Barium Has A Work Function Of 2.48 Ev. What Is The Maximum Kinetic Energy Of Electrons If The Metal Is

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Understanding the photoelectric effect and the energy dynamics involved when light interacts with metals is fundamental in physics. When a metal surface is illuminated with light of sufficient frequency, electrons are ejected from its surface. The maximum kinetic energy of these emitted electrons depends on the energy of the incident photons and the work function of the metal. In this article, we explore how to calculate the maximum kinetic energy of electrons emitted from barium, which has a work function of 2.48 eV, and the factors affecting this calculation.

Introduction to the Photoelectric Effect

The photoelectric effect is a phenomenon where electrons are emitted from a material when it absorbs incident electromagnetic radiation, such as ultraviolet or visible light. Albert Einstein explained this effect in 1905, proposing that light consists of quanta or photons, each carrying a discrete amount of energy proportional to its frequency.

The key components involved in the photoelectric effect are:

- Photon energy (E): The energy of the incident light photon.
- Work function (ϕ): The minimum energy required to liberate an electron from the metal surface.
- Kinetic energy of emitted electrons (K.E.): The energy with which electrons leave the metal.

The fundamental relationship governing this process is Einstein's photoelectric equation:

$$K.E._{\text{max}} = E - \phi$$

where:

- E is the energy of the incident photon.
- ϕ is the work function of the metal.
- $K.E._{\text{max}}$ is the maximum kinetic energy of the emitted electrons.

Understanding Work Function and Its Significance

The work function, denoted as ϕ, is a characteristic property for each metal, representing the energy barrier that electrons must overcome to escape the metal surface. It is measured in electron volts (eV).

For barium:

- Work function (ϕ) = 2.48 eV

This value indicates that incident photons must have energy equal to or greater than 2.48 eV to eject electrons. Photons with less energy will not cause emission regardless of their intensity.

Calculating the Maximum Kinetic Energy of Emitted Electrons

The maximum kinetic energy of photoelectrons depends on the energy of incident photons. To compute this, we need to know the photon energy, which is related to the wavelength or frequency of the incident light.

Key steps for calculation:

1. Determine the photon energy (E): Using the wavelength (λ) or frequency (ν) of incident light.

2. Apply Einstein's photoelectric equation: To find the maximum kinetic energy.

Photon Energy and Its Calculation

Photon energy is given by:

$$E = h \nu = \frac{hc}{\lambda}$$

where:

- h = Planck’s constant = $6.626 \times 10^{-34} \, \text{Js}$
- c = speed of light = $3.00 \times 10^{8} \, \text{m/s}$
- λ = wavelength of incident light in meters
- ν = frequency of incident light

Since the problem does not specify the wavelength or frequency, the maximum kinetic energy can be expressed generally in terms of photon energy.

Calculating Kinetic Energy for Specific Wavelengths

Suppose the incident light has a wavelength λ. The photon energy in electron volts is:

$$E (\text{eV}) = \frac{hc}{\lambda} \times \frac{1\, \text{eV}}{1.602 \times 10^{-19} \, \text{J}}$$

Simplifying:

$$E (\text{eV}) \approx \frac{1240}{\lambda (\text{nm})}$$

where λ is in nanometers (nm).

Example:

- For $\lambda = 300 \, \text{nm}$:

$$E = \frac{1240}{300} \approx 4.13\, \text{eV}$$

Using Einstein's equation:

$$K.E._{\text{max}} = E - \phi = 4.13\, \text{eV} - 2.48\, \text{eV} = 1.65\, \text{eV}$$

Thus, the maximum kinetic energy of electrons emitted under these conditions is approximately 1.65 eV.

Factors Affecting the Kinetic Energy of Emitted Electrons

Several factors influence the maximum kinetic energy of electrons in the photoelectric effect:

- Wavelength or frequency of incident light: Higher energy photons (shorter wavelength) lead to higher kinetic energies.
- Work function of the metal: Metals with lower work functions emit electrons with higher maximum kinetic energies for the same photon energy.
- Intensity of light: While intensity affects the number of emitted electrons, it does not influence their maximum kinetic energy.
- Surface conditions of the metal: Surface contamination or roughness can affect work function and electron emission.

Real-World Applications of Photoelectric Effect and Kinetic Energy Calculations

Understanding and calculating the maximum kinetic energy of electrons has multiple practical applications:

- Photovoltaic cells: Converting light into electrical energy efficiently.
- Photoelectron spectroscopy: Analyzing material composition and surface properties.
- Light sensors and detectors: Designing sensitive devices for various wavelengths.
- Quantum mechanics validation: Confirming the particle nature of light.

Summary and Conclusion

In conclusion, determining the maximum kinetic energy of electrons emitted from barium with a work function of 2.48 eV requires knowledge of the incident photon energy. Using Einstein's photoelectric equation, we see that:

\[K.E._{\text{max}} = E - \phi \]

where \(E \) depends on the wavelength or frequency of the incident light. For specific wavelengths, calculations can yield precise kinetic energies, which are essential in understanding the behavior of electrons in photoelectric processes and designing relevant technological applications.

Key takeaways:

- Photons must have energy greater than the work function to cause electron emission.
- The maximum kinetic energy of electrons is directly proportional to the photon energy minus the work function.
- Shorter wavelengths (higher energy photons) produce electrons with higher kinetic energies.
- Surface conditions and light intensity influence emission but not the maximum kinetic energy.

Additional Resources for Further Learning

- Books:
- "Introduction to Quantum Mechanics" by David J. Griffiths
- "Modern Physics" by Kenneth S. Krane
- Online Courses:
- Coursera's "Quantum Mechanics for Scientists and Engineers"

- Khan Academy's Physics courses on the photoelectric effect
- Research Articles:
- Studies on photoelectric emission from different metals
- Advances in photoelectron spectroscopy techniques

By mastering these principles, students and professionals can better understand the quantum nature of light and electrons, paving the way for innovations in energy, imaging, and materials science.

Frequently Asked Questions

What is the work function of Barium, and how does it relate to photoelectric emission?

The work function of Barium is 2.48 eV, which is the minimum energy needed to eject an electron from its surface when illuminated by light of sufficient energy.

How do you calculate the maximum kinetic energy of photoelectrons emitted from Barium?

The maximum kinetic energy is calculated using the photoelectric equation: $KE_{max} = hf - \varphi$, where hf is the photon energy and φ is the work function of Barium.

What is the significance of the work function value 2.48 eV for Barium in photoelectric experiments?

It determines the threshold photon energy required for photoemission; photons with energy greater than 2.48 eV can eject electrons, influencing the kinetic energy of emitted electrons.

If Barium is illuminated with light of wavelength 300 nm, what is the maximum kinetic energy of emitted electrons?

Using $KE_{max} = hf - \varphi$, first calculate photon energy: $hf = 1240 / 300 \approx 4.13$ eV. Then $KE_{max} = 4.13$ eV - 2.48 eV ≈ 1.65 eV.

How does increasing the incident photon energy affect the maximum kinetic energy of photoelectrons from Barium?

Increasing the photon energy (hf) increases the maximum kinetic energy of emitted electrons, as $KE_{max} = hf - \varphi$, with φ remaining constant.

What is the minimum photon wavelength required to eject electrons from Barium with a work function of 2.48 eV?

The threshold wavelength $\lambda = 1240 / \varphi = 1240 / 2.48 \approx 500$ nm. Photons with wavelength shorter than 500 nm can cause photoemission.

Why is the work function important in determining the photoelectric effect in metals like Barium?

The work function sets the minimum energy barrier electrons must overcome to escape the metal; it influences whether incident light can cause photoemission and the kinetic energy of emitted electrons.

Additional Resources

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Introduction

The phenomenon of photoelectric emission—where electrons are ejected from a metal surface upon exposure to incident light—has been a cornerstone in understanding quantum mechanics and electronic properties of materials. Central to this process is the concept of the work function (ϕ), the minimum energy needed to liberate an electron from the surface of a metal.

In this investigation, we focus on barium, a metal with a work function of 2.48 electron volts (eV). Specifically, we seek to determine the maximum kinetic energy of electrons emitted from barium when illuminated with light of a given wavelength or frequency. This analysis not only elucidates fundamental physics but also has practical implications in designing photoelectric devices, electron emitters, and understanding surface interactions at the quantum level.

Fundamental Concepts and Theoretical Framework

The Photoelectric Effect

Discovered by Heinrich Hertz and explained by Albert Einstein in 1905, the photoelectric effect describes how photons incident on a metal surface can eject electrons if the photon energy exceeds the work function of the material.

The core relation governing this process is Einstein's photoelectric equation:

$$
K_{\text{max}} = h\nu - \phi
$$

where:
- K_{max} is the maximum kinetic energy of the emitted electrons,
- h is Planck's constant ($6.626 \times 10^{-34}\, \text{Js}$),
- ν is the frequency of incident light,
- ϕ is the work function of the metal.

Alternatively, in terms of wavelength λ:

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

where c is the speed of light ($3.00 \times 10^{8}\, \text{m/s}$).

The Work Function of Barium

Barium's work function is given as 2.48 eV. This value signifies the threshold photon energy required to just liberate an electron from the metal surface without any excess kinetic energy.

Conversion note:
- 1 eV = 1.602×10^{-19} Joules.

Thus, the energy threshold in Joules:

$$
\phi = 2.48\, \text{eV} = 2.48 \times 1.602 \times 10^{-19}\, \text{J} \approx 3.975 \times 10^{-19}\, \text{J}
$$

Determining the Maximum Kinetic Energy: Key Parameters

The maximum kinetic energy of the emitted electrons depends on the incident light's energy:

$$
K_{\text{max}} = h\nu - \phi
$$

or

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

The critical factor is the energy of the incident photons relative to the work function. If the photon energy is less than 2.48 eV, no electrons are emitted. When the photon energy exceeds this threshold, electrons are emitted with a maximum kinetic energy equal to the excess energy.

Case Studies: Impact of Light Frequency and Wavelength

1. Illuminating Barium with Visible Light

Suppose the incident light has a wavelength within the visible spectrum, say, 500 nm (green light). What is the maximum kinetic energy of the electrons emitted?

Calculate photon energy:

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

where:

- $h = 6.626 \times 10^{-34}\, \text{Js}$,
- $c = 3.00 \times 10^{8}\, \text{m/s}$,
- $\lambda = 500\, \text{nm} = 500 \times 10^{-9}\, \text{m}$.

Plugging in:

$$
E_{\text{photon}} = \frac{6.626 \times 10^{-34} \times 3.00 \times 10^{8}}{500 \times 10^{-9}} = \frac{1.9878 \times 10^{-25}}{5 \times 10^{-7}} \approx 3.975 \times 10^{-19}\, \text{J}
$$

Convert to eV:

$$
E_{\text{photon}} = \frac{3.975 \times 10^{-19}}{1.602 \times 10^{-19}} \approx 2.48\, \text{eV}
$$

This is a critical point: the photon energy exactly matches the work function. Therefore:

$$
K_{\text{max}} = 2.48\, \text{eV} - 2.48\, \text{eV} = 0\, \text{eV}
$$

Implication: Photons at 500 nm just suffice to liberate electrons from barium, resulting in zero kinetic energy—electrons are emitted with negligible speed, sensitive to surface conditions and thermal effects.

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2. Using Shorter Wavelengths (Higher Energy Photons)

Suppose ultraviolet light at 300 nm:

$$
E_{\text{photon}} = \frac{6.626 \times 10^{-34} \times 3.00 \times 10^{8}}{300 \times 10^{-9}} \approx 6.626 \times 10^{-34} \times 1 \times 10^{15} = 1.987 \times 10^{-19}\, \text{J}
$$

In eV:

$$
E_{\text{photon}} \approx \frac{1.987 \times 10^{-19}}{1.602 \times 10^{-19}} \approx 1.24\, \text{eV}
$$

Since 1.24 eV < 2.48 eV, no electrons are emitted at this wavelength.

Similarly, for a photon energy exceeding 2.48 eV, say, at 200 nm:

$$
E_{\text{photon}} \approx \frac{6.626 \times 10^{-34} \times 3.00 \times 10^{8}}{200 \times 10^{-9}} \approx 9.939 \times 10^{-19}\, \text{J}
$$

Convert to eV:

$$
E_{\text{photon}} \approx \frac{9.939 \times 10^{-19}}{1.602 \times 10^{-19}} \approx 6.21\, \text{eV}
$$

Now, the maximum kinetic energy:

$$
K_{\text{max}} = 6.21\, \text{eV} - 2.48\, \text{eV} = 3.73\, \text{eV}
$$

Generalized Expression for Maximum Electron Kinetic Energy

The maximum kinetic energy of photoelectrons from barium under illumination with photon wavelength λ is:

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

where:
- $\frac{hc}{\lambda}$ is the photon energy,
- $\phi = 2.48\, \text{eV}$.

Key points:
- If $\frac{hc}{\lambda} \leq \phi$, then $K_{\text{max}} = 0$, no electrons are emitted.
- For $\frac{hc}{\lambda} > \phi$, electrons are emitted with kinetic energies proportional to the excess photon energy.

Practical Implications and Experimental Considerations

Threshold Wavelength

The threshold wavelength $\lambda_{\text{threshold}}$ is the maximum wavelength at which electrons can just be emitted:

$$
\lambda_{\text{threshold}} = \frac{hc}{\phi}
$$

Calculating:

$$
\lambda_{\text{threshold}} = \frac{6.626 \times 10^{-34} \times 3.00 \times 10^{8}}{2.48 \times 1.602 \times 10^{-19}} \approx \frac{1.9878 \times 10^{-25}}{3.975 \times 10^{-19}} \approx 500\, \text{nm}
$$

Thus, light with wavelengths shorter than 500 nm can cause photoemission from barium, with the electrons having kinetic energy depending on the photon’s wavelength.

Effect of Surface Conditions

Surface cleanliness, temperature, and crystalline structure can influence the effective work function. The values discussed assume an ideal, clean surface; real-world conditions may cause slight variations.

Use in Photoelectric Devices

Understanding the maximum kinetic energy is crucial for designing photoelectric cells, electron guns, and sensors, where the energy distribution of emitted electrons determines device efficiency and resolution.

Conclusion

The investigation into the maximum kinetic energy of electrons emitted from barium with a work function of 2.48 eV reveals a direct and fundamental relationship governed by Einstein’s photoelectric equation. The maximum kinetic energy depends on the incident photon energy, which is a function of the photon’s wavelength.

- When illuminated with light at the threshold wavelength of approximately

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