In A Photoelectric Experiment Using A Sodium Surface, You Find A Stopping Potential Of 1.61 V For A Wavelength

In A Photoelectric Experiment Using A Sodium Surface, You Find A Stopping Potential Of 1.61 V For A Wavelength of the incident light, an intriguing insight into the quantum nature of light and matter is revealed. This experiment provides valuable information about the photoelectric effect, the work function of sodium, and the fundamental constants that govern the interaction between photons and electrons. In this article, we will explore the principles behind the photoelectric effect, analyze the significance of the stopping potential, determine the wavelength of incident light, and understand how these findings contribute to our comprehension of atomic physics.

Understanding the Photoelectric Effect

What is the Photoelectric Effect?

The photoelectric effect is a phenomenon where electrons are ejected from a material—usually a metal surface—when it is exposed to electromagnetic radiation of sufficient energy. This effect was first observed by Heinrich Hertz and later explained by Albert Einstein, whose work earned him the Nobel Prize in Physics in 1921.

In simple terms:
- When photons (light particles) strike a metal surface, they transfer their energy to electrons.
- If this energy exceeds the work function (ϕ) of the metal, electrons are emitted.
- The kinetic energy (KE) of the emitted electrons depends on the photon energy minus the work function.

This effect provided crucial evidence for the quantization of energy and supported the development of quantum mechanics.

Key Concepts in the Photoelectric Effect

- Photon Energy: $E = hf = \frac{hc}{\lambda}$, where:
- h is Planck’s constant ($6.626 \times 10^{-34} \, \text{Js}$),
- f is the frequency,
- c is the speed of light ($3.00 \times 10^{8} \, \text{m/s}$),
- λ is the wavelength of incident light.
- Work Function (ϕ): The minimum energy required to eject an electron from the metal surface.
- Kinetic Energy of Ejected Electrons: $KE_{max} = hf - \phi$.

Role of Stopping Potential in the Photoelectric Experiment

Definition of Stopping Potential

The stopping potential (V_s) is the minimum reverse voltage applied between the electrodes to stop the most energetic photoelectrons from reaching the anode. It essentially measures the maximum kinetic energy of the emitted electrons.

Mathematically:

$$
KE_{max} = e V_s
$$

where:
- e is the elementary charge ($1.602 \times 10^{-19} \, \text{C}$),
- V_s is the stopping potential in volts.

In the given experiment, the stopping potential is 1.61 V, indicating the maximum kinetic energy of the photoelectrons.

Significance of the Stopping Potential

The stopping potential provides a direct measure of the maximum kinetic energy of the photoelectrons and allows us to determine the work function of the sodium surface and the properties of incident light. Importantly:
- It confirms the particle nature of light.
- It helps verify the linear relationship between photon energy and kinetic energy of electrons.
- It enables calculations of wavelength and frequency of incident light.

Calculating the Wavelength of Incident Light

Given:
- Stopping potential, $V_s = 1.61 \, \text{V}$,
- Planck's constant, $h = 6.626 \times 10^{-34} \, \text{Js}$,
- Elementary charge, $e = 1.602 \times 10^{-19} \, \text{C}$.

We know:

$$
KE_{max} = e V_s
$$

And from the photoelectric equation:

$$
hf = \phi + KE_{max}
$$

Rearranged:

$$
hf = \phi + e V_s

\]

To find the wavelength \(\lambda\), we use:
\[
hf = \frac{hc}{\lambda}
\]

Thus:
\[
\lambda = \frac{hc}{hf} = \frac{hc}{\phi + e V_s}
\]

However, to compute \(\lambda\), we need the work function \(\phi\). Since the problem provides a stopping potential but not the work function directly, we'll assume the work function for sodium is known:
- Work function of sodium (\(\phi\)): approximately 2.28 eV.

Note: 1 eV = \(1.602 \times 10^{-19}\) Joules.

Step-by-step calculation:

1. Convert \(\phi\) to Joules:
\[
\phi = 2.28 \, \text{eV} = 2.28 \times 1.602 \times 10^{-19} \approx 3.65 \times 10^{-19} \, \text{J}
\]

2. Convert \(e V_s\) to Joules:
\[
e V_s = 1.61 \times 1.602 \times 10^{-19} \approx 2.58 \times 10^{-19} \, \text{J}
\]

3. Calculate the total photon energy:
\[
hf = \phi + e V_s = 3.65 \times 10^{-19} + 2.58 \times 10^{-19} = 6.23 \times 10^{-19} \, \text{J}
\]

4. Find wavelength:
\[
\lambda = \frac{hc}{hf} = \frac{(6.626 \times 10^{-34})(3.00 \times 10^{8})}{6.23 \times 10^{-19}} \approx \frac{1.9878 \times 10^{-25}}{6.23 \times 10^{-19}} \approx 3.19 \times 10^{-7} \, \text{m}
\]

Final answer:
\[
\boxed{
\lambda \approx 319 \, \text{nm}
}
\]

This wavelength falls within the ultraviolet range, indicating that the incident light used in the experiment is ultraviolet radiation.

Implications of the Results

Understanding the Energy of Incident Light

The calculated wavelength of approximately 319 nm aligns with ultraviolet light, which has energies sufficient to overcome the work function of sodium and eject electrons. This confirms the experimental setup employed ultraviolet radiation.

Verifying Einstein's Photoelectric Equation

The linear relation between photon energy (hf) and the maximum kinetic energy of photoelectrons supports Einstein's theory:

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

The experiment's findings affirm the quantum hypothesis that light consists of discrete photons carrying quantized energy.

Determining the Work Function of Sodium

Using the known incident wavelength (or equivalently, photon energy), the work function of sodium can be validated or refined. The approximate value of 2.28 eV matches well with standard literature, confirming the validity of the experimental results.

Broader Significance and Applications

Technological Applications

Understanding the photoelectric effect with sodium surfaces has practical applications:

- Photodetectors and Solar Cells: Materials with specific work functions are selected for efficient photon-electron conversion.
- Photoelectron Spectroscopy: Used to analyze surface compositions and electronic properties of materials.
- Quantum Physics Experiments: The photoelectric effect remains fundamental in demonstrating quantum theory principles.

Fundamental Physics and Quantum Mechanics

Experiments like this provide empirical evidence for:

- The quantization of energy,
- The particle nature of light,
- The relation between energy, frequency, and wavelength.

These insights have paved the way for modern quantum physics, nanotechnology, and photonics.

Conclusion

The photoelectric experiment involving a sodium surface with a stopping potential of 1.61 V illustrates a core principle of quantum mechanics: the energy of incident photons determines whether electrons are emitted and with what kinetic energy. The calculated wavelength of approximately 319 nm confirms the ultraviolet nature of the incident light and validates Einstein’s photoelectric equation. Such experiments deepen our understanding of the interaction between light and matter, revealing the discrete, quantized nature of energy transfer at the atomic level. The insights gained from these studies continue to influence modern technological advancements and fundamental physics research, embodying the profound link between experimental observations and theoretical physics.

Frequently Asked Questions

What is the significance of measuring a stopping potential in a photoelectric experiment involving sodium surface?

Measuring the stopping potential helps determine the maximum kinetic energy of emitted photoelectrons, which is essential for calculating the work function of sodium and understanding the photoelectric effect.

How is the work function of sodium calculated from the stopping potential and incident wavelength?

The work function (ψ) is calculated using the photoelectric equation: $\psi = hf - eV_s$, where h is Planck's constant, f is the frequency of incident light, e is the charge of an electron, and V_s is the stopping potential. Alternatively, $\psi = hc/\lambda - eV_s$.

Given a wavelength, say 500 nm, and a stopping potential of 1.61 V, how do you find the work function of sodium?

Convert wavelength to meters ($500 \text{ nm} = 5 \times 10^{-7} \text{ m}$), calculate photon energy ($E = hc/\lambda$), then subtract the electron energy due to stopping potential: $\psi = (hc/\lambda) - eV_s$.

What does a stopping potential of 1.61 V indicate about the energy of incident photons in the sodium photoelectric experiment?

It indicates that the maximum kinetic energy of the emitted electrons is 1.61 eV, which helps determine the photon energy relative to sodium's work function.

How does changing the wavelength of incident light

affect the stopping potential in the photoelectric experiment?

Increasing the wavelength (lower photon energy) decreases the maximum kinetic energy of emitted electrons, resulting in a lower stopping potential; decreasing wavelength (higher energy) increases the stopping potential.

What is the role of the photoelectric equation in analyzing the experimental data involving sodium and wavelength?

The photoelectric equation relates photon energy, work function, and kinetic energy of electrons, allowing calculation of unknowns like work function or verifying the linearity of the photoelectric effect.

Why is sodium commonly used in photoelectric experiments involving specific wavelengths?

Sodium has a well-known work function and produces strong, characteristic photoelectric responses, making it ideal for studying the effect with visible light wavelengths.

How do experimental errors affect the measurement of stopping potential in such experiments?

Errors in voltage measurement, surface contamination, or light intensity can lead to inaccurate stopping potentials, affecting the calculation of work function and interpretation of results.

Can the photoelectric effect be explained using classical physics, and how does the stopping potential support or refute this?

Classical physics cannot explain the photoelectric effect; the dependence of stopping potential on frequency and the existence of a threshold wavelength support the quantum theory, where light behaves as quanta of energy.

What additional information is needed to fully determine the work function of sodium from the experiment with a given wavelength and stopping potential?

The exact wavelength of incident light is needed to calculate photon energy, along with precise measurements of the stopping potential, to compute the sodium's work function accurately.

Additional Resources

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Introduction

The photoelectric effect, a cornerstone in the development of quantum physics, continues to serve as a fundamental investigative tool for understanding light-matter interactions. Among various experimental setups, the use of sodium surfaces has historically played a pivotal role in elucidating the particle-like nature of light and the quantization of energy.

In a typical photoelectric experiment involving a sodium surface, the measurement of the stopping potential as a function of incident light wavelength provides critical insights into the underlying quantum mechanisms. The observation of a stopping potential of 1.61 V for a specific wavelength prompts a comprehensive analysis, encompassing theoretical foundations, experimental design, and implications for modern physics.

This article aims to thoroughly examine the significance of such findings, exploring the nuances of the photoelectric effect, the role of sodium surfaces, and the broader implications for quantum theory. Through detailed exploration, we seek to contextualize the experimental results within the framework of Einstein's photoelectric equation and contemporary research.

Historical Context and Significance of the Photoelectric Effect

The photoelectric effect was first observed in the late 19th century, but it was Albert Einstein's 1905 paper that provided a quantum explanation, earning him the Nobel Prize in Physics in 1921. Einstein proposed that light consists of discrete quanta, or photons, each carrying energy proportional to its frequency:

$$ E = h\nu $$

where h is Planck's constant and ν is the frequency of light.

This discovery challenged classical wave theories and laid the groundwork for quantum mechanics. The core principle is that when photons strike a metal surface, they transfer their energy to electrons. If the photon energy exceeds the work function ϕ of the metal, electrons are emitted with a maximum kinetic energy K_{max}:

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

The stopping potential V_s is related to the maximum kinetic energy of emitted electrons:

$$ eV_s = K_{max} $$

where e is the elementary charge. Measuring V_s at different wavelengths enables the determination of fundamental constants and properties of the metal surface.

The Sodium Surface: An Ideal Candidate for Photoelectric Studies

Sodium (Na), an alkali metal, is historically significant in photoelectric experiments due to its well-characterized electronic structure and relatively low work function, typically around 2.3 eV. This low work function makes sodium surfaces particularly sensitive to visible and ultraviolet light, facilitating experimental observations.

Key properties of sodium relevant to the experiment:

- Work Function (ϕ): approximately 2.3 eV
- Electron Affinity: conducive to electron emission at moderate wavelengths
- Surface Preparation: sodium surfaces need to be carefully prepared and maintained in ultra-high vacuum conditions to prevent oxidation and contamination, which can alter work function values and experimental outcomes.

The use of sodium surfaces allows researchers to explore the photoelectric effect at wavelengths where classical wave theory predicts no electron emission, thus providing evidence for the quantum nature of light.

Experimental Setup and Methodology

The typical photoelectric experiment involves several key components:

1. Light Source: a monochromatic wavelength selector, such as a mercury vapor lamp, sodium vapor lamp, or tunable laser, to vary incident wavelength λ.
2. Metal Surface: a clean, well-prepared sodium surface placed in an ultra-high vacuum chamber to prevent oxidation.
3. Photocell and Electrometers: to detect emitted electrons and measure photocurrent.
4. Voltage Supply: capable of applying a variable stopping potential V_s to the sodium surface.

Procedure:

- Illuminate the sodium surface with light of known wavelength.
- Gradually vary the stopping potential until the photocurrent drops to zero; the magnitude of this potential at cutoff is V_s.
- Repeat for different wavelengths to obtain a relationship between V_s and λ.

The critical measurement is the stopping potential corresponding to the maximum kinetic energy of photoelectrons, which directly relates to the photon energy and the metal's work function.

Analyzing the Observation: Stopping Potential of 1.61 V

Suppose the experimental data reveals a stopping potential $V_s = 1.61$ V at a certain wavelength λ. This measurement signifies that electrons emitted from the sodium surface acquire a maximum kinetic energy:

$$
K_{max} = eV_s = (1.61\, \text{V}) \times e
$$

Given that e (elementary charge) is approximately $1.602 \times$

10^{-19} C, the maximum kinetic energy in electronvolts is directly 1.61 eV.

Implications:

- The photon energy E_{ph} must be at least this value plus the work function ϕ:

$$
E_{ph} = h\nu = K_{max} + \phi
$$

- The wavelength λ associated with this photon energy can be calculated via:

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

where h is Planck’s constant (6.626×10^{-34} Js) and c is the speed of light (3.0×10^{8} m/s).

Calculating the Corresponding Wavelength

Let’s perform the calculation assuming the work function of sodium:

$$
\phi \approx 2.3\, \text{eV}
$$

The photon energy:

$$
E_{ph} = K_{max} + \phi = 1.61\, \text{eV} + 2.3\, \text{eV} = 3.91\, \text{eV}
$$

Converting electronvolts to joules:

$$
E_{ph} = 3.91\, \text{eV} \times 1.602 \times 10^{-19}\, \text{J/eV} \approx 6.27 \times 10^{-19}\, \text{J}
$$

Calculating λ:

$$
\lambda = \frac{hc}{E_{ph}} = \frac{6.626 \times 10^{-34} \times 3.0 \times 10^{8}}{6.27 \times 10^{-19}} \approx 3.17 \times 10^{-7}\, \text{m} = 317\, \text{nm}
$$

This wavelength falls within the ultraviolet (UV) spectrum, consistent with sodium’s photoelectric threshold.

Theoretical Significance and Validation of Einstein's Equation

This experimental result aligns with Einstein's photoelectric equation:

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

or equivalently,

$$
eV_s = \frac{hc}{\lambda} - \phi
$$

Plotting V_s versus $1/\lambda$ should yield a straight line with a slope of $\frac{h c}{e}$, enabling the experimental determination of Planck's constant.

The measured stopping potential of 1.61 V at a particular wavelength validates the quantum nature of light, confirming that energy is quantized in discrete packets and that the photoelectric effect cannot be explained by classical wave theory, which predicts no threshold frequency.

Broader Implications and Modern Perspectives

The precise measurement of stopping potentials and their dependence on wavelength has historically been instrumental in:

- Confirming the quantization of electromagnetic radiation.
- Determining fundamental constants such as Planck's constant.
- Understanding surface properties of metals and their electronic structures.

In modern research, similar principles are employed in:

- Developing photoelectric sensors and photovoltaic devices.
- Exploring surface electron dynamics at nanoscale interfaces.
- Investigating the effects of surface contamination, temperature, and external fields on work functions.

The experiment's findings also serve as a foundational reference for advanced quantum technologies, including quantum computing and nanophotonics.

Challenges and Considerations in the Experimental Setup

While the theoretical framework is straightforward, practical challenges can influence the accuracy of measurements:

- Surface Contamination: Oxidation or impurities can alter the work function, leading to discrepancies.
- Vacuum Quality: Maintaining ultra-high vacuum minimizes contamination.
- Light Intensity and Monochromaticity: Ensuring monochromatic, stable light sources is crucial for precise measurements.
- Contact Potentials and Surface States: These can introduce additional energy barriers or shifts.
- Measurement Precision: Accurate voltage calibration and current detection

are vital.

Addressing these challenges requires rigorous experimental protocols and calibration.

Conclusion

The observation of a stopping potential of 1.61 V in a photoelectric experiment involving a sodium surface, at a specific wavelength, exemplifies the quantum nature of light and the fundamental principles governing electron emission. Through meticulous analysis, this measurement not only confirms Einstein’s photoelectric equation but also provides a pathway to determine fundamental constants like Planck’s constant.

The experiment underscores the importance of surface preparation, precise measurement, and theoretical interpretation in advancing our understanding of quantum phenomena. As technology progresses, these foundational experiments continue to inform cutting-edge research in surface physics, quantum optics, and nanotechnology.

By thoroughly examining the implications of such measurements, physicists can deepen

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