What Is The Maximum Kinetic Energy Electron Of Electrons Ejected From This Metal By Light With A Wavelength

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Understanding the maximum kinetic energy of electrons ejected from a metal surface when illuminated by light involves delving into the principles of the photoelectric effect, quantum mechanics, and the relationship between light's wavelength and energy. This concept is fundamental in physics, particularly in the study of light-matter interactions, and has significant implications for technologies such as photodetectors, solar cells, and photoelectron spectroscopy. To accurately determine this maximum kinetic energy, it is essential to consider the properties of the incident light, the material's work function, and the physics governing photon-electron interactions.

Fundamentals of the Photoelectric Effect

Historical Context and Significance

The photoelectric effect was first explained comprehensively by Albert Einstein in 1905, which contributed to the development of quantum theory. It describes the phenomenon whereby electrons are emitted from a metal surface when it is exposed to electromagnetic radiation (light) of sufficient energy. Einstein proposed that light consists of quanta, or photons, each carrying a discrete amount of energy proportional to its frequency.

Basic Principles

- When light strikes a metal surface, photons transfer their energy to electrons.
- If the photon's energy exceeds the work function (ϕ) of the metal, electrons can escape.
- The excess energy of the photon after overcoming the work function manifests as the kinetic energy of the ejected electron.

Key Concepts: Wavelength, Energy, and Work Function

Photon Energy and Wavelength Relationship

The energy (E_{photon}) of a photon is directly related to its wavelength (λ) through the equation:

$$
E_{photon} = \frac{hc}{\lambda}
$$

where:
- h is Planck's constant ($6.626 \times 10^{-34}\, \text{Js}$),
- c is the speed of light in vacuum ($3.00 \times 10^{8}\, \text{m/s}$),
- λ is the wavelength of the incident light.

This inverse relationship means that shorter wavelengths correspond to higher photon energies, while longer wavelengths correspond to lower energies.

Work Function (ϕ) of the Metal

The work function is a material-specific property indicating the minimum energy needed to liberate an electron from the metal surface. Typical values range from about 2 eV to 5 eV. The work function can be expressed in joules (J) for calculations, with 1 eV equivalent to $1.602 \times 10^{-19}\, J$.

Calculating the Maximum Kinetic Energy of Ejected Electrons

Einstein's Photoelectric Equation

The maximum kinetic energy (K_{max}) of the ejected electrons can be expressed as:

$$
K_{max} = E_{photon} - \phi
$$

Substituting the photon energy:

$$
K_{max} = \frac{hc}{\lambda} - \phi
$$

Here:
- K_{max} is in joules (or electron volts if units are consistent),
- $\frac{hc}{\lambda}$ is the photon energy,
- ϕ is the work function.

If the photon energy is less than the work function ($E_{photon} < \phi$), no electrons are ejected, and K_{max} is zero.

Expressing Kinetic Energy in Electron Volts

Since electron volts (eV) are a convenient unit for energy in atomic-scale physics, the kinetic energy can be conveniently expressed as:

$$
K_{max} (\text{eV}) = \frac{1240}{\lambda (\text{nm})} - \phi (\text{eV})
$$

where:
- λ is in nanometers,
- ϕ is in eV.

This formula simplifies calculations and provides immediate insight into how varying wavelength affects electron kinetic energy.

Step-by-Step Calculation Example

Suppose the incident light has a wavelength of 400 nm, and the metal's work function is 2.5 eV.

1. Convert wavelength to energy:

$$
E_{photon} = \frac{1240}{400} = 3.1\, \text{eV}
$$

2. Calculate maximum kinetic energy:

$$
K_{max} = 3.1\, \text{eV} - 2.5\, \text{eV} = 0.6\, \text{eV}
$$

Thus, the maximum kinetic energy of the emitted electrons is 0.6 eV.

Factors Affecting the Maximum Kinetic Energy

Variation of Wavelength

- Shorter wavelengths (higher photon energies) result in higher maximum kinetic energies.
- If the wavelength increases beyond a certain point (longer than the cutoff wavelength), electrons cease to be emitted because the photon energy becomes insufficient to overcome the work function.

Material Properties

- Different metals have different work functions, directly influencing the energy threshold.
- Surface conditions and impurities can modify the effective work function.

Intensity of Light

- The intensity affects the number of emitted electrons but does not influence their maximum kinetic energy, which depends solely on photon energy and work function.

Practical Applications and Significance

Photoelectron Spectroscopy

- Used to study the electronic structure of materials.
- The kinetic energy distribution of emitted electrons provides information about energy levels within the material.

Photodetectors and Solar Cells

- Understanding the maximum kinetic energy helps optimize device performance.
- Ensures the incident light energy surpasses the work function to generate a photoelectric current.

Quantum Mechanics and Modern Physics

- Validates the photon model of light.
- Serves as evidence against classical wave theories that could not explain the photoelectric effect.

Conclusion

The maximum kinetic energy of electrons ejected from a metal due to incident light is a fundamental concept grounded in quantum physics. It is determined by the energy of incident photons, which depends on their wavelength, minus the work function of the material. The key formula:

$$
K_{max} = \frac{hc}{\lambda} - \phi
$$

or equivalently,

$$
K_{max} (\text{eV}) = \frac{1240}{\lambda (\text{nm})} - \phi (\text{eV})
$$

provides a straightforward means of calculation and underscores the importance of wavelength in controlling photoelectric emission. Recognizing how these variables interact enables scientists and engineers to harness photoelectric phenomena across various technological applications, advancing both fundamental science and practical innovations.

Frequently Asked Questions

What is the maximum kinetic energy of electrons ejected from a metal when illuminated with light of a specific wavelength?

The maximum kinetic energy of the ejected electrons can be calculated using the photoelectric equation: $KE_{max} = hf - \varphi$, where h is Planck's constant, f is the frequency of the incident light, and φ is the work function of the metal.

How does the wavelength of light affect the maximum kinetic energy of photoelectrons?

As the wavelength increases (meaning lower frequency), the maximum kinetic energy decreases because KE_{max} is proportional to the photon energy (hf). When the wavelength is too long, electrons may not be ejected at all if the photon energy is less than the work function.

What is the relationship between photon wavelength and energy in the context of the photoelectric effect?

Photon energy is inversely proportional to wavelength, given by $E = hc/\lambda$, where h is Planck's constant, c is the speed of light, and λ is the wavelength. Shorter wavelengths correspond to higher photon energies.

How can one determine the maximum kinetic energy of electrons ejected from a metal using the light wavelength?

Convert the wavelength to photon energy using $E = hc/\lambda$, then subtract the metal's work function φ

from this energy: $KE_{max} = (hc/\lambda) - \varphi$. If the result is positive, it gives the maximum kinetic energy.

What role does the work function of the metal play in the photoelectric effect with respect to electron ejection?

The work function φ is the minimum energy needed to eject an electron from the metal. The photon must have energy greater than φ for electrons to be emitted; the excess energy becomes the maximum kinetic energy of the ejected electrons.

Why does increasing the wavelength of incident light decrease the maximum kinetic energy of emitted electrons?

Because increasing wavelength reduces photon energy ($E = hc/\lambda$), resulting in less energy available to be converted into electron kinetic energy after overcoming the work function. If photon energy drops below the work function, no electrons are emitted.

What is the significance of the threshold wavelength in the photoelectric effect?

The threshold wavelength corresponds to the maximum wavelength at which photons still have enough energy ($E = hc/\lambda$) to eject electrons. Beyond this wavelength, photon energy is insufficient to overcome the work function, and no electrons are emitted.

How do experimental measurements of photoelectron kinetic energy help determine the work function of a metal?

By measuring the maximum kinetic energy of ejected electrons at different wavelengths, and plotting KE_{max} versus photon energy, one can find the work function φ as the intercept where KE_{max} becomes zero, according to the photoelectric equation.

What is the formula to calculate the maximum kinetic energy of photoelectrons when given the wavelength of incident light?

The formula is $KE_{max} = (hc/\lambda) - \varphi$, where h is Planck's constant, c is the speed of light, λ is the wavelength of the incident light, and φ is the work function of the metal.

Additional Resources

What Is The Maximum Kinetic Energy Electron Of Electrons Ejected From This Metal By Light With A Wavelength is a fundamental question in the realm of photoelectric phenomena, bridging concepts from quantum physics, electromagnetism, and materials science. Understanding this concept is essential for grasping how light interacts with metals at the atomic level and has practical implications in fields like photodetectors, solar cells, and quantum computing. In this comprehensive guide, we will explore the principles behind the photoelectric effect, derive the key equations, analyze factors influencing the maximum kinetic energy, and walk through examples to solidify understanding.

Introduction: The Photoelectric Effect and Its Significance

The photoelectric effect was first explained by Albert Einstein in 1905, earning him the Nobel Prize in Physics. It describes how electrons are emitted from a metal surface when illuminated by light of sufficient energy. The key insight was that light behaves as quanta (photons), each carrying a discrete amount of energy proportional to its frequency.

The maximum kinetic energy of the ejected electrons depends on the energy of the incident photons and the work function of the metal, which is the minimum energy needed to liberate an electron from the surface.

Fundamental Concepts

What is the Work Function?

- The work function (denoted as φ) is an intrinsic property of the metal.
- It represents the minimum photon energy required to eject an electron from the metal surface.
- Units: electronvolts (eV).

Photons and Their Energy

- The energy of a photon is given by:

$$E = h \nu$$

where:
- h = Planck's constant ($\sim 6.626 \times 10^{-34}$ Js),
- ν = frequency of light.

- Since frequency and wavelength are related by:

$$\nu = c / \lambda$$

where:
- c = speed of light ($\sim 3.00 \times 10^{8}$ m/s),
- λ = wavelength of light.

- Hence, photon energy can also be expressed as:

$$E = (h c) / \lambda$$

Photoelectric Equation

The maximum kinetic energy (K_{max}) of ejected electrons is given by Einstein's photoelectric equation:

$K_{max} = E_{photon} - \varphi$

or

$K_{max} = (h c / \lambda) - \varphi$

This formula indicates that the kinetic energy depends on the photon energy minus the work function.

Detailed Breakdown of the Maximum Kinetic Energy

Step 1: Calculating the Energy of Incident Light

Given the wavelength of the incident light, the photon energy is:

$E_{photon} = (h c) / \lambda$

- For example, with a wavelength of 500 nm (which is 500×10^{-9} m):

$E_{photon} = (6.626 \times 10^{-34}\ \text{Js}\ 3.00 \times 10^{8}\ \text{m/s}) / (500 \times 10^{-9}\ \text{m}) \approx 3.97 \times 10^{-19}\ \text{J}$

- To convert Joules to electronvolts:

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

So,

$E_{photon} \approx (3.97 \times 10^{-19}\ \text{J}) / (1.602 \times 10^{-19}\ \text{J/eV}) \approx 2.48\ \text{eV}$

Step 2: Considering the Metal’s Work Function

- Suppose the work function φ is known, for example, 2.3 eV for certain metals like zinc.
- The maximum kinetic energy of the ejected electrons in electronvolts:

$K_{max}\ (\text{eV}) = E_{photon}\ (\text{eV}) - \varphi\ (\text{eV})$

Using the previous example:

$K_{max} = 2.48\ \text{eV} - 2.3\ \text{eV} = 0.18\ \text{eV}$

- This value indicates the electrons are emitted with a maximum kinetic energy of 0.18 eV under these conditions.

Step 3: Converting Kinetic Energy to SI Units

- To understand the kinetic energy physically, sometimes it's useful to convert back to Joules:

$K_{max}\ (\text{J}) = K_{max}\ (\text{eV}) \times 1.602 \times 10^{-19}\ \text{J/eV}$

For 0.18 eV:

$K_{max} \approx 0.18 \times 1.602 \times 10^{-19}$ J $\approx 2.88 \times 10^{-20}$ J

Factors Affecting the Maximum Kinetic Energy

1. Wavelength of Incident Light

- Shorter wavelengths (higher photon energy) produce electrons with higher kinetic energies.
- As the wavelength decreases, energy increases, leading to a greater K_{max}, provided the photon energy exceeds the work function.

2. Metal’s Work Function

- Higher work function reduces the maximum kinetic energy for a given photon wavelength.
- Metals like cesium have low work functions (~2.1 eV), while platinum has higher (~5.3 eV).

3. Intensity of Light

- Intensity affects the number of electrons emitted but does not influence their maximum kinetic energy.
- The maximum kinetic energy depends solely on photon energy and work function.

4. Surface Conditions

- Surface cleanliness and smoothness can influence the work function and electron emission.

Step-by-Step Example Calculation

Let’s walk through an example to determine the maximum kinetic energy of electrons ejected from a metal surface by light with a given wavelength.

Given:

- Wavelength, $\lambda = 400$ nm
- Work function, $\varphi = 2.5$ eV

Step 1: Convert wavelength to photon energy

$E_{photon} = (h c) / \lambda$

- $\lambda = 400 \text{ nm} = 400 \times 10^{-9}$ m

Calculate:

$E_{photon} = (6.626 \times 10^{-34} \text{ Js } 3.00 \times 10^{8} \text{ m/s}) / (400 \times 10^{-9} \text{ m}) \approx 4.97 \times 10^{-19}$ J

Convert to eV:

$E\_photon \approx (4.97 \times 10^{-19}$ J) / (1.602×10^{-19} J/eV) ≈ 3.11 eV

Step 2: Calculate maximum kinetic energy

$K\_max = E\_photon - \varphi = 3.11$ eV - 2.5 eV = 0.61 eV

Step 3: Convert to Joules

$K\_max \approx 0.61$ eV $\times 1.602 \times 10^{-19}$ J/eV $\approx 9.77 \times 10^{-20}$ J

Result: The maximum kinetic energy of the emitted electrons is approximately 0.61 eV.

Applications and Implications

Understanding what is the maximum kinetic energy electron of electrons ejected from this metal by light with a wavelength has several implications:

- Photodetectors: Design optimized for specific wavelengths to maximize electron kinetic energy and improve sensitivity.
- Solar Cells: Tailoring materials to absorb specific wavelengths and eject electrons with high kinetic energies.
- Quantum Mechanics: Validating the photoelectric equation and the quantization of light.
- Material Science: Engineering metal surfaces with desired work functions for specific applications.

Limitations and Considerations

While the basic photoelectric equation provides a fundamental understanding, real-world scenarios involve complexities:

- Surface roughness can affect electron emission.
- Photon absorption probability varies with wavelength and material.
- Temperature effects can influence electron energies.
- Multi-photon processes: At high intensities, more complex phenomena may occur.

Summary and Key Takeaways

- The maximum kinetic energy electron ejected from a metal by light depends on the photon energy and the metal's work function.
- The fundamental formula is:

$K\_max = (h c / \lambda) - \varphi$

- Shorter wavelengths (higher photon energies) produce electrons with higher maximum kinetic energy.
- The work function acts as a threshold; if photon energy is less than the work function, no electrons

are emitted.
- Practical calculations involve converting wavelength to energy, then subtracting the work function.

Understanding this process is vital in designing devices that rely on photoelectric effects and in advancing our knowledge of quantum phenomena.

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