×10^{-20} Joules.

How much work is done by the electric field to bring the electron to rest?

The work done by the electric field equals the initial kinetic energy of the electron, approximately 9.66×10^{-20} Joules, since the field brings the electron to rest.

What is the electric potential difference required to stop the electron?

The potential difference V = work done / charge of the electron. Using q = 1.6×10^{-19} C, V ≈ (9.66×10^{-20} J) / (1.6×10^{-19} C) ≈ 0.604 V.

What is the significance of the initial speed of 460,000 m/s in this context?

The initial speed determines the initial kinetic energy of the electron, which directly influences the electric potential needed to bring it to rest.

Can an electric field alone bring an electron to rest from this initial speed?

Yes, an electric field can stop an electron if the potential difference is sufficient to provide the negative work equal to its initial kinetic energy.

What factors affect the amount of electric potential needed to stop the electron?

The initial speed of the electron, the mass and charge of the electron, and the strength of the electric field all influence the potential difference required.

If the electron is brought to rest by an electric field, what energy transformations occur?

The electron's initial kinetic energy is converted into electrical potential energy stored in the electric field or dissipated as heat, depending on the system.

How does the initial speed of the electron relate to the strength of the

electric field required?

Higher initial speeds require a stronger electric field (greater potential difference) to do enough work to stop the electron.

Additional Resources

An Electron With An Initial Speed Of 460,000 M/s Is Brought To Rest By An Electric Field. What Was The?

In the realm of classical physics, understanding the dynamics of subatomic particles such as electrons under the influence of electric fields is fundamental. When an electron, initially moving at a high velocity, is subjected to an electric field that ultimately brings it to rest, several intricate physical principles come into play. This investigation seeks to elucidate the underlying physics, derive the associated quantities, and explore the practical implications of such phenomena—specifically focusing on the question: An Electron With An Initial Speed Of 460,000 M/s Is Brought To Rest By An Electric Field. What Was The?

Introduction

Electrons are elementary particles with a negative electric charge and a rest mass of approximately 9.11 × 10^-31 kg. Their behavior in electric fields is governed by Coulomb's law and the principles of classical mechanics and electromagnetism. A typical scenario involves an electron initially moving at a known speed, then decelerated by an electric field, eventually coming to rest. This process encapsulates energy transfer, force interactions, and potential differences that are pivotal in understanding electron dynamics.

The core question focuses on the potential difference or electric field strength necessary to bring an electron from the given initial velocity to rest. To analyze this, we will delve into kinetic energy considerations, electric potential energy conversion, and the relevant equations.

Kinetic Energy and Initial Conditions

Initial Kinetic Energy of the Electron

The initial kinetic energy (KE) of the electron can be expressed as:

$$ KE_i = \frac{1}{2} m v^2 $$

Where:

- $m = 9.11 \times 10^{-31} \, \text{kg}$ (electron mass)
- $v = 460,000 \, \text{m/s}$

Calculating:

$$
KE_i = \frac{1}{2} \times 9.11 \times 10^{-31} \times (4.6 \times 10^5)^2
$$

$$
KE_i = 4.55 \times 10^{-31} \times 2.116 \times 10^{11}
$$

$$
KE_i \approx 9.63 \times 10^{-20} \, \text{J}
$$

This is the initial energy that must be dissipated or countered by the electric field to bring the electron to rest.

Conversion to Electron Volts

Since electronvolt (eV) is a common unit for electron energies:

$$
1 \, \text{eV} = 1.602 \times 10^{-19} \, \text{J}
$$

Thus,

$$
KE_i \approx \frac{9.63 \times 10^{-20}}{1.602 \times 10^{-19}} \approx 0.601 \, \text{eV}
$$

This indicates that the initial kinetic energy of approximately 0.6 eV must be neutralized by the electric field.

Electric Potential Difference Required

Relationship Between Potential Difference and Electron Energy

The work done by an electric field to stop the electron is related to the potential difference V:

$$
W = qV
$$

Where:
- $q = -e = -1.602 \times 10^{-19} \, \text{C}$ (electron charge)
- V is the potential difference

To bring the electron to rest, the energy supplied by the field must equal the initial kinetic energy:

$$
|qV| = KE_i
$$

Since the electron loses kinetic energy (which is positive), the potential difference must be:

$$
V = \frac{KE_i}{e}
$$

Plugging in the values:

$$
V = \frac{9.63 \times 10^{-20} \, \text{J}}{1.602 \times 10^{-19} \, \text{C}} \approx 0.601 \, \text{V}
$$

Thus, an electric potential difference of approximately 0.6 volts is required to bring the electron to rest from an initial velocity of 460,000 m/s.

Deep Dive into the Physics

How Does the Electric Field Impose Deceleration?

The electron experiences a force due to the electric field E:

$$
F = eE
$$

And a corresponding acceleration:

\[
a = \frac{F}{m} = \frac{eE}{m}
\]

Given the potential difference \(V \) across a distance \(d \):

\[
E = \frac{V}{d}
\]

The work-energy theorem states:

\[
\text{Work} = \text{Change in kinetic energy} = eV
\]

This indicates the importance of the potential difference over the path length in decelerating the electron.

The Role of Distance in Deceleration

While the potential difference provides the energy transfer, the actual deceleration depends on the distance over which the electric field acts. If the field is uniform, the electron's deceleration is constant, and the stopping distance \(d \) can be derived:

\[
KE_i = eV = eEd
\]

\[
d = \frac{KE_i}{eE}
\]

Alternatively, using kinematic equations:

\[
v_f^2 = v_i^2 + 2ad
\]

Since \(v_f = 0 \):

\[

$$
0 = v_i^2 + 2a d
$$

$$
d = - \frac{v_i^2}{2a}
$$

Expressing a in terms of E:

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

So,

$$
d = - \frac{v_i^2 m}{2 e E}
$$

This illustrates that for a given initial velocity, the deceleration distance depends on the electric field strength.

Practical Implications and Applications

Electron Deceleration in Devices

Understanding the energy transfer involved in stopping electrons is fundamental in designing electron microscopes, cathode ray tubes, and particle accelerators. Precise control over electron velocities enables high-resolution imaging and accurate measurements.

Electron Energy Filtering

The ability to determine the potential difference needed to halt electrons at specific velocities underpins energy filtering techniques in spectroscopy. For example, in electron energy loss spectroscopy (EELS), electrons are filtered based on their kinetic energy.

Limitations and Safety Considerations

- Voltage Limitations: Achieving a potential difference of only 0.6 V is straightforward; however, in high-energy applications, voltages can extend into the kilovolt or megavolt ranges.
- Radiation Emission: As electrons decelerate, especially in non-uniform fields, they may emit

bremsstrahlung radiation, which must be considered in high-energy settings.

Broader Context: From Classical to Quantum

While classical physics provides a good approximation for these calculations, at very small scales or high energies, quantum effects become significant. In particular:

- Quantum Tunneling: Electrons may tunnel through potential barriers, altering the simple energy considerations.
- Relativistic Effects: At speeds approaching a significant fraction of the speed of light (~3×10^8 m/s), relativistic mass increase must be accounted for, invalidating non-relativistic kinetic energy formulas.

However, at 460,000 m/s (~0.15c), relativistic corrections are minimal but not negligible, especially for precise applications.

Conclusion

The investigation into An Electron With An Initial Speed Of 460,000 M/s Is Brought To Rest By An Electric Field reveals that a potential difference of approximately 0.6 volts is sufficient to bring the electron to rest, assuming a uniform electric field. This result underscores the fundamental relationship between an electron's kinetic energy and the electric potential energy imparted or dissipated during acceleration or deceleration.

This analysis emphasizes how classical physics provides clear, quantifiable insights into subatomic particle dynamics. Furthermore, understanding these principles is vital for the development and operation of numerous electronic and scientific instruments, highlighting the importance of fundamental physics in technological innovation.

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Note: All calculations assume ideal conditions without considering relativistic effects, external forces, or quantum phenomena, which may be relevant at different energy regimes.

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