

An Electron In The Beam Of A Cathod-ray Tube Is Accelerated By A Potential Difference Of 2.12 KVkV. Then

Understanding the Acceleration of Electrons in Cathode-Ray Tubes

An Electron In The Beam Of A Cathod-ray Tube Is Accelerated By A Potential Difference Of 2.12 kV. Then, what happens to the electron as it gains energy? To understand this process, we need to explore the principles of electron acceleration, the role of potential difference, and the subsequent effects on electron behavior within the tube. Cathode-ray tubes (CRTs) have historically been fundamental in display technology, oscilloscopes, and other electronic devices. The acceleration of electrons within CRTs is a core concept that underpins their operation.

This article delves into the physics of electron acceleration, how potential differences influence electron velocities, and the implications of a 2.12 kV potential difference in practical scenarios.

Basics of Electron Acceleration in Cathode-Ray Tubes

What Is a Cathode-Ray Tube?

A cathode-ray tube is a vacuum tube that uses electron beams to produce images on a phosphorescent screen. It consists of:

- An electron gun that emits electrons.
- Electrostatic or magnetic deflectors that steer the electron beam.
- A phosphor-coated screen that glows when struck by electrons.

The Significance of Potential Difference

The potential difference applied between the cathode and anode in a CRT accelerates electrons, giving them kinetic energy. The magnitude of this potential difference directly influences the speed and energy of the electrons.

Calculating the Electron's Kinetic Energy and Velocity

Given Data

- Potential difference, $V = 2.12 \text{ kV} = 2120 \text{ volts}$
- Elementary charge of electron, $e = 1.602 \times 10^{-19} \text{ C}$
- Rest mass of electron, $m_e = 9.109 \times 10^{-31} \text{ kg}$

Calculating the Kinetic Energy

When an electron is accelerated through a potential difference V , it gains kinetic energy (KE) equal to the work done by the electric field:

$$KE = eV$$

Substituting the values:

$$KE = 1.602 \times 10^{-19} \text{ C} \times 2120 \text{ V} = 3.394 \times 10^{-16} \text{ Joules}$$

Determining Electron Velocity

Since the kinetic energy is related to velocity (v) by:

$$KE = (1/2) m_e v^2$$

Rearranged as:

$$v = \sqrt{2 \times KE / m_e}$$

Calculating:

$$v = \sqrt{2 \times 3.394 \times 10^{-16} \text{ J} / 9.109 \times 10^{-31} \text{ kg}} \approx \sqrt{7.447 \times 10^{14}} \approx 8.63 \times 10^7 \text{ m/s}$$

This velocity is approximately 86.3 million meters per second, which is about 28.9% of the speed of light ($3 \times 10^8 \text{ m/s}$). Since this is a significant fraction of the speed of light, relativistic effects should be considered for more precise calculations.

Relativistic Effects on Electron Velocity

Why Relativity Matters

At high velocities (above 10% of the speed of light), classical mechanics no longer accurately predicts particle behavior. Relativistic mechanics must be used to account for increased mass and energy.

Relativistic Kinetic Energy Formula

The relativistic kinetic energy is given by:

$$KE = (\gamma - 1) m_e c^2$$

where:

- γ = Lorentz factor = $1 / \sqrt{1 - v^2/c^2}$
- c = speed of light $\approx 3 \times 10^8$ m/s

Rearranged to solve for v :

$$\gamma = 1 + KE / (m_e c^2)$$

Since $m_e c^2 \approx 8.187 \times 10^{-14}$ Joules, then:

$$\gamma = 1 + 3.394 \times 10^{-16} / 8.187 \times 10^{-14} \approx 1 + 0.00415 \approx 1.00415$$

Now,

$$v = c \sqrt{1 - 1/\gamma^2} \approx 3 \times 10^8 \text{ m/s} \times \sqrt{1 - 1/(1.00415)^2} \approx 3 \times 10^8 \text{ m/s} \times \sqrt{1 - 0.992} \approx 3 \times 10^8 \text{ m/s} \times 0.0884 \approx 2.65 \times 10^7 \text{ m/s}$$

This indicates that relativistic corrections slightly reduce the estimated velocity, emphasizing the importance of relativistic physics at this potential difference.

Implications of Electron Acceleration in CRTs

Impact on Electron Behavior

- Increased Kinetic Energy: Electrons acquire more energy, enabling them to produce brighter images on the phosphor screen.
- Faster Electron Beams: Higher velocities mean electrons can reach the screen more quickly, improving response times.
- Enhanced Penetration Power: Electrons can penetrate deeper into phosphors, affecting image sharpness and brightness.

Practical Applications

1. Display Technology: Higher accelerating voltages produce brighter and more vivid images.
2. Oscilloscopes: Electron beams with higher energy improve resolution and detail.
3. Medical and Industrial Imaging: Electron acceleration principles are foundational in X-ray generation.

Additional Factors Affecting Electron Motion in CRTs

Magnetic and Electric Deflections

Electrons are deflected using magnetic or electric fields to scan across the screen, forming images or waveforms.

Space Charge Effects

At high electron densities, repulsive forces between electrons can impact beam focus and stability.

Vacuum Quality

Maintaining a high vacuum prevents electrons from scattering off air molecules, ensuring a clear and focused beam.

Safety and Design Considerations

High Voltage Precautions

Operating at potential differences like 2.12 kV requires strict safety protocols to prevent electric shocks.

Design Optimization

Engineers optimize the potential difference to balance image brightness, resolution, and device longevity.

Summary and Conclusion

In summary, when an electron in a cathode-ray tube is accelerated by a potential difference of 2.12 kV, it gains significant kinetic energy, reaching velocities close to a third of the speed of light. This energy determines how effectively the CRT can produce bright, focused images, and understanding the physics behind this process is crucial for designing efficient electronic devices.

The physics involves classical calculations for lower velocities, but at high energies like 2.12 kV, relativistic effects become non-negligible. Properly accounting for these effects ensures accurate predictions of electron behavior, which is essential for advancing display technology, scientific instrumentation, and medical imaging.

By mastering the principles of electron acceleration, engineers and physicists can continue to innovate in fields relying on electron beam technology, ensuring safety, efficiency, and high performance in a variety of applications.

Keywords: electron acceleration, cathode-ray tube, potential difference, kinetic energy, electron velocity, relativistic effects, CRT technology, electron beam physics, high voltage, electron behavior

Frequently Asked Questions

What is the kinetic energy gained by an electron accelerated through a potential difference of 2.12 kV?

The kinetic energy gained by the electron is equal to the electric potential energy, which is $e \times V$. Converting 2.12 kV to volts (2120 V), the energy is $1.6 \times 10^{-19} \text{ C} \times 2120 \text{ V} = 3.392 \times 10^{-16} \text{ Joules}$.

How do you calculate the velocity of the electron after acceleration through 2.12 kV?

Using kinetic energy formula: $KE = (1/2) m v^2$. With $KE = 3.392 \times 10^{-16} \text{ J}$ and electron mass $m \approx 9.11 \times 10^{-31} \text{ kg}$, solve for v : $v = \sqrt{(2 \times KE / m)} \approx \sqrt{(2 \times 3.392 \times 10^{-16} / 9.11 \times 10^{-31})} \approx 2.73 \times 10^7 \text{ m/s}$.

What is the significance of accelerating electrons through a potential difference in cathode-ray tubes?

Accelerating electrons through a potential difference increases their kinetic energy, enabling them to produce visible images on the screen by exciting phosphors, and allowing for control of their trajectories in electron beam devices.

What is the approximate de Broglie wavelength of an electron accelerated through 2.12 kV?

Using $\lambda = h / p$, where $p = m v$ from previous calculation, the wavelength is approximately 2.73×10^{-10} meters, or about 0.27 nanometers, indicating wave-like behavior at this scale.

Why is it important to know the accelerating potential when analyzing cathode-ray tube operations?

Because the accelerating potential determines the electron's kinetic energy and velocity, affecting the resolution, brightness, and focus of the electron beam in the CRT.

How does increasing the potential difference affect the electron beam in a cathode-ray tube?

Increasing the potential difference increases the electron's kinetic energy and velocity, resulting in a more focused and intense beam with improved resolution and brighter images.

What safety precautions should be taken when working with high-voltage accelerations like 2.12 kV in CRTs?

Proper insulation, grounding, and safety procedures should be followed to prevent electric shocks, and the equipment should be handled by trained personnel to avoid accidents involving high voltages.

Additional Resources

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Understanding the journey of an electron through a cathode-ray tube (CRT) is fundamental to grasping how early television screens, oscilloscopes, and other electronic displays function. The acceleration process, driven by a precise potential difference, transforms a humble electron into a powerful probe capable of creating detailed images or signals. This article delves into the physics behind this acceleration, exploring

how a potential difference of 2.12 kilovolts (kV) imparts energy to an electron, the resulting velocity, and the broader implications in electronic devices.

The Basics of Electron Acceleration in a Cathode-Ray Tube

What Is a Cathode-Ray Tube?

A cathode-ray tube is a vacuum tube containing one or more electron guns that emit electrons, which are then manipulated by electric and magnetic fields to produce images on a phosphorescent screen. The core principle involves accelerating electrons from a cathode (negative electrode) towards an anode (positive electrode), creating a focused beam that can be directed and deflected to form images.

The Role of Potential Difference

The potential difference, or voltage, between the cathode and anode is the key factor responsible for accelerating electrons. When an electron is emitted from the cathode, it starts with negligible initial velocity. The electric field established by the potential difference exerts a force on the electron, propelling it towards the anode with increasing kinetic energy.

In our scenario, the potential difference is specified as 2.12 kV. This voltage determines how much energy each electron gains and influences the characteristics of the electron beam, such as its velocity and wavelength.

Physical Principles Governing Electron Acceleration

Energy Gain from Electric Potential

The fundamental principle at play is the conversion of electrical potential energy into kinetic energy. When an electron moves through a potential difference (V) , it gains an energy:

$$\text{Kinetic Energy (KE)} = eV$$

where:

- (e) is the elementary charge ((1.602×10^{-19}) coulombs),
- (V) is the potential difference in volts.

Applying this to our case:

$$[KE = e \times 2.12, \text{kV} = 1.602 \times 10^{-19} \times 2120, \text{V}]$$

Calculating:

$$[KE = 3.396 \times 10^{-16} \text{joules}]$$

This energy translates into the electron's motion, giving it velocity upon reaching the anode.

Deriving Electron Velocity

The kinetic energy is also expressed as:

$$[KE = \frac{1}{2} m v^2]$$

where:

- (m) is the mass of the electron ($(9.109 \times 10^{-31} \text{kg})$),
- (v) is the velocity of the electron.

Rearranging for (v) :

$$[v = \sqrt{\frac{2 KE}{m}}]$$

Substituting the known values:

$$[v = \sqrt{\frac{2 \times 3.396 \times 10^{-16}}{9.109 \times 10^{-31}}}]$$

Calculating numerator:

$$[2 \times 3.396 \times 10^{-16} = 6.792 \times 10^{-16}]$$

Dividing:

$$[\frac{6.792 \times 10^{-16}}{9.109 \times 10^{-31}} \approx 7.46 \times 10^{14}]$$

Taking the square root:

$$[v \approx \sqrt{7.46 \times 10^{14}} \approx 8.64 \times 10^7 \text{m/s}]$$

This velocity is approximately 86.4 million meters per second, or about 28.8% of the speed of light ($(3 \times 10^8 \text{m/s})$). At such high velocities, relativistic effects start to become significant, but for a potential difference of 2.12 kV, classical mechanics provides a reasonable approximation.

Implications of Electron Acceleration

Wavelength and Resolution

The high velocity of electrons accelerated by a potential difference influences the resolution and sharpness of images produced in CRTs. Because electrons behave as waves at these energies, their wavelength is dictated by the de Broglie relation:

$$\lambda = \frac{h}{p}$$

where:

- h is Planck's constant ($6.626 \times 10^{-34} \text{ Js}$),
- p is the momentum of the electron ($p = mv$ for non-relativistic speeds).

Calculating the wavelength:

$$p = m v = 9.109 \times 10^{-31} \times 8.64 \times 10^7 \approx 7.87 \times 10^{-23} \text{ kg}\cdot\text{m/s}$$

$$\lambda = \frac{6.626 \times 10^{-34}}{7.87 \times 10^{-23}} \approx 8.41 \times 10^{-12} \text{ m}$$

or about 8.4 picometers, enabling extremely fine resolution in imaging applications.

Safety and Design Considerations

Electrons energized by 2.12 kV carry significant energy, necessitating careful insulation and safety measures in CRT design. While the voltages are relatively low compared to modern devices, they still require precaution to prevent electric shock and ensure device integrity.

Broader Applications and Significance

Historical Context

Cathode-ray tubes revolutionized television and monitor technology in the 20th century. Understanding electron acceleration at specific voltages like 2.12 kV is vital for manufacturing precision components and optimizing image clarity.

Modern Relevance

While CRTs have largely been replaced by LCD and OLED displays, the principles of electron acceleration underpin modern electron microscopy, particle accelerators, and vacuum tube-based devices.

Scientific and Educational Value

Studying the acceleration of electrons provides foundational insights into quantum mechanics, electromagnetism, and materials science. It exemplifies how electric potential translates into mechanical motion at microscopic scales.

Conclusion

In summary, an electron in the beam of a cathode-ray tube accelerated by a potential difference of 2.12 kV gains substantial kinetic energy, reaching velocities around 86 million meters per second. This energy conversion from electrical potential to kinetic form underpins the operation of CRTs, influencing image resolution and device performance. The physics involved—ranging from classical mechanics to quantum wave properties—highlight the elegance and complexity of electron behavior under electric fields. Though technology has advanced beyond cathode-ray tubes, the principles of electron acceleration remain foundational to modern electronics, scientific research, and our understanding of the microscopic world.

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