4. When Uv Light Of Wavelength 255 Nm Falls On A Metal Surface, The Maximum Kinetic Energy Of Emitted

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Understanding the interaction between ultraviolet (UV) light and metal surfaces is fundamental in fields ranging from photochemistry to material science. Specifically, when UV light of a certain wavelength strikes a metal, electrons are emitted through the photoelectric effect. This article explores the detailed physics behind this phenomenon, focusing on the case where UV light of wavelength 255 nm impacts a metal surface and analyzing the maximum kinetic energy of the emitted electrons.

Introduction to the Photoelectric Effect

The photoelectric effect describes the process where electrons are ejected from a material's surface when it absorbs electromagnetic radiation of sufficiently high energy. Albert Einstein's groundbreaking work in 1905 explained this effect, providing crucial evidence for the quantum theory of light.

Key points include:

- Electrons are emitted only if the incident photon energy exceeds the metal's work function.
- The maximum kinetic energy of emitted electrons depends on the energy of the incident photons and the work function.
- The phenomenon is independent of the light's intensity, provided the frequency exceeds a threshold.

Fundamental Concepts and Definitions

To analyze the specific case of UV light at 255 nm, we need to understand several core concepts:

Photon Energy

- Photons carry quantized energy given by the equation:

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

where:
- E = photon energy (in joules or electron volts)
- h = Planck's constant ($6.626 \times 10^{-34} \, \text{Js}$)
- ν = frequency of light
- c = speed of light ($3.0 \times 10^{8} \, \text{m/s}$)
- λ = wavelength of light

Work Function (ϕ)

- The minimum energy needed to eject an electron from the metal surface.
- Usually expressed in electron volts (eV).
- Different metals have different work functions, typically ranging from about 2 eV to 5 eV.

Maximum Kinetic Energy of Emitted Electrons (K_{max})

- Given by Einstein's photoelectric equation:

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

where:
- E_{photon} is photon energy
- ϕ is the work function of the metal

Calculating the Photon Energy at 255 nm Wavelength

Given that the wavelength λ is 255 nm:

1. Convert wavelength to meters:

$$
255\, \text{nm} = 255 \times 10^{-9}\, \text{m}
$$

$$
E = \frac{(6.626 \times 10^{-34}\, \text{Js})(3.0 \times 10^{8}\, \text{m/s})}{255 \times 10^{-9}\, \text{m}}
$$

3. Simplify the calculation:

$$
E = \frac{1.9878 \times 10^{-25}\, \text{Jm}}{255 \times 10^{-9}\, \text{m}} = \frac{1.9878 \times 10^{-25}}{2.55 \times 10^{-7}}
$$

$$
E \approx 7.79 \times 10^{-19}\, \text{J}
$$

4. Convert joules to electron volts:

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

$$
E_{eV} = \frac{7.79 \times 10^{-19}\, \text{J}}{1.602 \times 10^{-19}\, \text{J/eV}} \approx 4.86\, \text{eV}
$$

Result: The photon energy at 255 nm is approximately 4.86 eV.

Determining the Maximum Kinetic Energy of Emitted Electrons

The maximum kinetic energy depends on the metal's work function, which varies among different metals. To illustrate, consider a few typical metals:

- Cesium: $\phi \approx 2.1\, \text{eV}$

- Potassium: $\phi \approx 2.3\, \text{eV}$
- Sodium: $\phi \approx 2.3\, \text{eV}$
- Copper: $\phi \approx 4.7\, \text{eV}$
- Gold: $\phi \approx 5.1\, \text{eV}$

Calculating K_{max} for Different Metals

Using the photoelectric equation:

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

- For Cesium:

$$
K_{max} = 4.86\, \text{eV} - 2.1\, \text{eV} = 2.76\, \text{eV}
$$

- For Copper:

$$
K_{max} = 4.86\, \text{eV} - 4.7\, \text{eV} = 0.16\, \text{eV}
$$

- For Gold:

$$
K_{max} = 4.86\, \text{eV} - 5.1\, \text{eV} = -0.24\, \text{eV}
$$

Since negative kinetic energy is not physically meaningful, electrons are not emitted if the photon energy is less than the work function.

Implications:

- Metals with work functions less than 4.86 eV will emit electrons when irradiated with 255 nm UV light.
- The maximum kinetic energy decreases as the work function increases.
- For metals like copper and gold, the photon energy is insufficient to eject electrons.

Factors Affecting Electron Emission

While the calculations above assume ideal conditions, several real-world factors can influence the emission process:

Surface Condition
- Surface contamination, oxidation, or roughness can modify the effective work function.

Intensity of UV Light
- While the maximum kinetic energy is independent of light intensity, higher intensities increase the number of emitted electrons.

Temperature
- Elevated temperatures may influence electron emission via thermal effects but do not directly impact the maximum kinetic energy determined by photon energy and work function.

Applications of UV-Induced Photoelectric Emission

Understanding the maximum kinetic energy of electrons emitted due to UV light has practical applications:

- Photoelectron Spectroscopy: Analyzing material properties by measuring kinetic energies of emitted electrons.
- Photodetectors: Designing devices sensitive to specific wavelengths.
- Surface Analysis: Investigating surface contamination and work function variations.
- UV Photodetectors: Developing sensors for UV radiation detection.

Summary and Key Takeaways

- The energy of UV photons at 255 nm is approximately 4.86 eV.
- The maximum kinetic energy of emitted electrons depends on the metal's work function.
- Metals with work functions less than 4.86 eV will emit electrons when exposed to 255 nm UV light.
- The maximum kinetic energy can be calculated by subtracting the work function from the photon energy.

Quick Reference Table:

Metal	Work Function (ϕ)	K_{max} for 255 nm UV light (eV)
Cesium	2.1 eV	2.76 eV
Potassium	2.3 eV	2.56 eV
Sodium	2.3 eV	2.56 eV
Copper	4.7 eV	0.16 eV
Gold	5.1 eV	Not emitted

Conclusion

The interaction between UV light at 255 nm and metal surfaces exemplifies the fundamental principles of the photoelectric effect. By calculating the photon energy and considering the metal's work function, we can predict whether electrons will be emitted and determine their maximum kinetic energy. This understanding is crucial for designing experiments, sensors, and devices that rely on photoelectric phenomena. Whether analyzing surface properties or developing UV detectors, the principles outlined here serve as a foundation for leveraging the photoelectric effect across various scientific and technological fields.

Frequently Asked Questions

What is the maximum kinetic energy of electrons emitted when UV light of wavelength 255 nm falls on a metal surface?

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

How do you calculate the maximum kinetic energy of photoelectrons for UV light of 255 nm wavelength?

Calculate the photon energy using $E = hc/\lambda$, then subtract the work function φ of the metal: $KE_{max} = (hc/\lambda) - \varphi$. Ensure units are consistent for accurate results.

What factors influence the maximum kinetic energy of

electrons emitted by UV light?

The key factors are the wavelength (or frequency) of the incident light and the work function of the metal surface. Higher photon energy (shorter wavelength) results in higher maximum kinetic energy, provided it exceeds the work function.

If the wavelength of UV light is decreased, what happens to the maximum kinetic energy of emitted electrons?

Decreasing the wavelength increases the photon energy, which increases the maximum kinetic energy of emitted electrons, assuming the work function remains constant.

What is the significance of the work function in the photoelectric effect?

The work function is the minimum energy needed to eject an electron from the metal surface. It determines the threshold wavelength and influences the maximum kinetic energy of the emitted electrons.

Can UV light of wavelength 255 nm cause photoemission from all metals?

No, only metals with work functions less than the photon energy at 255 nm can emit electrons. If the work function exceeds the photon energy, photoemission will not occur.

How does the photon energy at 255 nm compare to typical work functions of metals?

Photon energy at 255 nm is approximately 4.86 eV, which is sufficient to cause photoemission from many metals with work functions less than this value, such as cesium or sodium, but not from metals with higher work functions like platinum or gold.

What is the role of Planck's constant in determining the maximum kinetic energy of emitted electrons?

Planck's constant relates the photon energy to its frequency via $E = hf$. It is essential for converting wavelength to energy, which is used to calculate the maximum kinetic energy of emitted electrons.

How does the photoelectric equation relate wavelength to the kinetic energy of emitted electrons?

The photoelectric equation $KE_{max} = hf - \varphi$ shows that the maximum kinetic energy depends directly on photon energy, which is inversely proportional to wavelength ($f = c/\lambda$). Shorter wavelengths produce higher kinetic energies.

What is the approximate maximum kinetic energy of electrons emitted when UV light of wavelength 255 nm falls on a metal with a work function of 2.0 eV?

First, calculate photon energy: $E = hc/\lambda \approx (1240 \text{ eV·nm}) / 255 \text{ nm} \approx 4.86$ eV. Then, $KE_{max} = 4.86 \text{ eV} - 2.0 \text{ eV} =$ approximately 2.86 eV.

Additional Resources

UV Light and Photoelectric Emission: An In-Depth Analysis of Kinetic Energy at 255 nm

The interaction of ultraviolet (UV) light with metal surfaces has long been a subject of scientific curiosity, especially in the context of the photoelectric effect. Understanding how photons of specific wavelengths influence the kinetic energy of emitted electrons provides vital insights into quantum physics, material properties, and practical applications like photoelectric sensors and photovoltaic devices. In this article, we explore the scenario where UV light with a wavelength of 255 nm strikes a metal surface, focusing on the maximum kinetic energy of the emitted electrons. This comprehensive analysis combines fundamental physics principles with practical implications, offering a detailed perspective suitable for both enthusiasts and professionals.

Fundamentals of the Photoelectric Effect

Before delving into the specifics of UV light at 255 nm, it is essential to establish a solid understanding of the photoelectric effect, the core phenomenon underlying electron emission from metals subjected to incident electromagnetic radiation.

What Is the Photoelectric Effect?

The photoelectric effect describes the process whereby electrons are ejected from a material—typically a metal—when it absorbs energy from incident photons of sufficient energy. Discovered experimentally by Heinrich Hertz and explained theoretically by Albert Einstein in 1905, this effect underscores the particle-like nature of light.

Key points include:
- Photon Energy: Light can be quantized into photons, each carrying energy $E = hf$, where h is Planck’s constant ($6.626 \times 10^{-34} \mathrm{Js}$) and f is the frequency of light.
- Threshold Frequency: For a given material, there exists a minimum frequency f_0 (or corresponding wavelength λ_0) below which no electrons are emitted, regardless of light intensity.
- Kinetic Energy of Emitted Electrons: When photons have energy exceeding the work function ϕ of the metal, electrons are emitted with a maximum kinetic energy given by Einstein’s photoelectric equation:

$$
K_{max} = hf - \phi
$$

where:
- K_{max} is the maximum kinetic energy of the emitted electrons,
- hf is the photon energy,
- ϕ is the work function of the metal (the minimum energy needed to liberate an electron).

Relevance of Wavelength

Since frequency f relates to wavelength λ by $f = c/\lambda$, where c is the speed of light (~3.0×10^8 m/s), the photon energy can also be expressed as:

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

This relationship is crucial because it allows us to determine photon energy directly from the wavelength, especially in the UV region where small changes in λ significantly affect E.

The Significance of 255 nm in UV Light

UV light spans wavelengths approximately from 10 nm to 400 nm, subdivided into UV-A, UV-B, and UV-C regions. At 255 nm, the light falls within the UV-C range, characterized by high-energy photons.

Properties of 255 nm UV Light

- Photon Energy Calculation:

Using the equation $E = \frac{hc}{\lambda}$, where:

- $h = 6.626 \times 10^{-34}$ Js,
- $c = 3.0 \times 10^8$ m/s,
- $\lambda = 255$ nm = 255×10^{-9} m,

the photon energy becomes:

$$
E = \frac{6.626 \times 10^{-34} \times 3.0 \times 10^8}{255 \times 10^{-9}} \approx \frac{1.9878 \times 10^{-25}}{2.55 \times 10^{-7}} \approx 7.79 \times 10^{-19} \text{ Joules}
$$

Converting to electronvolts (eV):

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

$$
E \approx \frac{7.79 \times 10^{-19}}{1.602 \times 10^{-19}} \approx 4.86\, \text{eV}
$$

So, each photon at 255 nm has an energy of approximately 4.86 eV.

- Implications:

This high photon energy makes 255 nm UV light suitable for inducing photoelectric emission in metals with work functions less than or around this value.

Maximum Kinetic Energy of Emitted Electrons at 255 nm

The core question is: When UV light of 255 nm strikes a metal surface, what is the maximum kinetic energy of the emitted electrons?

Applying Einstein's Photoelectric Equation

The maximum kinetic energy K_{max} depends on the photon energy E_{photon} and the work function ϕ of the metal:

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

Given that:

$$
E_{photon} \approx 4.86\, \text{eV}
$$

The value of ϕ varies depending on the metal:

Metal	Work Function ϕ (eV)	Emission Condition
Cesium (Cs)	~2.14	Easily emits electrons with 255 nm light
Zinc	~4.3	Near threshold; electrons barely emitted
Gold	~5.1	Not emitted at 255 nm
Aluminum	~4.28	Close to threshold
Copper	~4.7	Slightly above threshold

Key Point: For emission to occur, the photon energy must be greater than the work function ($E_{photon} > \phi$).

Case 1: Metal with $\phi < 4.86\, \text{eV}$

For metals like cesium ($\phi \approx 2.14\, \text{eV}$) or aluminum ($\phi \approx 4.28\, \text{eV}$), the photon energy exceeds the work function, enabling electron ejection.

- Maximum kinetic energy calculation:

$$
K_{max} = 4.86\, \text{eV} - \phi
$$

- Examples:

Metal	ϕ (eV)	K_{max} (eV)
Cesium	2.14	2.72

Aluminum	4.28	0.58

Note: The maximum kinetic energy is directly proportional to the difference between photon energy and work function.

Implication: Electrons emitted from metals with low work functions will possess significant kinetic energy, enabling their detection and use in various applications.

Case 2: Metal with $\phi > 4.86\, \text{eV}$

If the work function exceeds 4.86 eV, the photon energy is insufficient to eject electrons, resulting in no photoelectric emission at 255 nm.

- Example: Gold ($\phi \approx 5.1\, \text{eV}$):

$$
K_{max} = 4.86\, \text{eV} - 5.1\, \text{eV} = -0.24\, \text{eV}
$$

Since kinetic energy cannot be negative, no electrons are emitted; 255 nm light is ineffective for gold photoemission.

Practical Considerations and Applications

Understanding the maximum kinetic energy of emitted electrons at 255 nm is crucial for designing devices and experiments involving the photoelectric effect.

Material Selection Based on Work Function

- Photoelectric Sensors: Metals with low work functions (e.g., cesium, potassium) are ideal for UV detection at 255 nm.
- Photocathodes: Materials like cesium iodide or gallium arsenide can be engineered for efficient electron emission with UV light.

Photon Energy and Thresholds

- Since the photon energy (~4.86 eV) is close to the work functions of some

metals, precise material selection is essential.
- For metals like gold, alternative wavelengths with higher photon energies (shorter wavelengths) are necessary to induce emission.

Implications for Surface and Material Science

- Surface Conditions: Surface cleanliness and roughness influence the work function and emission efficiency.
- Photon Energy Tuning: Adjusting wavelength allows control over electron emission characteristics, vital in electron microscopy and spectroscopy.

Limitations and Additional Factors

While the core physics provides a clear picture, practical applications involve additional complexities:

- Surface Contamination: Oxides and impurities can alter

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