Violet Light Of Wavelength 390 Nm Ejects Electrons With A Maximum Kinetic Energy Of 0.83 EV From A Certain

Violet Light Of Wavelength 390 Nm Ejects Electrons With A Maximum Kinetic Energy Of 0.83 EV From A Certain material, illustrating a fundamental phenomenon in quantum physics known as the photoelectric effect. This process underscores the particle nature of light and forms the basis for numerous technological applications, from photodetectors to solar cells. In this article, we delve into the principles underlying this phenomenon, analyze the relevant physics equations, and explore the implications of the given data.

Understanding the Photoelectric Effect

Basics of the Phenomenon

The photoelectric effect occurs when light of a certain frequency or wavelength strikes a material, typically a metal, causing the ejection of electrons from its surface. This effect was crucial in establishing the quantum theory of light, contributing to Albert Einstein's Nobel Prize in Physics in 1921.

Key points include:
- Incident photons transfer energy to electrons.
- If the photon energy exceeds the work function of the material, electrons are emitted.
- The kinetic energy of emitted electrons depends on the photon energy and the work function.

Historical Significance

The classical wave theory of light could not explain why:
- Electrons are emitted only when the light surpasses a certain threshold frequency.
- The kinetic energy of emitted electrons is independent of light intensity.
Einstein's explanation introduced quantized packets of energy (photons), revolutionizing physics.

Analyzing the Given Data

Given Parameters

The problem provides:
- Wavelength of incident violet light: $\lambda = 390$ nm
- Maximum kinetic energy of emitted electrons: $KE_{max} = 0.83$ eV

Converting Wavelength to Photon Energy

The energy of a photon (E_photon) is related to its wavelength by:
$$ E_{photon} = \frac{hc}{\lambda} $$
where:
- $ h $ (Planck's constant) = $ 6.626 \times 10^{-34} \, \text{Js} $
- $ c $ (speed of light) = $ 3.00 \times 10^{8} \, \text{m/s} $
- $ \lambda $ = 390 nm = $ 390 \times 10^{-9} \, \text{m} $

Calculating:
$$
E_{photon} = \frac{6.626 \times 10^{-34} \times 3.00 \times 10^{8}}{390 \times 10^{-9}}
$$

$$
E_{photon} \approx \frac{1.9878 \times 10^{-25}}{3.9 \times 10^{-7}} \approx 5.096 \times 10^{-19} \, \text{J}
$$

To convert Joules to electron volts:
$$
1 \, \text{eV} = 1.602 \times 10^{-19} \, \text{J}
$$

$$
E_{photon} \approx \frac{5.096 \times 10^{-19}}{1.602 \times 10^{-19}} \approx 3.18 \, \text{eV}
$$

Thus, each photon carries approximately 3.18 eV of energy.

Calculating the Work Function

The maximum kinetic energy of the ejected electrons relates to the photon energy and the work function ($ \phi $) via Einstein's photoelectric equation:
$$ KE_{max} = E_{photon} - \phi $$

Rearranged:
$$ \phi = E_{photon} - KE_{max} $$

Given:
- $ KE_{max} = 0.83 \, \text{eV} $

Calculating:
$$
\phi = 3.18 \, \text{eV} - 0.83 \, \text{eV} = 2.35 \, \text{eV}
$$

This work function indicates the minimum energy needed to eject an electron from the material's surface.

Implications of the Results

Material Properties

The calculated work function (~2.35 eV) suggests that the material is likely a metal with a relatively low work function. Typical metals with work functions in this range include:
- Cesium (~2.1 eV)
- Potassium (~2.3 eV)
- Sodium (~2.28 eV)

These metals are known for their low work functions, making them more responsive to incident light in the UV-visible spectrum.

Understanding Electron Emission

The maximum kinetic energy of the emitted electrons is directly related to the photon energy minus the work function. Since the photon energy (3.18 eV) exceeds the work function (2.35 eV), electrons can be emitted with kinetic energies up to 0.83 eV under ideal conditions.

Further Analysis and Applications

Photoelectric Equation and Threshold Frequency

The threshold frequency (ν_0) corresponds to the minimum frequency to eject electrons:
$$\phi = h \nu_0$$

Calculating:
$$\nu_0 = \frac{\phi}{h}$$
Using $\phi = 2.35 \, \text{eV}$:
$$\phi = 2.35 \times 1.602 \times 10^{-19} \, \text{J} \approx 3.77 \times 10^{-19} \, \text{J}$$
Then:
$$\nu_0 = \frac{3.77 \times 10^{-19}}{6.626 \times 10^{-34}} \approx 5.69 \times 10^{14} \, \text{Hz}$$

Since the incident light frequency (ν) is:
$$\nu = \frac{c}{\lambda} = \frac{3.00 \times 10^8}{390 \times 10^{-9}} \approx 7.69 \times 10^{14} \, \text{Hz}$$

which exceeds ν_0, confirming photoemission occurs.

Applications of the Photoelectric Effect

Understanding the relationship between photon energy, work function, and kinetic energy of ejected electrons is crucial for:
- Designing photodetectors and cameras.
- Developing solar cells that convert light energy into electrical energy.
- Exploring quantum phenomena and the particle-wave duality of light.

Summary and Conclusions

- The incident violet light with wavelength 390 nm provides a photon energy of approximately 3.18 eV.
- The maximum kinetic energy of emitted electrons is 0.83 eV, indicating a work function of about 2.35 eV for the material.
- The analysis confirms that the incident photon energy exceeds the work function, enabling photoemission.
- The threshold frequency for the material is approximately 5.69×10^{14} Hz, which is below the incident light frequency, consistent with observed emission.
- This process exemplifies the quantum nature of light and provides foundational understanding for modern optoelectronic devices.

Final Remarks

The study of photoelectric phenomena not only deepens our understanding of atomic-scale interactions but also drives innovation in technology. The precise relationship between wavelength, photon energy, work function, and electron kinetic energy forms a cornerstone of quantum physics, illustrating how light’s particle properties directly influence material behavior. As research advances, these principles continue to underpin developments in energy harvesting, imaging, and quantum information science.

Frequently Asked Questions

What is the significance of violet light with a wavelength of

390 nm in photoelectric experiments?

Violet light at 390 nm has enough photon energy to eject electrons from certain materials, demonstrating the photoelectric effect and helping to determine the work function of the material.

How do you calculate the energy of a photon with a wavelength of 390 nm?

Photon energy (E) can be calculated using $E = hc/\lambda$, where h is Planck's constant (6.626×10^{-34} Js), c is the speed of light (3×10^{8} m/s), and λ is the wavelength in meters. For 390 nm, $E \approx 3.2$ eV.

Given the maximum kinetic energy of ejected electrons is 0.83 eV, how do you find the work function of the material?

Work function (ϕ) = photon energy (E) - maximum kinetic energy (KE). Using $E \approx 3.2$ eV, $\phi = 3.2$ eV - 0.83 eV = 2.37 eV.

What does the maximum kinetic energy of 0.83 eV tell us about the photoelectric process in this case?

It indicates the highest energy with which electrons are emitted after absorbing photons of 390 nm, reflecting the excess energy beyond the work function that is converted into electron kinetic energy.

Can the violet light of 390 nm cause photoemission in all materials?

No, only materials with a work function less than or equal to the photon energy (~3.2 eV) can emit electrons when illuminated with 390 nm light; materials with higher work functions will not exhibit photoemission at this wavelength.

How does the wavelength of 390 nm relate to the energy of the photons involved in the photoelectric effect?

A wavelength of 390 nm corresponds to a photon energy of approximately 3.2 eV, which provides the energy needed to eject electrons if it exceeds the material's work function.

Additional Resources

Violet Light

In the realm of photonics and quantum physics, the interaction between light and matter often reveals fascinating phenomena that challenge our understanding of the microscopic world. One such phenomenon involves the photoelectric effect, where electromagnetic radiation incident upon a material surface results in the ejection of electrons. Today, we delve into a specific case: the violet light with a wavelength of 390 nm capable of ejecting electrons with a maximum kinetic energy of 0.83 eV from a particular substance. This case study not only highlights fundamental principles of quantum mechanics but also exemplifies the practical implications and technological applications of photoelectric phenomena.

Understanding the Photoelectric Effect

The photoelectric effect is a cornerstone of quantum physics, first explained comprehensively by Albert Einstein in 1905. It describes how light can cause electrons to escape from a material, typically a metal, when it strikes its surface.

Key Principles:

- Photon Energy: Light consists of discrete packets of energy called photons. The energy of a photon is given by:

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

where:

- h is Planck's constant ($6.626 \times 10^{-34} \, \text{Js}$)
- ν is the frequency of light
- c is the speed of light ($3 \times 10^{8} \, \text{m/s}$)
- λ is the wavelength of light

- Work Function (ϕ): The minimum energy needed to eject an electron from the material.

- Kinetic Energy of Ejected Electrons: When photons with energy exceeding the work function strike a surface, electrons are emitted with a maximum kinetic energy:

$$
K_{\text{max}} = E - \phi
$$

where E is the photon energy.

Implication: The maximum kinetic energy of the emitted electrons depends directly on the photon energy (which depends on wavelength) and inversely on the work function of the material.

Analyzing the Violet Light with 390 nm Wavelength

The specific case involves violet light with a wavelength of 390 nm. Let’s explore what this entails:

Photon Energy Calculation

Using the photon energy formula:

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

Plugging in the known values:

- $h = 6.626 \times 10^{-34} \, \text{Js}$
- $c = 3 \times 10^{8} \, \text{m/s}$
- $\lambda = 390\, \text{nm} = 390 \times 10^{-9} \, \text{m}$

Calculating:

$$
E = \frac{6.626 \times 10^{-34} \times 3 \times 10^{8}}{390 \times 10^{-9}} \approx \frac{1.9878 \times 10^{-25}}{3.9 \times 10^{-7}} \approx 5.096 \times 10^{-19} \, \text{J}
$$

Converting to electronvolts (since $1\, \text{eV} = 1.602 \times 10^{-19} \, \text{J}$):

$$
E \approx \frac{5.096 \times 10^{-19}}{1.602 \times 10^{-19}} \approx 3.18\, \text{eV}
$$

Result: Photons of 390 nm wavelength possess approximately 3.18 eV of energy.

Maximum Kinetic Energy of Ejected Electrons

Given that the maximum kinetic energy of the emitted electrons is 0.83 eV, we can determine the work function (ϕ) of the material:

$$
\phi = E - K_{\text{max}} = 3.18\, \text{eV} - 0.83\, \text{eV} = 2.35\, \text{eV}
$$

Insight: The material's work function is approximately 2.35 eV, which is characteristic of certain metals and semiconductor surfaces.

Implications of the Photonic Interaction

Photoelectric Threshold

The threshold wavelength ($\lambda_{threshold}$) — the maximum wavelength capable of ejecting electrons — can be calculated via:

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

Using the work function:

$$
\lambda_{threshold} = \frac{6.626 \times 10^{-34} \times 3 \times 10^{8}}{2.35 \times 1.602 \times 10^{-19}} \approx \frac{1.9878 \times 10^{-25}}{3.765 \times 10^{-19}} \approx 527 \, \text{nm}
$$

Conclusion: Photons with wavelengths shorter than approximately 527 nm can eject electrons from this material. Since 390 nm < 527 nm, the incident violet light is sufficiently energetic.

Energy Distribution of Photoelectrons

The maximum kinetic energy corresponds to electrons emitted from the least bound states, while electrons originating from deeper energy levels would have less kinetic energy.

Technological and Scientific Significance

Understanding the photoelectric effect at this wavelength and energy level has multiple applications and implications:

Photodetectors and Solar Cells

- Photodetectors: Devices utilizing the photoelectric effect often rely on specific wavelength sensitivities. Knowing that violet light at 390 nm can eject electrons with a kinetic energy of 0.83 eV aids in designing sensitive and efficient photodetectors for ultraviolet and violet regions.

- Solar Cells: Semiconductor materials with suitably low work functions can harness violet and ultraviolet photons to generate electron flow, enhancing energy conversion efficiencies.

Spectroscopy and Surface Analysis

Photoelectric effects at specific wavelengths enable detailed surface characterization using techniques like photoelectron spectroscopy. The ability to control photon energy precisely allows scientists to probe surface compositions and electronic structures.

Quantum Mechanics and Educational Demonstrations

This case offers a tangible example of quantum principles, illustrating how photon energy relates directly to electron emission and how material properties influence photoelectric thresholds.

Material Considerations and Practical Aspects

Choice of Material

The material's work function (~2.35 eV) suggests it could be a metal such as cesium, potassium, or certain semiconductors with low work functions. The selection of material impacts:

- Efficiency: Lower work functions make photoemission more feasible at longer wavelengths.
- Durability: Some materials are more resistant to oxidation or surface contamination, affecting their photoelectric properties.

Surface Preparation and Cleanliness

- Surface cleanliness is critical, as contamination can alter the work function.
- Ultra-high vacuum conditions are often employed to maintain pristine surfaces for consistent photoelectric measurements.

Intensity of Light and Electron Yield

While photon energy determines whether electrons can be ejected, the intensity (or power density) of the incident light influences the number of electrons emitted per unit time. Higher intensity results in higher electron flux but does not affect the maximum kinetic energy, which depends solely on photon energy and work function.

Broader Context and Future Directions

The study of violet light at 390 nm and its photoelectric implications is more than an academic exercise; it forms the basis for emerging technologies:

- Quantum Computing: Precise control over electron emission is vital in quantum dot and qubit technologies.
- UV and Violet Photonics: Developing light sources, detectors, and materials optimized for these wavelengths is crucial for telecommunications, medical imaging, and environmental sensing.
- Material Engineering: Tailoring surface properties to manipulate work functions can lead to more efficient photoelectric devices.

Conclusion

The phenomenon where violet light at 390 nm ejects electrons with a maximum kinetic energy of 0.83 eV exemplifies the fundamental principles of quantum mechanics and the photoelectric effect. By calculating photon energy, work function, and threshold wavelengths, we gain a detailed understanding of the interaction between light and matter.

This case not only underscores the importance of wavelength and energy in photoemission but also highlights the critical role of material properties in dictating photonic responses. Whether for scientific research, technological innovation, or educational purposes, this insight into the photoelectric effect at violet wavelengths continues to inspire advancements across multiple fields.

In essence, this analysis offers a comprehensive glimpse into the quantum dance between photons and electrons—a dance that underpins many modern technologies and deepens our grasp of the universe’s fundamental workings.

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