When Ultraviolet Light With A Wavelength Of 400 Nm Falls On A Certain Metal Surface, The Maximum Kinetic

When Ultraviolet Light With A Wavelength Of 400 Nm Falls On A Certain Metal Surface, The Maximum Kinetic

---

Introduction

When ultraviolet light with a wavelength of 400 nm falls on a certain metal surface, a fascinating physical phenomenon occurs—photoelectric emission. This process, fundamental to quantum physics, involves the ejection of electrons from the metal surface when it absorbs incident light energy. Understanding the maximum kinetic energy of these emitted electrons is crucial for various applications, including photoelectric sensors, photovoltaic devices, and spectroscopy.

In this article, we explore the detailed physics behind the photoelectric effect triggered by 400 nm ultraviolet light, analyze the factors influencing the maximum kinetic energy of emitted electrons, and discuss how this knowledge applies to real-world technologies. We will delve into the concepts of photon energy, work function, and Einstein's photoelectric equation, providing a comprehensive understanding suitable for students, researchers, and enthusiasts alike.

The Photoelectric Effect: Fundamental Concepts

What Is the Photoelectric Effect?

The photoelectric effect is the emission of electrons from a material's surface when it is illuminated by electromagnetic radiation of sufficient energy. Discovered by Heinrich Hertz and explained by Albert Einstein in 1905, this effect played a pivotal role in establishing quantum theory.

How Does It Work?

When photons of light strike the metal surface:

- They transfer their energy to electrons within the metal.
- If the photon energy exceeds the metal's work function, electrons gain enough energy to escape.
- The excess energy becomes the electrons' kinetic energy.

Key Terms

- Photon energy (E_{photon}): The energy of the incident photon.
- Work function (ϕ): The minimum energy required to eject an electron from the metal.
- Maximum kinetic energy (K_{max}): The highest kinetic energy attained by the emitted electrons.

Calculating the Energy of Ultraviolet Light at 400 nm

Wavelength and Frequency

Given the wavelength (λ):

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

The frequency (f) of the light is:

$$
f = \frac{c}{\lambda}
$$

Where:

- $c = 3.00 \times 10^{8}\, \text{m/s}$ (speed of light)

Calculating:

$$
f = \frac{3.00 \times 10^{8}}{400 \times 10^{-9}} = 7.5 \times 10^{14}\, \text{Hz}
$$

Photon Energy

The energy of a photon is given by:

$$
E_{photon} = h \times f
$$

Where:

- $h = 6.626 \times 10^{-34}\, \text{Js}$ (Planck’s constant)

Calculating:

$$
E_{photon} = 6.626 \times 10^{-34} \times 7.5 \times 10^{14} = 4.97 \times 10^{-19}\, \text{J}
$$

Converting to electronvolts (eV):

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

$$
E_{photon} \approx \frac{4.97 \times 10^{-19}}{1.602 \times 10^{-19}} \approx 3.11\, \text{eV}
$$

Thus, the photon energy at 400 nm is approximately 3.11 eV.

Determining the Maximum Kinetic Energy of Ejected Electrons

The Photoelectric Equation

Einstein's photoelectric equation relates photon energy, work function, and maximum kinetic energy:

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

Where:

- K_{max}: Maximum kinetic energy of emitted electrons (in eV)
- E_{photon}: Energy of incident photons (in eV)
- ϕ: Work function of the metal (in eV)

Role of the Metal’s Work Function

The work function ϕ is a critical property of the metal surface, varying among different metals. Typical work functions include:

Metal	Work Function (ϕ) in eV
Cesium	2.14
Potassium	2.30
Sodium	2.28
Copper	4.7
Silver	4.26
Gold	5.1

Note: For the purpose of this analysis, let's assume the metal has a work function ϕ of 4.5 eV, which is common for metals like copper.

Calculating K_{max}

Using the photon energy:

$$
K_{max} = 3.11\, \text{eV} - 4.5\, \text{eV}
$$

Since this results in a negative value:

$$
K_{max} = -1.39\, \text{eV}
$$

This indicates that the photon energy is insufficient to eject electrons from this particular metal surface with a work function of 4.5 eV. Therefore, no photoelectric emission occurs under these conditions.

Implications

- If the metal's work function is less than 3.11 eV, electrons can be emitted.
- If the work function exceeds 3.11 eV, the incident light cannot eject electrons regardless of other factors.

Real-World Applications and Significance

Photoelectric Devices

Understanding the maximum kinetic energy of emitted electrons impacts the design of devices such as:

- Photocells and solar panels: Optimizing the incident light wavelength to maximize electron emission.
- Photoelectron spectrometers: Analyzing material properties based on emitted electron kinetic energies.
- Sensors and detectors: Utilizing the photoelectric effect to detect ultraviolet light.

Material Selection

Choosing appropriate metals with suitable work functions is crucial. For ultraviolet light at 400 nm:

- Metals with $\phi < 3.11\, \text{eV}$ are capable of photoelectric emission.
- Common low-work-function metals include cesium and potassium, which are often used in photoelectric applications.

Enhancing Photoelectric Efficiency

Strategies include:

- Using metals with lower work functions.
- Increasing light intensity to produce more electrons.
- Employing surface treatments to reduce the work function.

Factors Affecting the Maximum Kinetic Energy

Light Intensity

- While intensity influences the number of emitted electrons, it does not affect their maximum kinetic

energy.
- Higher intensity results in more electrons but the same maximum kinetic energy, assuming photon energy remains constant.

Surface Conditions

- Surface cleanliness, roughness, and contamination can alter the effective work function.
- Clean, smooth surfaces tend to have well-defined work functions.

Quantum Efficiency

- The probability that incident photons will eject electrons depends on the material and surface conditions.
- Higher quantum efficiency means more electrons are emitted per incident photon.

Summary and Conclusion

When ultraviolet light with a wavelength of 400 nm falls on a metal surface, the maximum kinetic energy of the emitted electrons depends fundamentally on the photon energy and the metal’s work function. Calculations show that:

- The photon energy at 400 nm is approximately 3.11 eV.
- To eject electrons, the metal must have a work function less than or equal to 3.11 eV.
- For metals with higher work functions (e.g., copper, gold), no photoelectric emission occurs at this wavelength.

This understanding underscores the importance of selecting appropriate materials and wavelengths in designing photoelectric devices. By tuning the incident light wavelength and choosing metals with suitable work functions, engineers can optimize the efficiency of photoelectric systems.

In conclusion, the maximum kinetic energy of electrons ejected by 400 nm ultraviolet light is directly determined by the difference between photon energy and the metal's work function. This principle, rooted in Einstein’s photoelectric equation, remains central to modern quantum physics and technological innovations.

References

- Halliday, D., Resnick, R., & Walker, J. (2014). Fundamentals of Physics (10th ed.). Wiley.
- Serway, R. A., & Jewett, J. W. (2018). Physics for Scientists and Engineers (9th ed.). Cengage Learning.
- Tipler, P. A., & Llewellyn, R. (2008). Modern Physics (4th ed.). W. H. Freeman.
- NASA. (2023). Photoelectric Effect. NASA Physics Classroom.

Frequently Asked Questions

What is the significance of a 400 nm wavelength ultraviolet light in photoelectric experiments?

A 400 nm wavelength UV light falls within the near-ultraviolet range and provides sufficient photon energy to eject electrons from certain metals, making it relevant for studying the photoelectric effect.

How does the wavelength of 400 nm affect the maximum kinetic energy of photoelectrons emitted from a metal surface?

The maximum kinetic energy of emitted photoelectrons is given by Einstein's photoelectric equation: $KE_{max} = hf - \varphi$, where h is Planck's constant, f is the frequency corresponding to 400 nm, and φ is the work function of the metal. Shorter wavelengths (higher energy photons) result in higher KE_{max}.

If ultraviolet light with 400 nm wavelength falls on a metal surface, what determines whether electrons will be emitted?

Electrons are emitted if the photon energy ($E = hc/\lambda$) exceeds the work function (φ) of the metal. For 400 nm, if $E > \varphi$, photoelectrons will be emitted; otherwise, no electrons will be ejected.

What is the relation between photon energy at 400 nm and the maximum kinetic energy of emitted electrons?

The photon energy at 400 nm is $E = hc/\lambda$. The maximum kinetic energy of emitted electrons is $KE_{max} = E - \varphi$. Thus, higher photon energy (shorter wavelength) increases KE_{max}, provided $E > \varphi$.

How can we experimentally determine the maximum kinetic energy of photoelectrons when UV light of 400 nm is used?

By measuring the stopping potential in a photoelectric experiment, where the stopping voltage equals KE_{max}/e, we can determine the maximum kinetic energy of the emitted electrons.

Why does increasing the intensity of 400 nm ultraviolet light not increase the maximum kinetic energy of photoelectrons?

Because the maximum kinetic energy depends on photon energy and the work function, increasing intensity (number of photons) increases the number of emitted electrons but does not affect their maximum kinetic energy.

What role does the work function of the metal play when

ultraviolet light of 400 nm wavelength is incident on its surface?

The work function determines the minimum photon energy needed to eject electrons. If the photon energy at 400 nm exceeds the work function, electrons will be emitted; otherwise, no photoelectric effect occurs.

Additional Resources

Ultraviolet Light

Understanding how ultraviolet (UV) light interacts with metal surfaces is fundamental in fields ranging from materials science and physics to engineering and environmental studies. At the core of these interactions lies the photoelectric effect—a phenomenon that has not only shaped our understanding of quantum mechanics but also underpins numerous practical applications, including photodetectors, solar cells, and surface analysis tools. This article delves deeply into the case where ultraviolet light with a wavelength of 400 nm strikes a metal surface, examining how this influences the maximum kinetic energy of ejected electrons, and what this reveals about the metal's properties.

The Fundamentals of the Photoelectric Effect

What is the Photoelectric Effect?

The photoelectric effect describes the emission of electrons from a material's surface when it is illuminated with electromagnetic radiation of sufficient energy. When photons—particles of light—strike a metal surface, their energy can be absorbed by electrons within the metal. If the energy supplied exceeds the material's work function (ϕ), electrons escape from the surface, producing a measurable current.

Key points include:
- Photon energy: Given by $E = h\nu$, where h is Planck's constant (6.626×10^{-34} Js), and ν is the frequency of the incident light.
- Work function: The minimum energy needed to liberate an electron from the metal surface, often expressed in electron volts (eV).
- Kinetic energy of emitted electrons: The excess energy after overcoming the work function manifests as the electrons' kinetic energy.

Relation Between Wavelength and Energy

The energy of a photon is inversely proportional to its wavelength (λ):
\[

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

where:
- h is Planck’s constant,
- c is the speed of light (3.00×10^{8} m/s),
- λ is the wavelength in meters.

A photon with a shorter wavelength carries more energy. For UV light at 400 nm (which is 4.00×10^{-7} meters), the photon energy determines whether electrons can be ejected and how energetic those electrons will be.

Calculating the Photon Energy at 400 nm

Photon Energy Computation

Given the wavelength $\lambda = 400\, \text{nm} = 4.00 \times 10^{-7}$ meters, the photon energy is:

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

Plugging in the constants:

$$
E = \frac{(6.626 \times 10^{-34}\, \text{Js})(3.00 \times 10^{8}\, \text{m/s})}{4.00 \times 10^{-7}\, \text{m}}
$$

$$
E \approx \frac{1.9878 \times 10^{-25}}{4.00 \times 10^{-7}} \approx 4.97 \times 10^{-19}\, \text{J}
$$

Converting joules to electron volts (1 eV = 1.602×10^{-19} J):

$$
E \approx \frac{4.97 \times 10^{-19}}{1.602 \times 10^{-19}} \approx 3.10\, \text{eV}
$$

Thus, each photon at 400 nm carries approximately 3.10 eV of energy.

Maximum Kinetic Energy of Ejected Electrons

The Photoelectric Equation

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

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

where:
- E is the photon energy,
- ϕ is the work function of the metal.

The work function varies among metals:
- For example, cesium (~2.14 eV),
- Sodium (~2.28 eV),
- Copper (~4.7 eV),
- Gold (~5.1 eV).

The actual maximum kinetic energy depends critically on the metal's work function.

Implications for Different Metals

- Metals with work functions less than 3.10 eV:
- Photoemission occurs, with electrons ejected possessing a maximum kinetic energy of $K_{\text{max}} = 3.10\, \text{eV} - \phi$.
- For cesium ($\phi \approx 2.14\, \text{eV}$), electrons can have a maximum kinetic energy of:

$$
3.10\, \text{eV} - 2.14\, \text{eV} = 0.96\, \text{eV}
$$

- Metals with higher work functions:
- No electrons are ejected because the photon energy is insufficient to overcome the work function.

Hence, for a metal surface with a work function less than 3.10 eV, ultraviolet light at 400 nm can cause photoemission, and the maximum kinetic energy of the emitted electrons can be directly calculated.

Interpreting the Results: Practical and Theoretical Insights

Understanding Electron Kinetic Energy in Practice

Knowing the maximum kinetic energy helps in designing devices like photodetectors and in understanding surface properties. For example:
- Photoemission efficiency: Metals with lower work functions are more responsive to UV light at 400 nm.
- Surface characterization: Measuring kinetic energies allows estimation of the work function, offering insights into surface cleanliness, contamination, or structural changes.

Limitations and Real-World Considerations

While theoretical calculations provide a clear picture, several factors influence real-world measurements:
1. Surface contamination: Adsorbed molecules can alter the effective work function.
2. Surface roughness: Impacts the uniformity of electron emission.
3. Temperature effects: Elevated temperatures can modify electron energies.
4. Photon flux: The intensity influences the rate but not the maximum energy.
5. Quantum efficiency: The probability of photoelectron emission varies among metals.

Practical Applications and Significance

Device Design and Material Selection

Selecting the right metal for UV photoelectric applications hinges on understanding these energy interactions:
- Photodetectors: Metals with low work functions are preferred for UV sensitivity.
- Photoelectron spectroscopy: Used to analyze surface composition by measuring kinetic energies.
- Solar cells and photocatalysis: Knowledge of energy interactions informs material choices and surface modifications.

Surface Analysis and Material Science

By analyzing the maximum kinetic energy of emitted electrons under UV illumination:
- Scientists can determine the work function of unknown metals.
- Surface modifications can be monitored over time.

- The effects of environmental factors on surface properties can be quantified.

Conclusion: The Significance of 400 nm UV Light in Metal Photoelectric Interactions

The interaction of ultraviolet light at a wavelength of 400 nm with a metal surface is a classic yet profoundly insightful phenomenon in physics. The photon energy (~3.10 eV) is sufficient to eject electrons from metals with work functions below this threshold, leading to measurable maximum kinetic energies that directly relate to the surface properties of the material.

Key Takeaways:
- The photon energy at 400 nm is approximately 3.10 eV.
- Metals with work functions less than this value can emit electrons under 400 nm UV illumination.
- The maximum kinetic energy of emitted electrons is given by $K_{\text{max}} = 3.10\, \text{eV} - \phi$.
- This phenomenon underpins critical technologies in surface science, photodetection, and quantum physics.

Understanding these interactions not only enhances our grasp of fundamental physics but also guides the development of advanced materials and devices. As research continues, the principles illuminated by the photoelectric effect remain at the forefront of scientific innovation, enabling precise control and manipulation of electron behavior at surfaces.

When Ultraviolet Light With A Wavelength Of 400 Nm Falls On A Certain Metal Surface The Maximum Kinetic

When Ultraviolet Light With A Wavelength Of 400 Nm Falls On A Certain Metal Surface The Maximum Kinetic

Related Articles

- The Input Impedance Of The CE Is Much Lower Than That Of A CB While Operating Under The Same Conditions.
- 2. A. Determine The Cartesian Equation Of The Plane With Intercepts At P(-1,0,0), (0,1,0), And R(0,0,-3).
- The Shaded Numbers Show A Pattern In The Multiplication Table. Which Expression Can Find The Number That

Back to Home