The Photoelectric Effect

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12-15-2000

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Around the turn of the century, physics was going through a paradigm shift. A lot of research had been done in areas such as heat transfer, electromagnetism, and optics with many inconclusive results and unexplained phenomena. New ideas were coming about to attempt to explain optical phenomena and atomic theories of matter. The most revolutionary new paradigm was that of quantum mechanics. [1] Quantum theory is based on some fundamental postulates. One of these associates particles with a probability density function. This function describes the position of a particle in terms of a probability, changing the classical concept of the idea of the classical trajectory of particles. In classical physics, when a particle travels from point A to point B, there is a definite and deterministic trajectory. This is, we can define or predict the exact position of particle at any instance between the two points. Quantum theory, on the other hand, uses a probabilistic approach to describing the same trajectory. With this view, we can perceive no trajectory. A particle simply disappears from one point and appears at another. There is a cloud around it describing its probable position. One of the main controversial issues raised by this new paradigm is the particle-wave duality of light. It was Einstein's 1905 publication of the photoelectric effect that put an end to the controversy, [1] and particle-wave duality was accepted among physicists.

In classical physics, wave theory explains light as a wave, not a particle. This was the predominant theory of light before the definition of the photoelectric effect and the development of quantum theory. Quantum theory states that light is both a particle and a wave. The main concept of the theory is that energy transmission takes place in bundles or packets, known as quanta. This theory was strongly supported by the photoelectric effect.

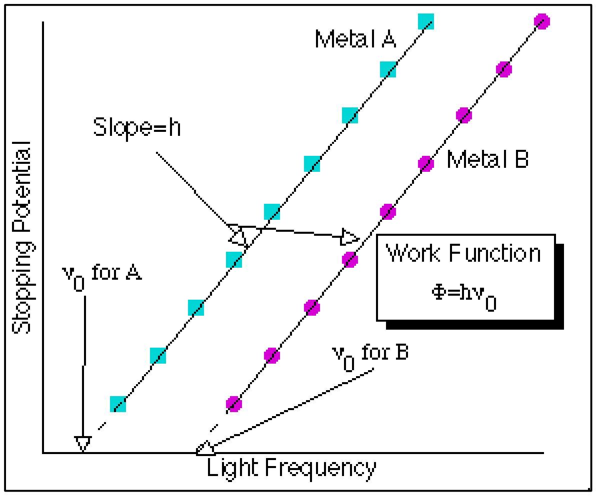
Summarized, the photoelectric effect is the transfer of energy from a photon to an electron upon bombardment. The photon, which is a light particle, hits an electron from an atom and transfers some of its energy to it. The photon's energy (E_{photon}) is Planck's constant (h, or $6.36*10^{-34}$ J/s) multiplied by the frequency of the light (f). The frequency is equivalent to the speed of light (c), divided by the wavelength (λ). Thus, the equation is

$$E_{photon} = hf = h(c/\lambda) = \text{the Photon's Energy}$$

This energy of the photon is transferred to the electron. The electron's maximum kinetic energy (K_{Emax}) is the photon's energy minus the work function (Φ). Hence, it may be concluded that the more energy a photon has, the more excess energy will be devoted to the movement of the electron from the following equation:

K = Electron's Maximum Kinetic Energy

In this equation, Φ represents the work function. The work function is the amount of energy required for an electron to be released. The work function depends on the number of electron shells an atom has. The more shells, the less the work function. This is due to the weak force. The weak force is the force that the nucleus of an atom has to retain its electrons. The farther the electron resides in relation to the nucleus, the weaker the force, and the less energy is needed to let it loose. This is why heavy elements, which have more shells, have a low work function.



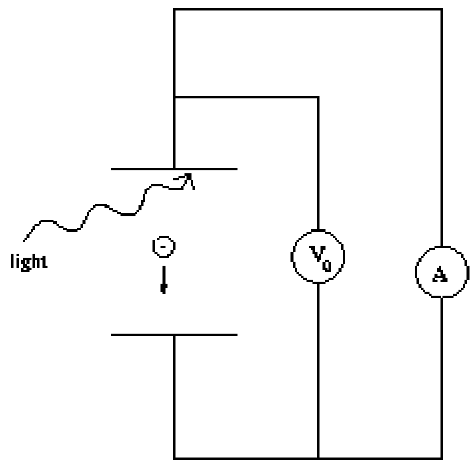
The minimum energy needed to release an electron is the minimum frequency (f_{min}), or cutoff frequency. Because we know that the wavelength decreases as the frequency increases, the f_{min} is proportionate to the maximum wavelength (λ_{max}). Since

$$\lambda_{max} = \Phi/hc$$
and
$$f = c/\lambda$$

We may deduce that

$$f_{min} = c/\lambda_{max} = \Phi/h$$
and
$$\Phi = f_{min}h$$

From this, we conclude that the work function and the cutoff frequency are very closely related. [2]



Stopping voltage is used to measure the strength of the electrical flow. A counter voltage is applied to reduce an electron's kinetic energy to 0. The voltage is called the stopping voltage, or V_{stop} (also known as V_0). The stopping voltage is equivalent to the kinetic energy (K_E) of the electron divided by the magnitude of the electron charge (e) in electron volts. [3]

$$K_E - V_{stop} = 0$$
$$V_{stop} = K_E/e$$
$$V_{stop} = K_E$$

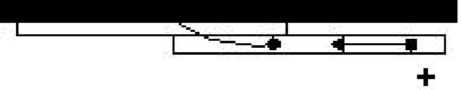
This shows why the stopping voltage is used to measure the electron's kinetic energy, as well as how the stopping voltage and the kinetic energy are the same. This is logical, since the higher the current (higher the K_E), the higher the voltage required to stop it.

Energy is available in many ways from many different sources. One of those sources is solar energy, considered free energy because it is so easily harnessed. This availability is due to photovoltaic and other solar cells, which function on the photoelectric effect.

[redacted]

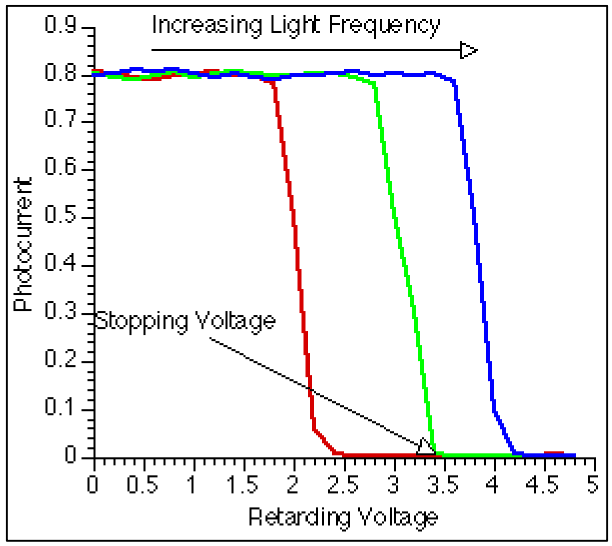
Solar cells usually have three layers: a glass protective layer, the n-type layer, and the p-type layer. The glass layer is the uppermost layer, but is not very important. In the middle, the n-type layer, or n-layer, derives its name from negatively charged type semiconductor. It is composed of a semiconductor, which is usually silicon, germanium, or copper oxide, along with impurities.[4] Lead is a commonly used impurity, due to its low work function.[1] (Let us recall that heavy elements have a low work function.) The type and amount of the impurity is what distinguishes the n-layer from its lower

[redacted]



been used for visible light. [7] Photovoltaic cells with cadmium and zinc are used for detection of visible light in appliances such as light-sensitive lamps. Zinc oxide is used in photocopiers and some scanners for visible light detection.

The photoelectric effect confirms some hypotheses supported by quantum theory. If the cutoff frequency (f_{min}) is recalled, it may be realized that the minimum amount of energy needed to release an electron is reflected by the requirement of a specific frequency (or wavelength). This is supported by quantum theory. [6] Quantum theory states that a high frequency photon has more energy than a photon with a smaller frequency, in discrete increments. Wave theory, however, states that the energy of a photon increases continuously, which is inconsistent with results observed during experimentation. Wave theory incorrectly states that a certain frequency doesn't have to be retained by the incoming photon.

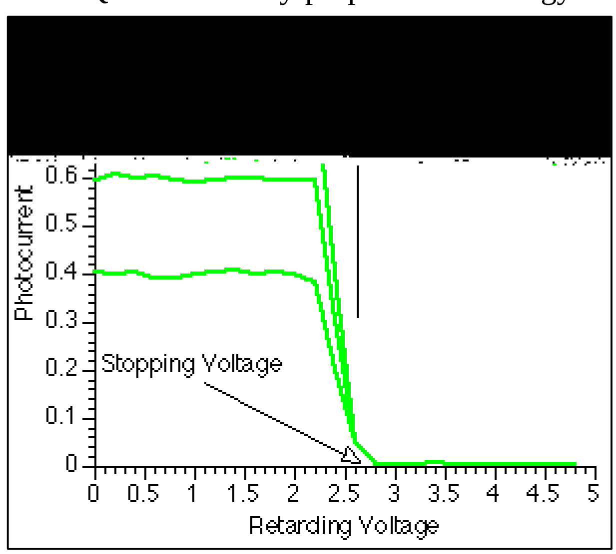


In the equation describing the kinetic energy of a photon

$$K_{Emax} = E_{photon} - \Phi = \text{Electron's Maximum Kinetic Energy}$$

It is easy to see that the energy of a electron depends on the energy of the photon that bombards it. Because we know that a photon's energy depends on its frequency, we also know that an electron's energy depends on the photon's frequency. This is again suggested by the statement that the higher a photon's frequency, the higher its energy. Under wave theory, a photon's energy dependency on its frequency is again inconsistent with test results. [6]

The release of energy, flow of electrons to be specific, starts as soon as a photon strikes an electron. There is virtually no delay in the process. Quantum theory proposes that energy is transferred to an electron in a single step. This is due to the statement that energy is retained in quanta. However, wave theory predicts that extreme lengths of time be required for electrons to gain enough energy to be released. [6]



Not all predictions of the two theories disagree to the extent of a different result. It is proposed by both quantum and wave theory that the electrical current depends on the luminosity predicts that a higher luminosity density will result in an increase in current. This is because wave theory calculates the energy of a wave based on its magnitude.

Quantum theory was one of the most revolutionary topics in 20th century physics. [1] It reshaped our view of the universe. Its acceptance was due to one of Einstein's most prestigious papers.

Heisenberg's Uncertainty Principle, one of the postulates of quantum theory, states that the product of the uncertainty of position times the uncertainty of momentum is always greater than a fixed constant. [1] (The uncertainty is an error in measurement.) Essentially, this means that it is impossible to know both a particle's speed and its position with total certainty. There is only a very high probability of the position and speed being correct. Albert Einstein, the physicist who first explained the photoelectric effect, didn't like the idea of such uncertainty. Ironically, he wrote the very paper that provided quantum theory's wide acceptance, resulting in his reward of the Nobel Prize in 1922. He didn't intend to support quantum theory, he just had a simple idea that photons could transfer their energy to electrons.

Works Cited

[1] Caro, Armando. Personal Interview. 16 Nov. 2000

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[5] Solar Energy Basics… and More 9 Oct. 2000 <http://www.agen.ufl.edu/~fees/pubs/eh220.html>

[6] Assignment 6: Technical Description 10 Oct. 2000 <http://www3.umassd.edu/Public/Exhibit/enl600/assign6.html>

[7] "Photoelectric Effect." Van Nostrand's Scientific Encyclopedia. ed. Considine, Douglas M., 5th ed. (New York City, NY: Van Nostrand Reinhold Company, 1976), pp. 1764-1765

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