Bincang Sains dan Teknologi (BST)
DOI: 10.56741/bst.v3i03.702
E-ISSN 2961-8746
P-ISSN 2961-8932

Understanding the Concept of Photo Electricity: Applications and Implications in Quantum Physics

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Abstract

This research investigates the photoelectric effect using PhET Simulation to verify and test hypotheses related to this phenomenon. The study focuses on the interaction between ultraviolet (UV) light and sodium electrodes, analyzing the relationship between light wavelength and the resulting electron energy. Through experiments, critical constants in physics, such as Planck's constant, are calculated to validate the theories of the photoelectric effect. The findings demonstrate a non-linear relationship between UV light wavelength and current strength, with optimal photon energy required to induce maximum electron ejection at specific wavelengths. This research highlights the significance of simulation tools in understanding quantum physics concepts and aims to enhance teaching methods for more effective and engaging physics education.

Keywords: *PhET Simulation, Photoelectric Effect, Planck's Constant, Sodium Electrodes, UV Light*

Introduction

Science is a systematic and organized knowledge obtained through scientific methods involving observation, experimentation, and data analysis to understand natural phenomena and life [1]. This knowledge continues to evolve to provide a more accurate and in-depth explanation of the world around us [2]. The branches of science are divided into several main categories: natural sciences, social sciences, and formal sciences [3]. Natural sciences include physics, chemistry, biology, and astronomy, all seeking to understand the natural laws that govern the universe [4]. Social sciences include sociology, psychology, and anthropology, which study human behavior and social structures [5]. Meanwhile, the formal sciences, such as mathematics and logic, provide the tools and frameworks for analysis and deduction used in the other sciences [6].

As one of the main branches of natural science, physics focuses on studying the nature and behavior of matter and energy [7]. Its main goal is understanding the fundamental laws governing the interaction between matter and energy, from the smallest subatomic particles to the most significant cosmic structures [8]. Physics has been the basis of many technological inventions we enjoy today and has provided deep insights into the universe's workings [9]. From Newton's laws of motion that govern macroscopic objects [10] to Einstein's theory of relativity [11] that transformed our understanding of space and time, physics has continued to adapt and evolve as science advances.

Physical scientists are individuals dedicated to studying and understanding natural phenomena through experimentation and theory [12]. Some of the most influential discoveries and theories in the history of physics come from the work of scientists such as Isaac Newton, who is known for his laws of gravity and laws of motion [13], and Albert Einstein, who is famous for his theory of relativity [14]. In addition, in the early 20th century, physics underwent a major revolution with the emergence of quantum physics [15]. Scientists such as Max Planck, who introduced the concept of energy quanta [16], and Niels Bohr, who developed the atomic model, played critical roles in forming quantum physics [17]. Werner Heisenberg contributed significantly with his uncertainty principle [18] and Erwin Schrödinger's wave equation [19].

Quantum physics is a branch of physics that studies phenomena on atomic and subatomic scales [20]. It is a very different field from classical mechanics, which describes the macroscopic world. The term "quantum" refers to quanta, the most minor units of energy that can be measured or transferred [21]. Quantum physics began in the early 20th century when Max Planck introduced the concept of energy quanta to explain the spectrum of blackbody radiation [22]. Einstein's explanation of the photoelectric effect in 1921 showed that light consists of photons that can eject electrons from metal surfaces [23].

The photoelectric effect is when electrons escape from a metal surface when exposed to light of a specific frequency [24]. This was first observed by Heinrich Hertz in 1887, but the theoretical explanation was only given by Albert Einstein. According to Einstein's theory, light consists of tiny particles called photons, which carry energy in specific quanta [25]. When photons with large enough energy hit a metal surface, they can transfer their energy to electrons in the metal. If the photon's energy is sufficient to overcome the work function of the metal, the electron will be detached from the surface [26]. The work function is the minimum energy required to release electrons from the metal surface [27]. The relationship between photon energy (E) and light frequency (f) is given by the equation $E=hf$, where h is Planck's constant. This relationship describes how photons can eject electrons if their energy is large enough to overcome the work function of the metal. The maximum kinetic energy of the detached electrons can be calculated by the equation $hf = \phi + K$, where ϕ is the work function of the metal. K is the maximum kinetic energy of the electrons.

The photoelectric effect has many vital applications in quantum physics and modern technology [28]. One of its main applications is manufacturing solar cells, which convert light energy into electricity using the photoelectric effect [29]. In addition, this effect is also used in light detection devices such as photodiodes and photo-multiplier tubes [30]. PhET Simulation is used to observe the virtual photoelectric effect.

In the world of technology, PhET Simulation has become a handy tool for teaching physics concepts such as the photoelectric effect. PhET simulations make it possible to visualize and manipulate the parameters of photoelectricity experiments, such as light intensity and frequency, to see how they affect the number and energy of electrons released [31]. Photoelectric effect experiments using PhET simulations make it possible to set various parameters and record the resulting data to analyze the relationship between light frequency, intensity, and electron energy.

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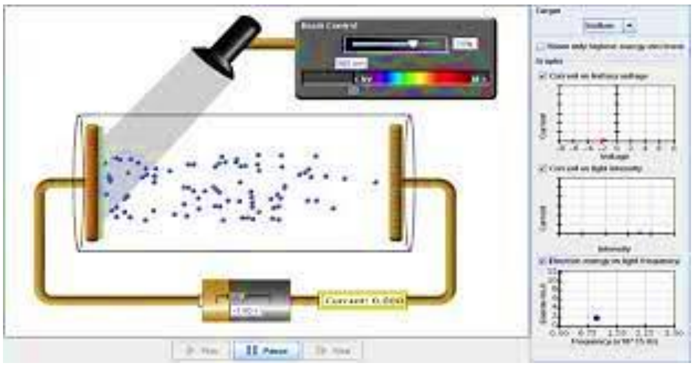

Fig 1. Simulation of photoelectric effect with PhET software

This research aims to prove and test the hypotheses of previous scientists related to the photoelectric effect through PhET Simulation-based experiments. By conducting this experiment, we can verify the theories proposed by scientists such as Albert Einstein and understand how quantum physics concepts apply in the real world. This research also aims to explore new ways of teaching quantum physics that can make learning more effective and exciting for students.

The main benefit of this research is to help students understand the concept of photo electricity and its implications in quantum physics. By using PhET Simulation, students can learn in a more interactive and immersive way, which can improve their understanding of the subject matter. In addition, this research can also contribute to more effective and exciting quantum physics teaching methods for students, helping them develop critical scientific skills and increasing their interest in science.

Literature Review

A. Relevant Research

Ref. [28] developed a simple LED-based tool to demonstrate the photoelectric effect, aiming at laboratory education to teach quantum physics through an economical and easy-to-use device. They showed that LEDs can function as light emitters and receivers, offering an effective and safe way to visualize the photoelectric effect. Meanwhile, Ref. [27] used photoemission spectroscopy with subfemtosecond light pulses to investigate electron emission processes from metals and semiconductors. Their study introduced the atomic chronoscope method to determine the absolute time of the photoemission process, finding that the emission from the conduction band of tungsten is faster than previously thought. In contrast, the core electron emission duration agrees with the semiclassical model [28]. These two studies show that innovative and high-tech experimental methods can achieve a deep understanding of the photoelectric effect and its applications in quantum physics.

Another research was also conducted by [29], in their study entitled "DIY Innovation in Quantum Physics: Proving the Dualism of Light with Photoelectric Effect and Double Slit Experiments," which proved the dualism of the nature of light through photoelectric effect experiments and double slits using simple tools, showing that light can be both a particle and a wave. Another study titled "Photoelectric Effect on Metal Work Function Using Test Simulation" by [30] used PhET simulation to test the photoelectric effect on metal work function, compared the simulation results with theoretical

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calculations and found a slight difference between simulation results and theory. Both studies show that the photoelectric effect can be observed and analyzed through direct experiments and computer simulations, highlighting the importance of innovative experimental methods in facilitating the understanding of complex physics concepts. This research also focuses on using PhET Simulation to understand the photoelectric effect, which aligns with previous research emphasizing simulation's importance in studying quantum physics phenomena. However, this research further tests the hypotheses of earlier scientists and explores the application of quantum physics concepts.

B. Theory Basics

The process by which light of a high enough frequency strikes a metal surface and causes electrons to be released from it is known as the photoelectric effect. The types of instruments used in photoelectric experiments are depicted in Fig. 2.

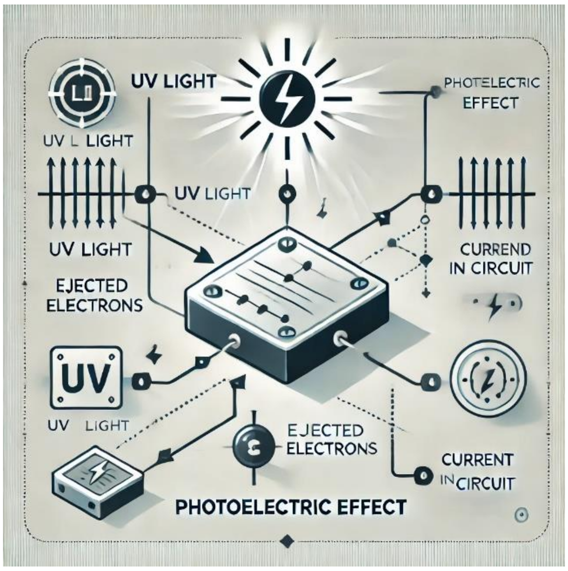

Fig 2. Experimental circuit of the photoelectric effect

In research on the photoelectric effect, two electrodes in a vacuum tube are connected to an external circuit with the anode as the irradiated metal piece. Energetic electrons from the irradiated surface can go to the cathode, but the current drops as the blocking potential (Vb) increases because fewer electrons reach the cathode. The current stops when Vb reaches a specific value (V_0) as no electrons reach the cathode. Research shows that metals exposed to light release electrons and generate electric current when connected to a closed circuit. Experiments found that increasing light intensity does not necessarily increase the current. However, a higher frequency of light can release electrons from the metal despite the low intensity. This shows that light energy depends on frequency, not intensity, and light is quantified in photons. To release an electron, the photon must have enough power to surpass the bond energy of the electron. This phenomenon challenges the assumption that light is a continuous wave. It supports the quantum theory that light energy is quantized in the form of photons, which is relevant in applications of photonic devices such as LEDs and light detectors.

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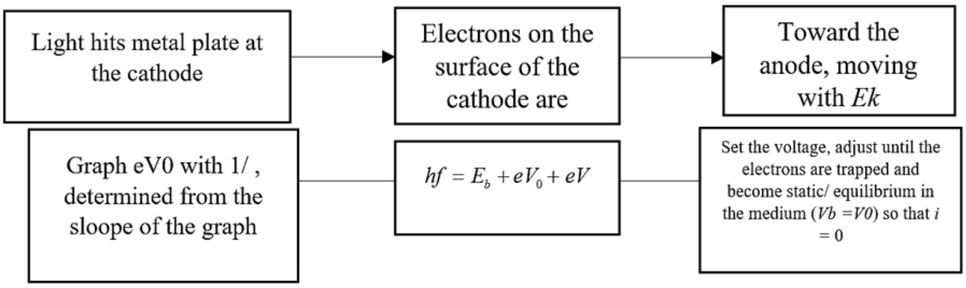

Fig 3. Schematic of the process of the photoelectric effect

Electrons will be liberated from the metal surface with kinetic energy equal to if the photon energy of the light beam striking the cathode metal surface is hf and the threshold energy of the cathode material is *hf₀*.

$$E_k : hf - hf_0 \quad (1)$$

Where;
E_k: kinetic energy of the released electron
hf: photon energy of light beam from outside
f_0: threshold energy of metal material (cathode)

Another way to express equation (1) is (as a work function). Thus, the residual energy can be used to free the electrons from the metal surface, thus using it as the kinetic energy of the electrons. From the explanation given by Einstein;

- If $hf = hf_0 f < f_0$ so, the electrons will not escape from the surface ion bonds of the metal material. So $f > f_0$, for the photoelectric effect to occur, then or must be $\lambda < \lambda_0$.
- The potential difference between the cathode and anode (V_b) is proportional to the kinetic energy of the electrons released. So $eV_b = E_k$.
- Since one photon can only be absorbed by one electron, increasing the irradiation intensity for light with frequency f only increases the number of photons, each having energy *hf*. Consequently, increasing the number of photons does not affect the magnitude and only increases the number of electrons E_k released from the metal storage surface.

Equation (1) becomes true if we know the threshold wavelength of the metal and the external light beam:

$$E_k = \frac{hc}{\lambda} - \frac{hc}{\lambda_0} \quad (2)$$

Planck's constant can be found using the slope of an experimentally determined line, h/e, in Milikan's experimental findings of the photoelectric effect on sodium [32]. The peak frequency is found at the intersection of this curve with the flat axis. However, at the time of Milikan's experiment, the exact electrode contact potential was unknown, so a few tenths of a volt shifted the vertical scale. This adjustment did not affect the slope of the curve. Planck stated that light consists of energy sources known as photons, each of which has a certain amount of energy:

$$E_p = hf \quad (3)$$

Where *f* is the frequency of light and h is Planck's constant. Where according to Einstein, each photon interacts with one electron so that it becomes:

$$E_p = E_b + E_k \quad (4)$$

where the maximal kinetic energy E_k of photo-electrons goes to the anode, and the energy of metal electrons E_b is found. This equation shows that the kinetic energy of electrons depends on the frequency of light, not on its intensity. Suppose the reverse voltage V_b is increased to a value $V_0(V_b = V_0)$, and it turns out that the ammeter shows zero (I = 0). In that case, this means that the magnitude of the electron reverse voltage is equal to that of kinetic energy that carries the electrons toward the anode. If the reverse voltage is applied, not all electrons can reach the anode because the current strength shown by the ammeter decreases.

$$eV_0 = E_k \tag{5}$$

Because kinetic energy is intensity-independent, meaning it solely depends on frequency or wavelength, equation (4) becomes:

$$h\frac{c}{\lambda}E_b + eV_0 \tag{6}$$

Material and Methods

The PhET software's light function selection panel selects a light with a specific intensity and wavelength. The return voltage V_0 data is then adjusted to match the kinetic energy rate of electrons traveling toward the anode. Furthermore, as Figure 3 illustrates, the linear regression approach is used to assess the mathematical data of electronvolt (eV_0) with a wavelength of light. Equation (6) becomes the following when it is transformed into a straight-line equation:

$$eV_0 = hc\frac{1}{\lambda} - E_b \tag{7}$$

The gradient (slope) of the graph between eV_0 with 1/λ is then used to calculate the Planck constant h magnitude. Equation (7) can be derived from $\hat{y} = ax + b$ where $y = \frac{eV_0}{1/\lambda}$ and $a = hc$. Where equation:

$$h = \frac{a}{c} \tag{8}$$

error size,

$$s_h = \frac{s_c}{c} \tag{9}$$

where a is the slope of the graph formulated by

$$a = \frac{N\sum(x_i y_i) - \sum x_i \sum y_i}{N\sum x_i^2 - (\sum x_i)^2} \tag{10}$$

and the intersection point of the graph is:

$$b = \frac{\sum x_i^2 \sum y_i - \sum x_i \sum(x_i y_i)}{N\sum x_i^2 - (\sum x_i)^2} \tag{11}$$

An approximated straight-line equation is then created using the acquired values for a and b: $\hat{y} = ax_i + b$ The error that arises when estimating is the standard error of the estimate.

$$s_{\hat{y}} = \sqrt{\frac{\sum\left(y_i - \hat{y}\right)^2}{N-2}} \tag{12}$$

The standard errors of the coefficients a and b are

$$S_a = s_{\hat{y}}\sqrt{\frac{N}{N\sum x_i^2 - (\Sigma x_i)^2}} \tag{13}$$

$$s_b = s_{\hat{y}} \sqrt{\frac{\sum x_i^2}{N\sum x_i^2 - (\sum x_i)^2}} \quad (14)$$

Equation (8) can be used to compute the Planck constant based on the slope of the curve between eV_0 and $1/\lambda$ then, and equation (9), which uses the principle of error propagation to calculate the error, can be used to calculate the error. Additionally, the weighted average technique determines each light's average Planck constant value.

Results and Discussions

To understand the phenomenon of the photoelectric effect, experiments were conducted using ultraviolet (UV) light on sodium electrodes through PhET Simulation. This experiment aims to measure the relationship between the wavelength of light used and the photon energy produced and test the validity of the laws of physics governing the photoelectric effect. Measurements were made by varying the wavelength of light and recording the stopping voltage produced by the absorbed photons. The data obtained from this experiment was then analyzed to calculate fundamental constants in physics, such as Planck's constant, and to understand the fundamental properties of the photoelectric effect. In the following table, the observational data from the experiment is presented.

Table 1 presents the experimental analysis of the photoelectric effect with UV light on sodium electrodes. The data show the relationship between the wavelength of light and the resulting stopping voltage, and the inverse of wavelength and photon energy is calculated. The calculation results include the product values between the variables, the square of the wavelength inverse, the estimated photon energy, and the squared difference between the observed and calculated values. This analysis enables the calculation of Planck's constant through linear regression, helping to validate the theory of the photoelectric effect and measure the accuracy of the experiment.

Table 1. Data analysis for UV (Ultra Violet) light, Electrode: Sodium, and Intensity: 100%

No	Trial Data		x	y	x y	x^2	y est	(y-y est)^2
	λ(nm)	Vo(volt)	1/λ(M^-1)	eV_0(CV)	(CV/m)	(m^-2)	(CV)	(CV)
1	670	8	1.49254E-12	1.28E-18	1.91045E-30	2.22767E-24	1.10448E-18	3.08081E-38
2	640	7.6	1.5625E-12	1.22E-18	1.9E-30	2.44141E-24	1.0625E-18	2.35622E-38
3	610	7.2	1.63934E-12	1.15E-18	1.88852E-30	2.68745E-24	1.01639E-18	1.83891E-38
4	580	6.8	1.72414E-12	1.09E-18	1.87586E-30	2.97265E-24	9.65517E-19	1.5002E-38
5	550	6.4	1.81818E-12	1.02E-18	1.86182E-30	3.30579E-24	9.09091E-19	1.32041E-38
6	520	6	1.92308E-12	9.6E-19	1.84615E-30	3.69822E-24	8.46154E-19	1.29609E-38
7	490	5.6	2.04082E-12	8.96E-19	1.82857E-30	4.16493E-24	7.7551E-19	1.45178E-38
8	460	5.2	2.17391E-12	8.32E-19	1.8087E-30	4.7259E-24	6.95652E-19	1.85907E-38
9	430	4.8	2.32558E-12	7.68E-19	1.78605E-30	5.40833E-24	6.04651E-19	2.66828E-38
10	400	4.4	2.5E-12	7.04E-19	1.76E-30	6.25E-24	5E-19	4.1616E-38
Σ	**5350**	**62**	**1.92001E-11**	**9.92E-18**	**1.84661E-29**	**3.78823E-23**	**8.47995E-18**	**2.15334E-37**

Table 2 presents data on the relationship between the wavelength of light and the current strength produced in photoelectric effect experiments. The data shows that the current strength peaks at a specific wavelength before gradually decreasing to zero. This trend reflects that only specific

E-ISSN 2961-8746
P-ISSN 2961-8932

wavelengths have enough energy to eject electrons from the sodium electrode. This provides empirical evidence of the minimum wavelength limit required for the photoelectric effect to occur by the quantum theory of light.

Table 2. Wavelength and current strength

No	Wavelength (Nano Meter)	Current Strength (I)
1	100	0.441
2	130	0.574
3	160	0.706
4	190	0.838
5	220	0.675
6	250	0.487
7	280	0.35
8	310	0.247
9	340	0.17
10	370	0.113
11	400	0.071
12	430	0.04
13	460	0.02
14	490	0
15	520	0
16	550	0
17	580	0
18	610	0
19	640	0
20	670	0

Fig. 4 shows the relationship between current strength and wavelength of UV light. The graph shows that the current strength increases as the wavelength increases until it reaches a peak, after which the current strength begins to decrease gradually until it approaches zero. This indicates an optimal wavelength at which UV light energy is most effective in producing maximum current strength. In contrast, longer or shorter wavelengths than the optimal point produce lower or no current. This graph confirms the theory that only specific wavelengths have enough energy to trigger the photoelectric effect at the sodium electrode.

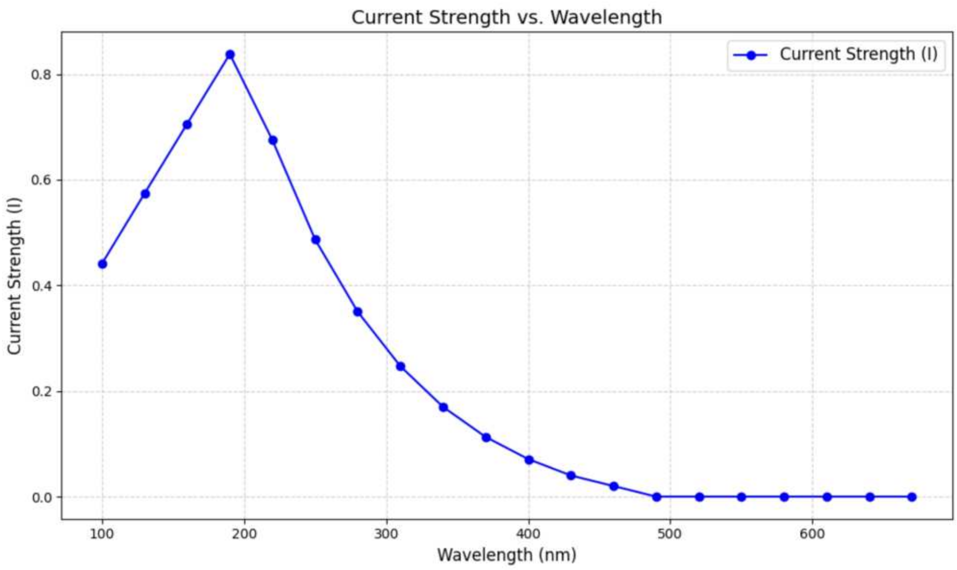

Fig. 4. The relationship between current strength and wavelength of UV light

Than,

$$c = 3.00E + 08 \text{ m/s}$$

$$a = -5.70106E - 07 \text{ CVm}$$

$$S_a = 1.62606E - 07 \text{ CVm}$$

$$b = 2.08661E - 18 \text{ CV}$$

$$S_b = 3.16487E - 19 \text{ CV}$$

Therefore,

$$\text{h} = -1.90035\text{E} - 15 \qquad J.s, (CVs)$$

$$s_{\text{h}} = 5.42021E - 16 \qquad J.s, (CVs)$$

This study explores the relationship between the wavelength of ultraviolet (UV) light and the current strength generated by sodium electrodes. The findings showed significant variations in the wavelength values and the resulting current strength, with the collected data showing a clear trend: the current strength increases at a specific wavelength and then decreases as the wavelength increases. The resulting graph shows that the current strength peaks at about 190 nm with a current strength of 0.838 A, then decreases gradually to near zero at a wavelength of about 490 nm and beyond.

The results of this study can be explained through the photoelectric theory proposed by Albert Einstein. This theory states that when light with a specific frequency hits a metal surface, the photons in the sunlight can energize the electrons on the metal surface so that the electrons can leave the metal surface. The amount of electric current generated depends on the energy of the photons absorbed, which is directly related to the wavelength of the light used. In the context of this research, sodium electrodes exhibit specific properties that allow the photoelectric effect to occur with measurable efficiency.

In particular, the results showed a non-linear relationship between the wavelength of UV light and the current generated by the sodium electrode. At a wavelength of 100 nm, the current strength generated is 0.441 A. This current strength continues to increase as the wavelength increases, reaching a peak at 190 nm with a value of 0.838 A. This phenomenon is consistent with the photoelectric effect theory, which states that only photons with a specific minimal energy can cause electron emission. The 190 nm wavelength is at which photons have sufficient power to eject electrons with maximum efficiency from the sodium electrode.

The decrease in current strength at wavelengths above 190 nm indicates that the photon energy becomes insufficient to eject electrons from the sodium electrode. For example, at a wavelength of 220 nm, the current strength drops to 0.675 A and continues to decrease until it reaches 0 A at a wavelength of 490 nm. This shows that the photon energy, determined by its wavelength, is essential in determining the number of excited electrons and the resulting current. In other words, only photons with sufficient energy or the right wavelength can cause a significant photoelectric effect at the sodium electrode.

These results reinforce the findings of previous studies that also explored the photoelectric effect using different types of metals and wavelengths of light. Some earlier studies have shown that alkali metals like sodium have good photoelectric potential at specific wavelengths. However, there are differences in the peak current strength generated at particular wavelengths compared to previous

DOI: 10.56741/bst.v3i03.702
P-ISSN 2961-8932

studies. For example, potassium metal studies showed current peaks at different wavelengths than sodium. This study showed current peaks at more specific wavelengths than studies using different metals or light intensities. This shows the importance of experimental conditions, including electrode type and light intensity, in determining the outcome of the photoelectric effect.

This finding is particularly relevant in the context of Planck's theory of quantum energy. According to this theory, only photons with sufficient energy can cause electron emission. The energy of a photon is determined by the frequency of light, which is inversely proportional to the wavelength. Therefore, shorter wavelengths, meaning higher photon energy, cause more significant electron emission than longer wavelengths. A graph showing the peak of electric current at a particular wavelength supports the concept that the energy of a photon is inversely proportional to its wavelength.

This research also shows sodium electrodes have unique characteristics in response to UV light wavelengths. These properties may differ from those of other metals, which can also exhibit photoelectric effects but with different optimal wavelengths. For example, potassium metal may show current peaks at varying wavelengths compared to sodium. This highlights the importance of electrode material selection in photoelectric experiments and how variations in the material can affect the final results. In addition, this study provides insight into the practical application of quantum theory in experimental systems. By understanding how variations in the wavelength of light affect the electric current generated, we can develop more effective technologies that utilize the photoelectric effect. For example, the design of light sensors and photovoltaic devices can be improved by using electrodes optimized for specific wavelengths of light, which can increase the efficiency and performance of such devices.

Many previous research series have studied the photoelectric effect on various metals and experimental conditions. Some studies show that metals such as potassium, rubidium, and cesium have different characteristics in response to UV light. Compared to sodium, these metals show electric current peaks at other wavelengths, reflecting differences in the photon energy required to cause electron emission. This comparison shows that although the basic principles of the photoelectric effect remain the same, variations in materials and experimental conditions can produce different results. This research adds to our understanding of how sodium electrodes behave under UV light and how the results can be compared to other metals that have been studied.

Conclusion

This study demonstrates the relationship between UV light wavelength and current strength in sodium electrodes, revealing that current strength increases with wavelength up to a peak at 190 nm, gradually decreasing to zero. These findings align with the photoelectric effect theory, which states that only photons with sufficient energy can eject electrons from a metal surface, with the photon energy being inversely proportional to the wavelength. The results underscore the importance of selecting appropriate materials and wavelengths for optimizing the photoelectric effect, which has practical implications for developing light sensors and photovoltaic devices.

E-ISSN 2961-8746
P-ISSN 2961-8932

References

[1] W. A. Aripin, H. Sahidu, and M. Makhrus, "Efektivitas Perangkat Pembelajaran Fisika Berbasis Model Problem Based Learning untuk Meningkatkan Kemampuan Pemecahan Masalah dan Kemampuan Berpikir Kritis Peserta Didik," *Jurnal Penelitian dan Pembelajaran Fisika Indonesia*, vol. 3, no. 1, Jul. 2021, doi: 10.29303/jppfi.v3i1.120.

[2] M. R. Fadli, "Hubungan Filsafat dengan Ilmu Pengetahuan dan Relevansinya Di Era Revolusi Industri 4.0 (Society 5.0)," *Jurnal Filsafat*, vol. 31, no. 1, p. 130, Apr. 2021, doi: 10.22146/jf.42521.

[3] S. Erduran and Z. R. Dagher, "Reconceptualizing Nature of Science for Science Education," 2014, pp. 1–18. doi: 10.1007/978-94-017-9057-4_1.

[4] E. J. Chaisson, "The Natural Science Underlying Big History," *The Scientific World Journal*, vol. 2014, pp. 1–41, 2014, doi: 10.1155/2014/384912.

[5] Z. Aeni and W. A. Wiwaha, "Kontribusi Ilmu Psikologi dan Sosiologi dalam Perilaku Organisasi serta Implikasinya Terhadap Pengelolaan Lembaga Pendidikan Islam," *JURNAL MAHASANTRI*, vol. 2, no. 2, pp. 517–536, Mar. 2022, doi: 10.57215/pendidikanislam.v2i2.161.

[6] M. Ridwan, A. Syukri, and B. Badarussyamsi, "Studi Analisis Tentang Makna Pengetahuan Dan Ilmu Pengetahuan Serta Jenis Dan Sumbernya," *Jurnal Geuthèë: Penelitian Multidisiplin*, vol. 4, no. 1, p. 31, Apr. 2021, doi: 10.52626/jg.v4i1.96.

[7] S. A *et al.*, "Kebermaknaan Fisika Kuantum Sebagai Solusi Membangun Karakter Peserta Didik," *Jurnal Ilmiah Profesi Pendidikan*, vol. 7, no. 2b, pp. 672–679, May 2022, doi: 10.29303/jipp.v7i2b.555.

[8] V. S. Netchitailo, "Review Article: Cosmology and Classical Physics," *Journal of High Energy Physics, Gravitation and Cosmology*, vol. 08, no. 04, pp. 1037–1072, 2022, doi: 10.4236/jhepgc.2022.84074.

[9] I. N. Hula, M. Rizki Gunawan, H. Boham, and M. Podungge, "Tafsir Tarbawi : Pendidikan Fisika dalam Al-Quran," *Jurnal Pendidikan dan Ilmu Fisika*, vol. 3, no. 1, p. 184, Jun. 2023, doi: 10.52434/jpif.v3i1.2359.

[10] A. Acke, "Newton’s Law of Universal Gravitation Explained by the Theory of Informatons," *Journal of High Energy Physics, Gravitation and Cosmology*, vol. 10, no. 03, pp. 918–929, 2024, doi: 10.4236/jhepgc.2024.103056.

[11] E. N. Sanusi and R. Haryadi, "STUDI LITERATUR METODE PYTHAGORAS DALAM PENYELESAIAN SOAL-SOAL TEORI RELATIVITAS KHUSUS EINSTEIN," *EduFisika: Jurnal Pendidikan Fisika*, vol. 7, no. 2, pp. 242–244, Dec. 2022, doi: 10.59052/edufisika.v7i2.22309.

[12] E. Murdani, "HAKIKAT FISIKA DAN KETERAMPILAN PROSES SAINS," *Jurnal Filsafat Indonesia*, vol. 3, no. 3, pp. 72–80, Sep. 2020, doi: 10.23887/jfi.v3i3.22195.

[13] E. Erwin, M. S. Hayat, and S. Sutarno, "Epistemologi dan Keterbatasan Teori Gravitasi," *Titian Ilmu: Jurnal Ilmiah Multi Sciences*, vol. 9, no. 1, pp. 33–40, Aug. 2017, doi: 10.30599/jti.v9i1.79.

[14] D. Lehmkuhl, "Why Einstein did not believe that general relativity geometrizes gravity," *Studies in History and Philosophy of Science Part B: Studies in History and Philosophy of Modern Physics*, vol. 46, pp. 316–326, May 2014, doi: 10.1016/j.shpsb.2013.08.002.

[15] A. Celi, A. Sanpera, V. Ahufinger, and M. Lewenstein, "Quantum optics and frontiers of physics: the third quantum revolution," *Physica Scripta*, vol. 92, no. 1, p. 013003, Jan. 2017, doi: 10.1088/1402-4896/92/1/013003.

[16] M. Nauenberg, "Max Planck and the birth of the quantum hypothesis," *American Journal of Physics*, vol. 84, no. 9, pp. 709–720, Sep. 2016, doi: 10.1119/1.4955146.

[17] P. Weinberger, "Niels Bohr and the dawn of quantum theory," *Philosophical Magazine*, vol. 94, no. 27, pp. 3072–3087, Sep. 2014, doi: 10.1080/14786435.2014.951710.

[18] H. Firman, "Kepastian Dan Ketidakpastian Dalam Sains," *Jurnal Filsafat Indonesia*, vol. 2, no. 1, p. 33, May 2019, doi: 10.23887/jfi.v2i1.17549.

[19] K. Barley, J. Vega-Guzmán, A. Ruffing, and S. K. Suslov, "Discovery of the relativistic Schrödinger equation," *Physics-Uspekhi*, vol. 65, no. 1, pp. 90–103, Jan. 2022, doi: 10.3367/UFNe.2021.06.039000.

[20] A. Puspitasari, F. Mufida, and B. Setiaji, "Analysis of the Influence of Analytical Mechanics Concept on the Development of Modern Physics," *Jurnal Pendidikan dan Ilmu Fisika*, vol. 4, no. 1, p. 60, Jun. 2024, doi: 10.52434/jpif.v4i1.4004.

[21] W. Nawrocki, *Introduction to Quantum Metrology*. Cham: Springer International Publishing, 2015. doi: 10.1007/978-3-319-15669-9.
[22] G. Kunstatter and S. Das, "Introduction to the Quantum," 2022, pp. 163–196. doi: 10.1007/978-3-030-92346-4_8.
[23] D. C. Chang, "The Birth of Quantum Mechanics: Arriving of the Photon Concept," in *On the Wave Nature of Matter*, Cham: Springer Nature Switzerland, 2024, pp. 15–25. doi: 10.1007/978-3-031-48777-4_2.
[24] M. Giliberti and L. Lovisetti, "The Photoelectric Effect and the Electron Charge," 2024, pp. 159–228. doi: 10.1007/978-3-031-57934-9_5.
[25] K. Hentschel, "Planck's and Einstein's Pathways to Quantization," in *Photons*, Cham: Springer International Publishing, 2018, pp. 9–38. doi: 10.1007/978-3-319-95252-9_2.
[26] C. Hugenschmidt, "Positrons in surface physics," *Surface Science Reports*, vol. 71, no. 4, pp. 547–594, Dec. 2016, doi: 10.1016/j.surfrep.2016.09.002.
[27] S. Sutarno, E. Erwin, and M. S. Hayat, "Radiasi Benda Hitam dan Efek Fotolistrik Sebagai Konsep Kunci Revolusi Saintifik dalam Perkembangan Teori Kuantum Cahaya," *Titian Ilmu: Jurnal Ilmiah Multi Sciences*, vol. 9, no. 2, pp. 51–58, Sep. 2017, doi: 10.30599/jti.v9i2.92.
[28] G. Schirripa Spagnolo, F. Leccese, and M. Leccisi, "LED as Transmitter and Receiver of Light: A Simple Tool to Demonstration Photoelectric Effect," *Crystals (Basel)*, vol. 9, no. 10, p. 531, Oct. 2019, doi: 10.3390/cryst9100531.
[29] A. K. Hidayati, A. Izzulhaq, R. Oktamaypasha, and S. B. I. Rini, "DIY Innovations in Quantum Physics: Proving Light Dualism with Photoelectric Effect and Double Slit Experiments," *Jurnal Pendidikan dan Ilmu Fisika*, vol. 4, no. 1, p. 17, Jun. 2024, doi: 10.52434/jpif.v4i1.3428.
[30] K. Riyadi, A. Salleang, and N. Taqhira, "Photoelectric Effect on Metal Work Function Using Test Simulation," *IndonesianJournalofAdvancedResearch*, vol. 2, no. 3, pp. 209–220, 2023, doi: https://doi.org/10.55927/ijar.v2i3.3866.
[31] R. K. Nugraha, T. Novandi, W. A. Wardhana, G. B. Sembodho, and S. Santoso, "Analisis Strategi Pengembangan Kain Tenun Ikat Sumba oleh Pelaku Kriya dan Komunitas," *Jurnal Pengabdian Seni*, vol. 3, no. 1, pp. 73–82, Nov. 2022, doi: 10.24821/jps.v3i1.5233.
[32] R. K. Nugraha, T. Novandi, W. A. Wardhana, G. B. Sembodho, and S. Santoso, "Analisis Strategi Pengembangan Kain Tenun Ikat Sumba oleh Pelaku Kriya dan Komunitas," *Jurnal Pengabdian Seni*, vol. 3, no. 1, pp. 73–82, Nov. 2022, doi: 10.24821/jps.v3i1.5233.

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E-ISSN 2961-8746
P-ISSN 2961-8932

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