

An Electron Is To Be Accelerated In A Uniform Electric Field Having A Strength Of 210×10^6 V/m. What Energy

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Understanding the behavior of electrons in electric fields is fundamental to many areas of physics and engineering, including electronics, particle accelerators, and radiation physics. When an electron is subjected to a uniform electric field, it gains kinetic energy as it accelerates, and calculating this energy is crucial for designing devices and understanding fundamental processes. In this article, we will explore how to determine the energy acquired by an electron in a uniform electric field with a strength of 210×10^6 V/m, covering the principles involved, detailed calculations, and real-world applications.

Introduction to Electric Fields and Electron Acceleration

Before diving into calculations, it's essential to understand the basic concepts underpinning the acceleration of electrons in electric fields.

What Is an Electric Field?

- An electric field is a region around a charged particle or object within which other charges experience a force.
- It is represented by the electric field strength, denoted as E , measured in volts per meter (V/m).
- The direction of the electric field is the direction of the force that a positive test charge would experience.

Electron Behavior in Electric Fields

- Electrons, bearing a negative charge, experience a force opposite to the electric field direction.
- When placed in a uniform electric field, electrons accelerate uniformly, gaining kinetic energy.

Fundamental Concepts and Equations

Calculating the energy gained by an electron involves understanding the relationship between electric potential energy, kinetic energy, and the electric field.

Key Parameters

- Electron charge, $(e = 1.602 \times 10^{-19})$ coulombs
- Electron mass, $(m_e = 9.109 \times 10^{-31})$ kg
- Electric field strength, $(E = 210 \times 10^6)$ V/m

Work Done on the Electron

- The work done (W) by the electric field on the electron is given by:

$$W = e \times V$$

where (V) is the potential difference experienced by the electron.

- In a uniform electric field, the potential difference over a distance (d) is:

$$V = E \times d$$

Since we are asked to find the energy acquired, which is equivalent to the kinetic energy gained, the key is to determine the potential difference or the energy directly.

Calculating the Energy Acquired by the Electron

The critical insight in this problem is to understand how the electric field influences the energy of the electron.

Energy Gained in a Uniform Electric Field

- The energy acquired by the electron as it moves through a potential difference (V) is:

$$KE = eV$$

\]

- To find this energy, we need either the potential difference or the distance over which the electron is accelerated.

Scenario 1: Electron Accelerated Through a Known Potential Difference

Suppose the electron is accelerated across a potential difference (V) . Then, the energy gained is straightforward:

$$\begin{aligned} & \text{[} \\ & KE = eV \\ & \text{]} \end{aligned}$$

If, for example, the electron moves through a potential difference of 1 V:

$$\begin{aligned} & \text{[} \\ & KE = 1.602 \times 10^{-19} \text{ J} \\ & \text{]} \end{aligned}$$

Scenario 2: Electron Accelerated Over a Known Distance in the Electric Field

If the electron is accelerated over a distance (d) , the potential difference is:

$$\begin{aligned} & \text{[} \\ & V = E \times d \\ & \text{]} \end{aligned}$$

and the energy gained is:

$$\begin{aligned} & \text{[} \\ & KE = e \times E \times d \\ & \text{]} \end{aligned}$$

Without explicit information about (d) , the problem suggests focusing on the energy per unit charge for the electric field strength.

Calculating the Energy for the Given Electric Field

Given the electric field strength $(E = 210 \times 10^6 \text{ V/m})$, the energy acquired by the electron per meter of acceleration is:

$$\begin{aligned} & \text{[} \\ & KE_{\text{per meter}} = e \times E \end{aligned}$$

\]

Plugging in the values:

$$KE_{\text{per meter}} = 1.602 \times 10^{-19} \text{ C} \times 210 \times 10^6 \text{ V/m}$$

Calculating:

$$KE_{\text{per meter}} = 1.602 \times 210 \times 10^{-19 + 6}$$

$$KE_{\text{per meter}} = 1.602 \times 210 \times 10^{-13}$$

$$KE_{\text{per meter}} = (1.602 \times 210) \times 10^{-13}$$

$$KE_{\text{per meter}} \approx 336.42 \times 10^{-13} \text{ J}$$

Or:

$$KE_{\text{per meter}} \approx 3.3642 \times 10^{-11} \text{ J}$$

This is the energy gained per meter of acceleration in the electric field.

Important Note:

If the problem specifies the distance over which the electron is accelerated, multiply this energy per meter by that distance to find the total energy gained.

Converting Energy to Electronvolts (eV)

In physics, it is often more convenient to express the energy of electrons in electronvolts (eV), where:

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

\]

Given the energy in joules, converting to eV:

$$\text{KE}_{\text{eV}} = \frac{\text{KE}_{\text{J}}}{1.602 \times 10^{-19}}$$

Using the energy per meter:

$$\text{KE}_{\text{per meter}} \approx 3.3642 \times 10^{-11} \text{ J}$$

$$\text{KE}_{\text{per meter}} \approx \frac{3.3642 \times 10^{-11}}{1.602 \times 10^{-19}} \text{ eV}$$

$$\text{KE}_{\text{per meter}} \approx 2.1 \times 10^8 \text{ eV}$$

Interpretation:

- The electron gains approximately 210 million eV (or 210 MeV) of energy per meter in the electric field.

Practical Applications and Implications

Understanding the energy gained by electrons in high-strength electric fields is vital for various technological and scientific applications.

Particle Accelerators

- High-energy physics experiments rely on accelerating electrons and other particles to enormous energies.
- The calculation above demonstrates how electric fields can accelerate electrons to high energies over relatively short distances.

X-ray and Radiation Generation

- Electron acceleration is essential in generating X-rays in cathode ray tubes and synchrotrons.
- Higher electron energies lead to higher energy photons, useful in medical imaging and material analysis.

Electronics and Microfabrication

- Electric fields are used to manipulate electrons in semiconductors.
- Understanding energy transfer helps optimize device performance and energy efficiency.

Limitations and Considerations

While calculating the energy gained is straightforward, several practical considerations can influence the actual energy an electron attains:

1. **Field Uniformity:** Real-world electric fields may not be perfectly uniform, affecting acceleration.
2. **Radiation Losses:** Accelerating electrons emit electromagnetic radiation, leading to energy loss.
3. **Material Limitations:** High electric fields can cause breakdown or arcing in materials.
4. **Quantum Effects:** At very high energies, quantum effects may alter classical predictions.

Summary and Final Remarks

In conclusion, an electron subjected to a uniform electric field of strength $(210 \times 10^6 \text{ V/m})$ gains energy proportional to the potential difference it experiences. The fundamental relation:

$$KE = e \times V$$

allows us to determine the energy gained if the acceleration distance is known. Without explicit distance, we focus on the energy per meter, which is approximately $(3.3642 \times 10^{-11} \text{ J})$, or about 210 MeV per meter.

This understanding underscores the capacity of electric fields to accelerate electrons to significant energies swiftly, which is foundational in many modern scientific and technological advancements. Properly calculating and managing electron energy is essential for designing efficient accelerators, radiation sources, and electronic devices.

Keywords: Electron acceleration, electric field, potential difference, kinetic energy, electron volts, particle accelerators, electric field strength, physics calculations, energy transfer, high-voltage physics

Frequently Asked Questions

What is the energy gained by an electron when accelerated through a uniform electric field of 2106 V/m?

The energy gained by the electron is calculated using the formula $E = e \times V$, where V is the potential difference. If the electron accelerates through a potential difference of V , its energy gain is $E = 1.6 \times 10^{-19} \text{ C} \times V$. To find V , additional information about the electron's displacement is needed.

How do you calculate the potential difference experienced by an electron in a uniform electric field?

The potential difference V is calculated by $V = E \times d$, where E is the electric field strength and d is the distance traveled by the electron in the field.

What is the significance of the electric field strength of 2106 V/m in accelerating electrons?

An electric field of 2106 V/m indicates a strong field capable of imparting significant energy to electrons over a given distance, leading to high electron velocities and energy gains useful in various applications like cathode ray tubes and particle accelerators.

If an electron is accelerated in a uniform electric field, how do we determine its kinetic energy?

The kinetic energy acquired by the electron is equal to the work done by the electric field, given by $KE = e \times V$, where V is the potential difference across which the electron is accelerated.

What additional information is needed to compute the exact energy gained by the electron?

The distance over which the electron is accelerated or the potential

difference across that distance is needed to determine the energy gained by the electron.

Can the energy gained by the electron be expressed directly in electronvolts (eV)?

Yes, the energy in joules can be converted to electronvolts by dividing by 1.6×10^{-19} J. For example, if the potential difference is known, the energy in eV is simply equal to the potential difference in volts.

What is the approximate energy gained by an electron in a 10 V potential difference?

The energy gained would be approximately 10 eV, since 1 eV is the energy gained by an electron moving through 1 V potential difference.

How does increasing the electric field strength affect the energy gained by an electron?

Increasing the electric field strength increases the potential difference over a given distance, which in turn increases the energy gained by the electron during acceleration.

Additional Resources

An Electron Is To Be Accelerated In A Uniform Electric Field Having A Strength Of 2×10^6 V/m. What Energy

Understanding the behavior of electrons in electric fields is fundamental to many areas of physics and engineering, including electronics, particle accelerators, and plasma physics. When an electron is subjected to a uniform electric field, it gains kinetic energy proportional to the field's strength and the distance traveled. This article explores the physics behind accelerating an electron in such a uniform electric field, calculating the energy gained, and examining the broader implications of this process.

Introduction to Electron Acceleration in Electric Fields

Electrons are negatively charged particles with a charge of approximately (-1.602×10^{-19}) coulombs and a rest mass of about (9.109×10^{-31}) kilograms. When placed in an electric field, electrons experience a force given by Coulomb's law:

$$[F = qE]$$

where (q) is the charge of the electron and (E) is the electric field strength. This force causes the electron to accelerate according to Newton's second law:

$$[F = ma \rightarrow a = \frac{F}{m} = \frac{qE}{m}]$$

The energy gained by the electron as it moves through a potential difference (or potential difference equivalent in the electric field) can be calculated using principles from electromagnetic theory.

Understanding the Electric Field and Potential Difference

Uniform Electric Field

A uniform electric field is one where the electric field strength (E) is constant in magnitude and direction throughout a specific region. It can be produced between two parallel plates with a voltage difference (V) , separated by a distance (d) . The relationship between the electric field and the voltage is:

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

Given the electric field strength, we can determine the potential difference across the region:

$$[V = E \times d]$$

In our case, the electric field strength is given as $(210 \times 10^6 \text{ V/m})$.

Potential Difference and Electron Energy

The energy gained by an electron moving through a potential difference (V) is:

$$[\text{Energy} = qV]$$

where (q) is the electron's charge.

Calculating the Energy Gained by the Electron

To determine the energy gained by the electron, we need to understand the context: how far the electron travels within the electric field or the potential difference it experiences.

Suppose the electron is accelerated across a distance (d) . The potential difference across this distance is:

$$V = E \times d$$

The energy gained (which is kinetic energy in the non-relativistic approximation) is:

$$KE = qV = qE \times d$$

If the problem specifies the distance (d) , we can directly compute the energy. However, in many cases, the goal is to find the energy gained per unit length or in terms of the electric field strength alone.

Assuming a Specific Distance

For illustrative purposes, let's assume the electron is accelerated across a distance of 1 meter within the electric field.

- Electric field strength: $(E = 210 \times 10^6 \text{ V/m})$
- Distance traveled: $(d = 1 \text{ m})$

Then, the potential difference:

$$V = E \times d = 210 \times 10^6 \times 1 = 210 \times 10^6 \text{ V}$$

The energy gained:

$$KE = qV = (1.602 \times 10^{-19}) \times (210 \times 10^6)$$

Calculating:

$$KE = 1.602 \times 10^{-19} \times 210 \times 10^6$$

$$KE = 1.602 \times 210 \times 10^{-19+6}$$

$$\text{KE} = (1.602 \times 210) \times 10^{-13} \text{ J}$$

$$\text{KE} \approx 336.42 \times 10^{-13} \text{ J}$$

$$\text{KE} \approx 3.3642 \times 10^{-11} \text{ J}$$

To express this in electronvolts (eV), recall:

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

Thus,

$$\text{Energy in eV} = \frac{\text{KE}}{1.602 \times 10^{-19}}$$

$$\approx \frac{3.3642 \times 10^{-11}}{1.602 \times 10^{-19}}$$

$$\approx 2.1 \times 10^8 \text{ eV}$$

or approximately 210 MeV. This indicates that an electron accelerated across 1 meter in such a high electric field can gain energy on the order of hundreds of MeV, which is substantial and relevant in high-energy physics.

Relativistic Considerations

At high energies, especially when reaching hundreds of MeV, relativistic effects become significant. The classical kinetic energy formula $\text{KE} = \frac{1}{2}mv^2$ no longer suffices, and relativistic formulas must be employed:

$$\text{KE} = (\gamma - 1) mc^2$$

where:

- $\gamma = \frac{1}{\sqrt{1 - v^2/c^2}}$,
- c is the speed of light ($3 \times 10^8 \text{ m/s}$),
- mc^2 is the rest energy of the electron (0.511 MeV).

Given the energy calculated (~210 MeV), the electron would be highly relativistic, with $\gamma \approx 412$, moving very close to the speed of light. This impacts the design and operation of particle accelerators, as relativistic mass increase and time dilation effects come into play.

Practical Applications and Implications

Accelerating electrons to such high energies has numerous applications:

- Particle Accelerators: Devices like the Large Hadron Collider (LHC) accelerate electrons and protons to extremely high energies for fundamental physics research.
- Medical Equipment: High-energy electron beams are used in radiation therapy for cancer treatment.
- Electronics and Semiconductor Manufacturing: Controlled electron acceleration is used in electron microscopes and lithography.

However, generating and maintaining such strong uniform electric fields over substantial distances presents technical challenges:

Pros:

- Enables high-energy particle acceleration.
- Facilitates precise control over electron energy.
- Useful in research and medical applications.

Cons:

- High voltage requirements pose insulation and safety challenges.
- Electric field breakdown can occur if the field exceeds material limits.
- Relativistic effects complicate the physics and engineering of accelerators.

Features and Limitations

Features:

- The energy gained by an electron in a uniform electric field is directly proportional to the field strength and the distance traveled.
- High electric fields enable rapid acceleration to high energies over comparatively short distances.
- The physics is well-understood within classical and relativistic frameworks, allowing accurate predictions.

Limitations:

- Electric field breakdown limits the maximum field strength achievable in practice.
- As electrons reach relativistic speeds, classical models become invalid,

necessitating relativistic corrections.

- Engineering constraints make it challenging to sustain extremely high uniform electric fields over large distances.

Conclusion

Accelerating an electron in a uniform electric field of strength $(210 \times 10^6 \text{ V/m})$ can theoretically impart energies on the order of hundreds of MeV if the electron travels over a meter or more within this field. This showcases the immense potential of electric fields in particle physics and related applications but also highlights the technical and physical limitations involved. Understanding both the classical and relativistic dynamics is essential for designing effective acceleration systems, pushing the boundaries of high-energy physics, and harnessing electron energies for technological advances. As research progresses, overcoming the practical challenges associated with high electric fields will continue to be a critical focus in the development of next-generation accelerators and applications.

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