

An Electron Microscope Uses Electrons Accelerated By A Voltage Of 50 KV. Determine The De-Broglie Wavelength

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Determine The De-Broglie Wavelength**

Electron microscopy is a powerful technique that allows scientists to visualize objects at an atomic and nanometer scale. At the heart of this technology lies the principle that electrons, when accelerated to high velocities, exhibit wave-like properties described by quantum mechanics. Specifically, the De Broglie wavelength of these electrons determines the resolution and imaging capabilities of the electron microscope. In this article, we will delve into how electrons are accelerated in an electron microscope, understand the physics behind their wave nature, and perform calculations to determine the De Broglie wavelength when electrons are accelerated by a voltage of 50 kV. This comprehensive guide aims to provide insights into both the theoretical and practical aspects of electron microscopy, optimized for clarity and SEO.

Understanding Electron Microscopy

Electron microscopes utilize a beam of electrons to produce high-resolution images of specimens. Unlike optical microscopes that rely on visible light, electron microscopes can achieve resolutions down to the atomic level due to the shorter wavelength of electrons compared to visible light.

Principles of Electron Microscopy

- **Electron Acceleration:** Electrons are accelerated through a potential difference, gaining kinetic energy.
- **Wave-Particle Duality:** Electrons exhibit both particle and wave properties, with their wave nature characterized by the De Broglie wavelength.
- **Image Formation:** The electron beam interacts with the specimen, and the resulting interactions are used to construct detailed images.

Types of Electron Microscopes

- **Transmission Electron Microscope (TEM):** Electrons pass through thin specimens to reveal internal structures.
- **Scanning Electron Microscope (SEM):** Electrons scan the surface, producing detailed topographical images.
- **Scanning Transmission Electron Microscope (STEM):** Combines features of TEM and SEM for advanced imaging.

Acceleration of Electrons in an Electron Microscope

In an electron microscope, electrons are emitted from a cathode and then accelerated towards an anode by applying a high voltage, typically in the range of 10 kV to 300 kV. The acceleration voltage directly influences the electrons' kinetic energy, velocity, and consequently, their De Broglie wavelength.

The Role of Voltage in Electron Acceleration

- The applied voltage provides the potential energy that converts into kinetic energy.
- Higher voltages result in higher electron velocities.
- The typical acceleration voltage for high-resolution electron microscopes is around 50 kV, which balances resolution, brightness, and specimen damage.

Calculating Electron Velocity from Voltage

The kinetic energy (KE) acquired by an electron when accelerated through a voltage (V) is given by:

$$KE = eV$$

where:

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

The corresponding velocity (v) of the electron can be approximated by:

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

where:

- (m) is the mass of the electron (9.109×10^{-31} kg).

However, at high voltages like 50 kV, relativistic effects become significant, and the relativistic equations must be used for accurate calculations.

Determining the De-Broglie Wavelength of Accelerated Electrons

The De Broglie wavelength (λ) describes the wave nature of particles such as electrons. It is given by:

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

where:

- h is Planck's constant (6.626×10^{-34} Js),
- p is the momentum of the electron.

Since the electrons are accelerated to relativistic speeds at 50 kV, the relativistic expression for the momentum is:

$$p = \frac{mv}{\sqrt{1 - \frac{v^2}{c^2}}}$$

or more conveniently, the wavelength can be calculated using the relativistic energy-momentum relation:

$$\lambda = \frac{h}{\sqrt{2meV(1 + \frac{eV}{2mc^2})}}$$

where:

- c is the speed of light (3.00×10^8 m/s),
- eV is the kinetic energy imparted to the electron,
- mc^2 is the rest energy of the electron (~ 0.511 MeV).

Step-by-Step Calculation of the De Broglie Wavelength at 50 kV

Let's perform a detailed calculation to find the De Broglie wavelength of electrons accelerated by 50 kV.

1. Convert the Voltage to Kinetic Energy

$$KE = eV = (1.602 \times 10^{-19} \text{ C}) \times (50,000 \text{ V}) = 8.01 \times 10^{-15} \text{ Joules}$$

Expressed in electronvolts (eV):

$$KE = 50,000 \text{ eV} = 50 \text{ keV}$$

2. Calculate the Relativistic Wavelength

Using the relativistic wavelength formula:

$$\lambda = \frac{h}{\sqrt{2meV(1 + \frac{eV}{2mc^2})}}$$

where:

- $h = 6.626 \times 10^{-34} \text{ Js}$,
- $m = 9.109 \times 10^{-31} \text{ kg}$,
- $eV = 8.01 \times 10^{-15} \text{ Joules}$,
- $mc^2 = 0.511 \text{ MeV} = 0.511 \times 10^6 \text{ eV}$.

Convert eV to eV units for ease:

$$eV = 5.0 \times 10^4 \text{ eV}$$

Calculate the relativistic correction factor:

$$\frac{eV}{2mc^2} = \frac{50,000 \text{ eV}}{2 \times 511,000 \text{ eV}} \approx 0.049$$

Now, the denominator becomes:

$$\sqrt{2meV(1 + 0.049)}$$

Expressed in SI units, the numerator remains h .

Alternatively, a more straightforward practical formula used in electron microscopy is:

$$\lambda = \frac{h}{\sqrt{2meV} \sqrt{1 + \frac{eV}{2mc^2}}}$$

which simplifies to:

$$\lambda = \frac{h}{\sqrt{2meV(1 + \frac{eV}{2mc^2})}}$$

Plugging in the values:

$$\lambda = \frac{6.626 \times 10^{-34}}{\sqrt{2 \times 9.109 \times 10^{-31} \times 8.01 \times 10^{-15} (1 + 0.049)}}$$

Calculating the denominator step-by-step:

- $2 \times m = 1.8218 \times 10^{-30} \text{ kg}$,
- $1.8218 \times 10^{-30} \times 8.01 \times 10^{-15} = 1.459 \times 10^{-44}$,
- Multiply by $(1 + 0.049 = 1.049)$:

$$\sqrt{1.459 \times 10^{-44} \times 1.049 \approx 1.530 \times 10^{-44}}$$

Taking the square root:

$$\sqrt{1.530 \times 10^{-44}} \approx 1.237 \times 10^{-22}$$

Finally, the wavelength:

$$\lambda = \frac{6.626 \times 10^{-34}}{1.237 \times 10^{-22}} \approx 5.355 \times 10^{-12} \text{ meters}$$

Result: The De Broglie wavelength of electrons accelerated by 50 kV is approximately 0.0054 nm.

Implications of the De Broglie Wavelength in Electron Microscopy

The wavelength of electrons is a critical factor in determining the resolution of an electron microscope. Shorter wavelengths allow for finer detail to be resolved, enabling scientists to visualize structures at the atomic level.

Resolution and Wavelength

- Theoretical Resolution Limit: Approximately equal to the De Broglie wavelength.
- Practical Resolution: Often slightly worse due to aberrations and other factors, but still closely related to the electron wavelength.

Advantages of High Voltage Acceleration

- Higher acceleration voltages produce electrons with shorter wavelengths.
- Shorter wavelengths lead to higher resolution images.
- Typical operating voltages are optimized based on the desired resolution and sample sensitivity.
