Research on the Characteristics of Light Based on Photoelectric Effect Method

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Keywords: Photoelectric effect, Light intensity, Different distances, Apertures

Abstract: In this paper, the properties of light are studied by means of photoelectric effect. Einstein's theory of light quantum, which reveals that the energy of photon E = hν, is very important to study the specific heat of solid, radiation theory and atomic spectrum. The propagation of light shows its wave property, which produces interference, diffraction, polarization and other phenomena. When light interacts with objects, its corpuscular property is highlighted again. Wave particle duality is the inherent property of all micro objects, and quantum mechanics has been developed to describe and explain the motion law of micro objects, which makes a great progress in people's understanding of the objective world. Based on the photoelectric effect method, the cut-off voltages of five different frequencies of light are studied: As each frequency of light have a unique photon energy, the energy for moving that the escaping electrons got is different. The experiment shows that: The higher the frequency of photons, the higher the energy of escaping electrons, so the cut-off voltage(COV) is higher. At the same time, when the incident ray has a frequency lower than regular value, no photocurrent will be generated no matter what the intensity of light and the time of irradiation is. The volt ampere saturation(AS)characteristic curve of different frequencies and the intensity of light is further studied: different spectral lines at the same aperture and the same distance; a certain spectral line at different light intensities and the same aperture; a spectral line at different luminous flux and the same distance. These research results provide a good significance for the future optical research.

1. Introduction

Since ancient times, People have tried to explain what light is. By the 17th century [1-5], Geometrical optics is established to study the law of reflection, refraction and imaging of light. Newton and other physicists studied the geometrical optics phenomenon. According to the linear propagation of light, they think of light as a kind of particle flow, which fly out of the light source and move in a uniform straight line with the law of mechanics. The theory of particle flow naturally explains the linear propagation of light, but it is difficult to explain the interference phenomenon like Newton's ring, etc. [6-9].

Huygens and others put forward the wave theory of light in the 17th century, in which it is believed that light is produced and propagated in the form of waves. However, the early wave theory lacks mathematical basis, so it is not perfect and has not been paid attention to. In the early 19th century, Thomas Young developed Huygens' wave theory and successfully explained the interference phenomenon. The famous Young's double slit interference experiment is proposed, which provides good evidence for the wave theory. In 1818, Fresnel, who was only 30 years old, from the point of view that light is shear wave, perfectly explained the polarization of light in an essay contest on diffraction of light bay the French Academy of Sciences. With rigorous mathematical reasoning, the diffraction patterns produced by light passing through obstacles of round hole and circular plate are calculated quantitatively. The results are in good agreement with the experiment, which made the Award Committee greatly impressed and won the science award of this session for Fresnel. The wave theory is gradually accepted by people. Between 1856 and 1865, Maxwell established the electromagnetic field theory, pointing out that light is an electromagnetic wave, and the wave theory of light was established.

In 1887[16-19], two sets of electrodes were used in Hertz's experiment of transmitting and receiving electromagnetic waves. It is found that when ultraviolet light irradiates the negative

  DOI: 10.25236/cseem.2020.030

electrode of the receiving electrode, it is easier to generate discharge between receiving electrodes. The discovery of Hertz has attracted many people to do research in this field. Stoletov found that when the negative electrode was irradiated by light, it emits negatively charged particles, forming photocurrent which has a liner relationship with the intensity of incident light. Photocurrent is produced immediately at the beginning of irradiation without any accumulation of time needed. In 1899, Thomson measured the nuclear-cytoplasmic ratio of photocurrent and proved that photocurrent is caused by the electron emitted by the cathode after irradiated by light. In 1900, Lenard studied the maximum velocity of electrons escaping from the metal surface by applying a reverse voltage between the anode and cathode[19-23].It is found that both the light source and cathode material have influence on the cut-off voltage, but the intensity of light has no effect on, which means that the maximum velocity of electron escaping from metal surface is irrelevant to light intensity, Lenard won the Nobel Prize in physics in 1905 for his work in this field.

The experimental law of photoelectric effect is not consistent with the classical electromagnetic theory. According to the classical theory, the energy of electromagnetic wave is continuous, so when the electron receives greater energy of light, the kinetic energy should be greater and the initial velocity of the electron should be greater. However, the experimental results show that the initial velocity of the electron is independent from the intensity of light. Moreover, as long as there is enough light intensity and exposure time, no matter what frequency the light wave has, electrons should get enough energy to escape the metal surface. The experimental results show that: for a certain kind of metal material, photoelectrons will be produced immediately after the metal is irradiated if the incident light frequency exceeds a certain value[24-29]. Conversely, when the frequency of incident light is lower than this value, there will be no photoelectrons no matter how strong the light is and how long the exposure time is.

Einstein, with his amazing insight, was the first to realize the great significance of quantum hypothesis, and he got the famous equation in photoelectric effect from his photon hypothesis, which explains the experimental results of photoelectric effect. Einstein's photon theory was doubted and ignored at first because of its conflict with the classical electromagnetic theory. On the one hand, people are bound by traditional ideas; on the other hand, the photoelectric effect equation could not be verified because the accuracy of experiments for photoelectric effect was not high enough at that time. Millikan began the experiment of photoelectric effect in 1904. After ten years, Einstein's theory of light quantum was confirmed by experiments. In 1921 and 1923, two physicians won the Nobel Prize in physics for their outstanding contributions in studying photoelectric effect. In his 1924 speech, Millikan talked about his work in this way: "After ten years of testing and changing and learning and sometimes blundering, all efforts being directed from the first toward the accurate experimental measurement of the energies of emission of photoelectrons, now as a function of temperature, now of wavelength, now of material (contact e.m.f. relations), this work resulted, contrary to my own expectation, in the first direct experimental proof in 1914 of the exact validity, within narrow limits of experimental error, of the Einstein equation, and the first direct photoelectric determination of Planck's h."[34-35]

This paper studies the properties of light based on photoelectric effect method,Light of different frequencies,Analysis of the relationship between the intensity of light and light and the factors affecting the intensity of light, further optimize the research.

2. Experimental Principle of Photoelectric Effect

Photoelectric effect refers to: when the light of a certain frequency irradiates on the surface of the metal material, there will be electrons escaping. For understanding the characteristics of light and the development of Early Quantum Theory, the experiment of Photoelectric effect has milestone significance. Photoelectric effect is divided into internal photoelectric effect and external photoelectric effect. In this paper the external photoelectric effect is studied: Electrons generated by light escape from the surface of matter, forming electrons in a vacuum, which produces a photocurrent.

2.1 Experimental Instruments Used

The experimental instrument used in this paper consists of mercury lamp, power supply, filter, diaphragm, photocell and tester. As shown in Figure 1: five different frequency filters, used to provide monochromatic light at different frequencies. As shown in Figure 2:three apertures with different aperture diameters,They are 2mm, 4mm and 8mm respectively. As shown in Figure 3, Photoelectric effect tester, etc.

Fig.1 Five Different Frequency Filters

Fig.2 Three Apertures with Different Aperture Diameters

Fig.3 Experimental Mercury Lamp and Photocell

2.2 Experimental Principle

The experimental schematic diagram is shown in Fig. 4. When the frequency of monochromatic incident light is greater than the cut-off frequency of the metal material used as the cathode K,under the electric field, the photoelectrons migrate to anode A and form photocurrent,changing applied voltage UAK. Through the measurement of photocurrent I, the volt ampere characteristic curve of the photoelectric tube in this experiment can be obtained.

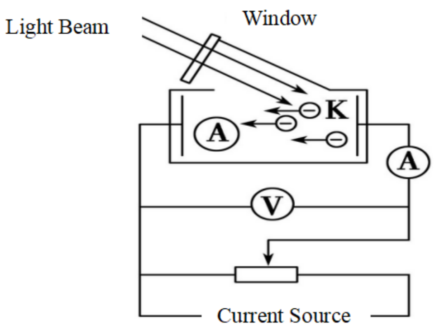

Fig.4 Experimental Schematic Diagram

On the basis of Einstein's Quantum Theory of Light, Light energy is not distributed evenly in the wave as the Electromagnetic wave theory. However, the particles still retain the concept of frequency (or wavelength). Photons at frequency v have energy [7]:

$E = h\nu$, (1)

h: Planck Constant

When light irradiates on the surface of the metal, the energy in photons is absorbed by all electrons in the metal at one time without extra time to accumulate energy. Electrons use part of this energy to overcome the attraction of metal surfaces, and the rest becomes the energy of motion of the electrons as they leave the metal surface. On the basis of the law of energy conservation, Einstein put forward the famous equation of photoelectric effect:

$$h\nu = \frac{1}{2}m\upsilon_0{}^2 + A \quad (2)$$

Where, A: is the work escaping from the metal.

1/2mv02: is the initial energy of motion obtained by photoelectron.

v0: is the maximum speed.

m: is the mass of photoelectron.

It can be seen from equation (2), the higher the frequency of the incident ray on the surface of metal, the greater the energy of motion that electrons can get. Therefore, even if the anode potential is lower than the cathode potential, electrons will fall into the anode to form photocurrent. The photocurrent remains zero until the anode potential(AP) is lower than the COV. At this point, it is relevant:

$$eU_0 = \frac{1}{2}m\upsilon_0{}^2 \quad (3)$$

The COV is lower than the anode potential. With the increase of the AP, the collection effect of the anode on the electrons emitted from the cathode becomes stronger, and the photocurrent increases; when the anode voltage reaches a certain level, almost all photoelectrons emitted from the cathode have been collected to the anode. When UAK is increased again, I does not change and photocurrent saturates. The saturation photocurrent IM is proportional to the intensity P of incident light.

When the photon energy h0 < A, Electrons cannot do without the metal, Therefore, no photocurrent is generated. The lowest frequency (cut-off frequency) for photoelectric effect is h0 = A / h. From this we can see that:

$$eU_0 = h\nu - A \quad (4)$$

The formula shows that the COV U0 is a linear function of frequency.As long as the COV corresponding to different frequency is obtained by experimental method, Einstein's theory of photons successfully expound the law of electric-optic effect.

3. Experimental Process

3.1 Preparation Before Test

a) Connect the power supply of the tester and mercury lamp, cover the mercury lamp and photoelectric tube cassette cover, and preheat for 20 minutes.

b) Aim the light output port of the mercury lamp cassette to the light input port of the photocell and adjust the distance between the photoelectric tube and the mercury lamp to about 40cm and keep it invariant.

c) Connect the voltage input end of the photocell cassette with the voltage output terminal of the tester (on the back panel) with a special connecting wire (red -red, blue -blue).

d) zero adjustment: the “current range” selector switch is placed in the selected gear position, the instrument is fully preheated before the test is zeroed. The experimental instrument will automatically enter the zero setting state after starting up or changing the current range. Turn the “zero adjustment” knob to make the current indicate “+” and “-” zero conversion point. After adjustment, connect the current output end of the photocell cassette with the micro current input end of the experimental instrument with the high frequency matching cable, and press the “zero setting confirmation / system reset” key, and the system will enter the test state.

3.2 Measurement of Cut-Off Voltage:

When measuring the cut-off voltage, the “volt ampere characteristic test /

cut-off voltage test” status key should be the cut-off voltage test state. The “current range” switch should be at 10-13A. Put a 4mm Diameter diaphragm and 365nm color filter on the light input port of the photocell cassette, and open the mercury lamp shading cover. At this time, the voltmeter displays the value of UAK in volts; the ammeter displays the current value I corresponding to the UAK in the selected “current range”. Adjust the voltage from low to high (the absolute value decreases), observe the changing of current value, find the corresponding UAK when the current is zero (the current indicates “+”, “-” zero conversion point), and take its absolute value as the value of U0 corresponding to the wavelength, and record the data. In order to find the value of U0 as soon as possible, adjust it from high level to low level, first determine the value of high level, and then adjust to low level successively. Replace with 405 nm, 436nm, 546 nm, 577 nm filters, and repeat the above measurement steps.

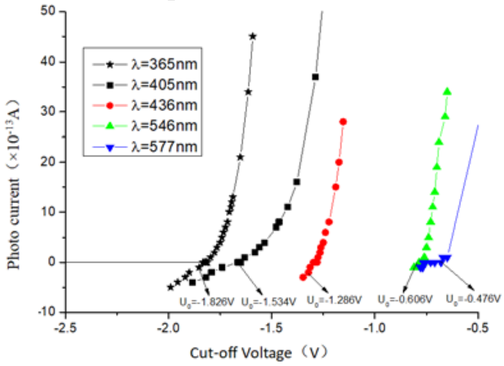

Fig.5 U_{ak}-I Images Near Cut-Off Voltage U_0 At Different Wavelengths

As shown in Figure 5, the cut-off voltage U0 corresponding to different wavelengths is different, and increases with the increase of incident light frequency.

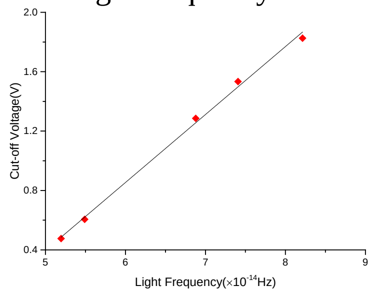

Fig.6 Relationship between the Cut-Off Voltage U_0 and Frequency

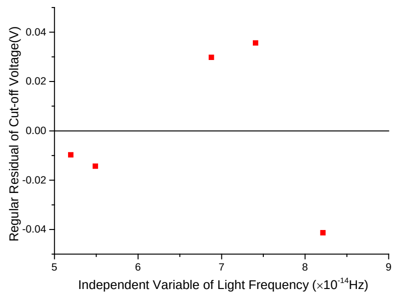

Fig.7 Relationship between the Regular Residual Cut-Off Voltage U_0 and Frequency

As shown in Figure 6 and 7, the cut-off voltage U0 has a linear relationship with the optical Frequency, and the range of conventional residual error is small, which is in line with the expected results of the experiment.

3.3 Relationship between Photocurrent and Frequency and Flux of Incident Light:

Adjust the voltage selection key to the “volt ampere characteristic” position, and record the corresponding current value at intervals from - 1 to 50 V (increase the voltage selection interval appropriately when the current changes slowly). Keep the filter unchanged, change the aperture with different diameter, repeat the above operation, and record the experimental data.

a) Simultaneously , the volt AS curves of different spectral lines at the same aperture and distance can be observed at the same time.

b) At the same time, the volt AS characteristic curve of a certain spectral line at different light intensities and the same aperture can be observed at the same time.

c) The volt AS characteristic curve of a certain spectral line at different luminous flux and the same distance can be observed at the same time. It can be verified that the saturation photocurrent of the photocell is ratio to the incident ray.

When the UAK is 50V, set the instrument to manual mode, measuring and recording the current values corresponding to the same spectral line and the same incident distance, when the apertures are 2mm, 4mm and 8mm, and verify that the saturated photocurrent of the photocell is directly proportional to the incident light intensity. At the same time, the corresponding current values of the photocell and the incident light at different distances, such as 300 mm, 320 mm, 340 mm, 360 mm, 380 mm, 400 mm, etc., are measured and recorded for the same spectral line and the same aperture. It is also verified that the saturation current of the photocell is directly ratio to the incident light intensity.

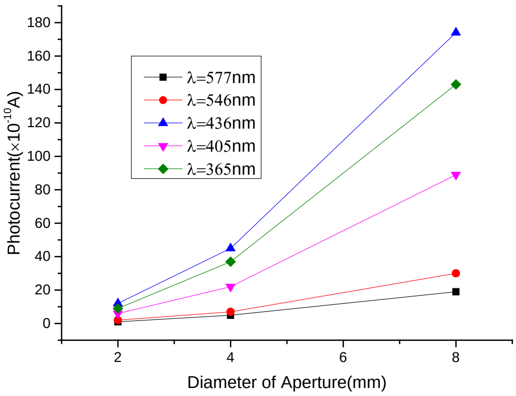

Fig.8 The Relationship between Aperture with Different Diameter and Light Intensity

As shown in Figure 8,For the same distance and frequency light, the larger the aperture, the greater the intensity of the light passing through. For different frequencies of light, the greater the frequency, the greater the intensity of light passing through,For the light with wavelength of 436 nm, there are contact potential difference and anode in the experiment, The influence of photocurrent, dark current, background current, etc. Dark current is generated by thermal excitation in the absence of light, and

increases linearly with the increase of voltage.

The background current has more uncertainty, and there are many factors affecting the background current, such as indoor light intensity, impurities in the air and other environmental factors.

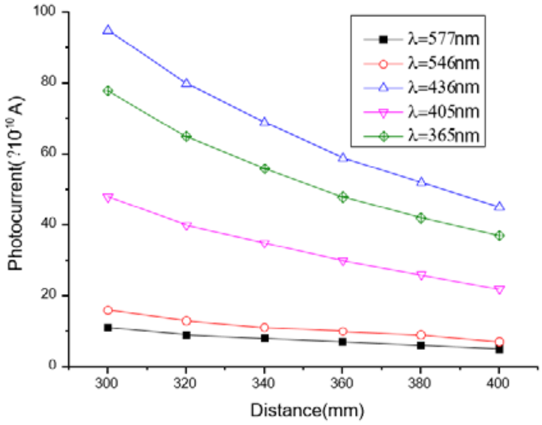

Fig.9 The Relationship between Distance and Light Intensity

As shown in Figure 9, For the same aperture and frequency light, the closer the distance is, the greater the intensity of the light passing through. For different frequencies of light, the greater the frequency, the greater the intensity of light passing through,For the light with wavelength of 436 nm, there are contact potential difference and anode in the experiment, the influence of photocurrent, dark current, background current, etc. Dark current is generated by thermal excitation in the absence of light, and increases linearly with the increase of voltage.

The background current has more uncertainty, and there are many factors affecting the background current, such as indoor light intensity, impurities in the air and other environmental factors.

4. Summary

Starting from the photoelectric effect equation, this paper studies the influence factors of the intensity characteristics of light with different frequencies. The results show that: The higher the frequency, the higher the COV. For the same aperture, The higher the frequency of light, the greater the intensity of light, For the same distance, the same frequency of light, the larger the aperture, the greater the intensity of light. For the same aperture and frequency light, the closer the distance is, the greater the intensity of the light passing through, this is of great significance to the study of optical intensity.

References

[1] Hewitt P G . The Photoelectric Effect[J]. The ence Teacher, 2019, 87.

[2] A Y Z , A Y L , A J Z , et al. Simultaneous morphology manipulation, upconversion luminescence enhancement and the photoelectric effect of NaGd 0.78-x Zr x F 4 :Yb 3+ /Er 3+ nanophosphors[J]. Journal of Luminescence, 2019, 207:443-453.

[3] Stocking K C , Vazquez A L , Kozai T . Intracortical neural stimulation with untethered, ultrasmall carbon fiber electrodes mediated by the photoelectric effect[J]. IEEE Transactions on Biomedical Engineering, 2019:1-2.

[4] Ying, Wang, Laipan. Comprehensive Pyro‐Phototronic Effect Enhanced Ultraviolet Detector with ZnO/Ag Schottky Junction[J]. Advanced Functional Materials, 2019.

[5] Eichler J , St?Hlker T . Radiative electron capture in relativistic ion-atom collisions and the photoelectric effect in hydrogen-like high-Z systems[J]. Physics Reports, 2007, 439(1-2):152-154.

[6] L. Miaja, G. Saathoff, Chifong Lei,et al. The Laser-Assisted Photoelectric Effect on Surfaces[C]// Conference on Lasers & Electro-optics. IEEE, 2008.

[7] Philipp Kanzow, Annette Wiegand Teaching of composite restoration repair: Trends and quality of teaching over the past 20 years[J] Journal of Dentistry, 2020, 95

[8] José A. Gómez-Tejedor, Ana Vidaurre, Isabel Tort-Ausina et al. Effectiveness of flip teaching on engineering students' performance in the physics lab[J] Computers & Education, 2020, 144.

[9] R E Warburton, G Intermite, M Myronov, P Allred, D R Leadley, K Gallacher, D J Paul, N JPilgrim, L J M Lever, Z Ikonic, R W Kelsall, E Huante-Cerón, A P Knights and G S Buller, IEEETrans. Electron Dev.60, 3807 (2013)

[10] Howard Patricia B., Williams Tracy E., El-Mallakh Peggy et al. An innovative teaching model in an academic-practice partnership for a Doctor of Nursing Practice Program[J] Journal of Professional Nursing, 2020(prepublish).

[11] Eichler J , St?Hlker T . Radiative electron capture in relativistic ion-atom collisions and the photoelectric effect in hydrogen-like high-Z systems[J]. Physics Reports, 2007, 439(1-2):235-239.

[12] Mckagan S B , Handley W , Perkins K K , et al. A Research-Based Curriculum for Teaching the Photoelectric Effect[J]. American Journal of Physics, 2009, 77(1):87-94.

[13] Ichihara A , Eichler J . Cross sections for radiative recombination and the photoelectric effect in the K,L, and M shells of one electron systems with 1 lt; Z lt; 112 calculated within an exact relativistic description[J]. Atomic Data & Nuclear Data Tables, 2000, 74(1):119-121.

[14] Beier T , Artemyev A N , Eichler J , et al. QED in heavy few-electron ions[J]. Nuclear Instruments & Methods in Physics Research, 1999, 154(1-4):102–112.

[15] A. Bediako-Bowan, E. Owusu, S. Debrah et al. Surveillance of surgical site infection in a teaching hospital in Ghana: a prospective cohort study[J] Journal of Hospital Infection, 2020, 104(3).

[16] Eichler J , St?Hlker T . Radiative electron capture in relativistic ion-atom collisions and the photoelectric effect in hydrogen-like high-Z systems[J]. Physics Reports, 2007, 439(1-2):456-459.

[17] Juan Pedro Sánchez, Jacobo Sáenz, Torre L D L , et al. The photoelectric effect and study of the diffraction of light: Two new experiments in UNILabs virtual and remote laboratories network[J]. IL Nuovo Cimento C, 2016, 38(3).

[18] W. Thomas, J. Varley, A. Johnston et al. Thrombotic complications of patients admitted to intensive care with COVID-19 at a teaching hospital in the United Kingdom[J] Thrombosis Research, 2020, 191.

[19] Thelin B T B . Some new efforts concerning the photoelectric effect using the inverted new intensity formula and some efficiency raising mechanisms of solar cells[J]. Iosr Journal of Applied Physics, 2013, 3(5):59-66.

[20] Tatsuya Konishi, Satoshi Jinno, Takato Hirayama. Development of a low energy electron beam source using the photoelectric effect[C]// 2012.

[21] In. The Physics of Photovoltaic Cells The Photoelectric Effect[J].

[22] Pardy M . The photoelectric effect on graphene[J]. entific Research & Essays, 2010, 5(12):1571-1575.

[23] Foong S K , Lee P , Wong D , et al. On the Conceptual Understanding of the Photoelectric Effect[J]. 2010:114-117.

[24] Warner, A. H . Variation of The Photoelectric Effect with Temperature and Determination of the Long Wave-length Limit for Tungsten[J]. Physical Review, 1929, 33(5).

[25] Vouagner D , Beleznai C , Girardeau-Montaut J P . Characterization of the photoelectric effect on K+-implanted W samples[J]. Applied Surface Science, 1999, 138-139(none):517-521.

[26] Brian Lim, P. McEuen. Determination of h/e from the Photoelectric Effect[J]. Physical Review Letters, 2005, 72(16):2516-2519.

[27] Mina Najafi Ashtiani, Ashkan Toopshekan, Fatemeh Razi Astaraei et al. Techno-economic analysis of a grid-connected PV/battery system using the teaching-learning-based optimization algorithm[J] Solar Energy, 2020, 203.

[28] Wang L , Jin K J , Ge C , et al. Electro-photo double modulation on the resistive switching behavior and switchable photoelectric effect in BiFeO3 films[J]. Applied Physics Letters, 2013, 102(25):5-6.

[29] Wang L , Jin K J , Ge C , et al. Electro-photo double modulation on the resistive switching behavior and switchable photoelectric effect in BiFeO3 films[J]. Applied Physics Letters, 2013, 102(25):5-6.

[30] Yazed AlRuthia, Hadeel Alkofide, Fahad Dakheel Alosaimi et al. Drug-drug interactions and pharmacists’ interventions among psychiatric patients in outpatient clinics of a teaching hospital in Saudi Arabia[J] Saudi Pharmaceutical Journal, 2019, 27(6).

[31] Lisa Sullivan, Laura Magaña, Sandro Galea Peering into the future of public health teaching[J] The Lancet Public Health, 2018, 3(6).

[32] Leone C J D , Oberem G E . Toward Understanding Student Conceptions of the Photoelectric Effect[J]. 2004.

[33] Lucie Hubickova Heringova, Eva Manakova Why and what are we teaching the medical students in the course of developmental toxicology about?[J] Toxicology Letters, 2017, 280.

[34] Chee, Yu Ping, Munirah Shaik Kadir, Lim, Chim Chai,et al. On improving students' understanding of the photoelectric effect[J]. 2009.

[35] Drube W , Himpsel F J , Feibelman P J . Inverse of the Photoelectric Effect in Al[J]. Physical Review Letters, 1988, 60(20):2070.