STUDY OF PHOTOELECTRIC EFFECT FOR THE SMALLEST UNIT OF TIME EVER OBSERVED

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Abstract:
In this study the phenomenon of photoelectric effect was fundamentally important in the development of modern physics and advanced materials used as a source of energy. This phenomenon in which electrically charged particles is released from or within a material when it absorbs electromagnetic radiation. The effect is often defined as the ejection of electrons from a metal plate when light falls on it. In a broader definition, radiant energy may be infrared, visible, ultraviolet, X-ray, or gamma rays, different materials may be used; solid, liquid, or gaseous, and particles emitted ions, as well as electrons. The new research has an impact on Two basic fields of science, namely: nanotechnology, as scientists in the future will be able to manufacture much more accurate nano-devices, in addition to a more understanding of quantum physics, and the motion of subatomic particles, the accuracy of time monitored by Max Institute scientists plank equal to one millionth of a femto-second will enable biological and biophysicists to monitor interactions that occur at the level of atoms, which will change the future of industries such as pharmaceuticals, superconductors, and an astounding number of other applications. In this article, we will give a brief definition of the photovoltaic effect and link it to modern technology, and we will discuss the latest development include experiments in photon science and others science.

Key-words: Photoelectric Effect, Electrons, Photon, Ions, Atoms.

ملخص البحث:

في هذه الدراسة ، كانت ظاهرة التأثير الكهروضوئية مهمة بشكل أساسي في تطوير الفيزياء الحديثة والمواد المتقدمة المستخدمة كمصدر للطاقة. هذه الظاهرة التي يتم فيها إطلاق الجزيئات المشحونة كهربائياً من أو داخل مادة عندما تمتص الإشعاع الكهرومغناطيسي. غالبًا ما يتم تعريف التأثير على أنه طرد الإلكترونات من لوحة معدنية عندما يسقط الضوء عليه. في تعريف أوسع ، قد تكون الطاقة المشعة بالأشعة تحت الحمراء أو المرئية أو الأشعة فوق البنفسجية أو الأشعة السينية أو أشعة جاما ، يمكن استخدام مواد مختلفة ؛ الصلبة أو السائلة أو الغازية والجزيئات المنبعثة ، وكذلك الإلكترونات. إن البحث الجديد له تأثير على مجالين أساسيين للعلوم ، وهما: تكنولوجيا النانو ، حيث أن العلماء في المستقبل سيكونون قادرين على تصنيع أجهزة نانوية أكثر دقة ، بالإضافة إلى فهم أكثر للفيزياء الكمومية ، وحركة الجسيمات دون الذرية إن دقة الوقت التي يراقبها العلماء في معهد ماكس تساوي تقريبا مليون واحد مـن فيمتو / ثانية التي ستمكن علماء الفيزياء البيولوجية والفيزيائية من مراقبة التفاعلات التي تحدث على مستوى الذرات ، والتي ستغير مستقبل الصناعات مثل الأدوية ، والمدافع الفائقة ، و عدد مذهل من التطبيقات الأخرى. في هذه المقالة ، سنقدم توضيحا موجزًا للتأثير الكهروضوئي وربطه بالتكنولوجيا الحديثة ، وسنناقش أحدث التطورات تشمل التجارب في علوم الفوتون وغيرها من العلوم.

1. Introduction:

The photoelectric effect was discovered in 1887 by the German physicist Heinrich Hertz. Regarding working on radio waves, Hertz noted that when ultraviolet light shines on two metal electrodes with a voltage applied across them, the light changes the voltage at which a spark occurs [1]. This relationship between light and electricity (and thus photo electricity) was demonstrated in (1902) by another German physicist, Philip Lenard. He showed that electrically charged particles are released from a metal surface when it is illuminated and that these particles are identical to the electrons discovered by the British physicist "Joseph John Thomson" in the year (1897). Further research showed that the photoelectric effect represents an interaction between light and matter that cannot be explained by classical physics, which describes light as an electromagnetic wave. One inexplicable observation was that the maximum kinetic energy of the liberated electrons did not change with the intensity of the light, as would be expected according to wave theory, but was instead proportional to the frequency of the light. Another puzzling observation is that there was almost no time difference between the arrival of the radiation and the emission of electrons [1,2].

The photoelectric effect is a phenomenon in which electrons are stripped from the surface of a metal when light is shone on it. Electrons released in this way are called photoelectrons. This phenomenon is attributed to the transfer of energy from photons (light) to electrons attached to the metal surface. Although the release of photoelectrons can be observed by shining a beam of light onto any material, it is most easily observed in metals (and other conductors). The reason behind this is that the incident light liberates electrons from the metal surface because it has relatively less binding to it [2,3]. The aims of this study has reviewed the main definition of the photovoltaic effect and link it to modern technology as well as, the latest development researches include experiments in photoelectric science and other applications in the near future.

2. How the classical physics fail to explain the photoelectric phenomenon:

Physicists attempted to explain the emission of electrons from a metallic surface using the principles of classical physics. Classical physics is simply the branch of physics that does not use quantum mechanics or the theory of relativity, and classical physics is concerned with the study of the kinetic of objects and the forces that cause their motion considering that the measurements are certain and at fixed points. Classical physicists, that treated light as a wave, hypothesized that the oscillating electric field of light hitting the surface of a metal heats the electrons inside. They also believed that the brightness (intensity) of a light wave is proportional to its energy. Using the theory of light waves, classical physicists came to these Three results:

- The higher brightness (intensity) of the incident light, the higher energy of the electrons emitted from the surface.
- Any frequency of the light wave will be able to liberate electrons from the metal surface, provided that a reasonable intensity is maintained.
- If the incident light is of low intensity (too weak), the metal surface must be exposed continuously and for more time until enough waves hit the surface to release electrons. According to the classical theory, if the intensity of the incident light is low, the metal surface must be exposed to a sufficient time to obtain photoelectrons.

However, when experiments were conducted, the results and predictions of classical physics turned out to be incorrect. As it was shown by scientific experience that:

- The energy of the liberated electrons does not depend on the intensity of the incident light.
- Electrons cannot be released from the metal surface unless the frequency of the incident light wave is more than a critical value (threshold frequency).
- Electrons are released as soon as light falls on the surface of the metal.

Therefore, classical physicists could not explain the photoelectric phenomenon using the wave theory of light. And the mystery continued accompanying the photoelectric phenomenon until the intervention of theory of Albert Einstein [2].

3. Quantum physics and explained the photoelectric phenomenon:

In 1905, the physicist Albert Einstein published a paper explained that; according to the assumption to be taken into account here, the energy of a beam of light propagating from a point source is not propagated continuously but in the form of finite energy quanta centered in points of space (hereafter called a photon), which move as a single unit, which cannot be produced and absorb them only as whole units [3,4].

In simple words, he suggested that in experiments related to the photoelectric phenomenon light did not behave as a wave, but rather as a particle, which a photon. His theory succeeded in explaining the observations regarding the results of laboratory experiments of the photoelectric phenomenon. The energy of the electrons liberated from the metal surface does not depend on the intensity of the light, because the electron absorbs only one photon at a time. If the energy of the photon is large enough, the electrons are released from the surface. If not, the electron dissipates the energy it gets from the photon by colliding with neighboring electrons and atoms and is not liberated from the metal surface [4].

3.1. Electron Emission:

Photons have a specific energy proportional to the frequency of the light. In the process of photoemission, if an electron in a material absorbs the energy of one photon and its energy is greater than the electron binding energy of the material, the electron will be emitted [4]. However, if the energy of the photon is very low, the electron will not be able to be freed from matter. When the intensity of the light increases, the number of emitted photons increases, and this leads to an increase in the number of emitted electrons, but does not lead to an increase in the energy absorbed for one electron. From this we conclude that the energy carried by the emitted electron does not depend on the intensity of the light falling on it, but rather depends only on the frequency (energy) of this light, this relates the energy of the incident photon and the energy of the emitted electron. Electrons can absorb the energy of photons when exposed to a beam, but they usually follow the all or nothing principle. All of the photon's energy is absorbed and used to free one electron from the atomic bond; otherwise the photon's energy will be emitted again. If the energy of a photon is absorbed, part of the energy will free the electron from the atom, and the rest will increase the kinetic energy of the free electron as shown in Figure 1.

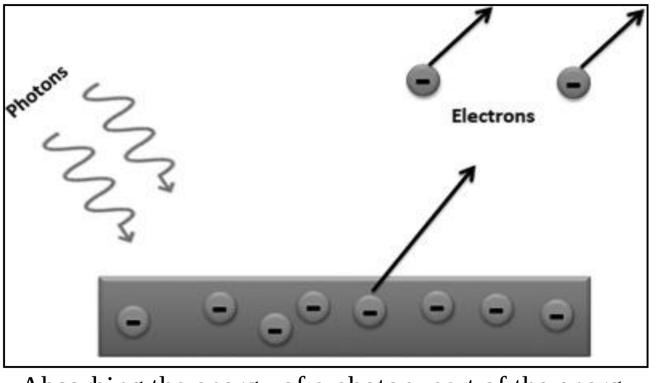

Figure 1. Absorbing the energy of a photon, part of the energy will free the electron from the atom, and the rest will increase the kinetic energy of the free electron [3].

No electrons can be released from the surface if the frequency of the incident light is less than a critical value, which is known as the threshold frequency. The electrons are only ejected if the frequency of the light exceeds the frequency threshold. However, for two different beams of light with frequencies above the threshold frequency, the higher energy light rays release electrons with higher kinetic energy [3,4].

3.2. The theory of the photoelectric effect:

Considering these unexpected behaviors led Albert Einstein to formulate a new particle theory of light in which each particle of light or photon contains a fixed amount of energy, or quantum, which depends on the frequency of the light. Planck postulated that the energy of a particular quantum of radiant energy could be described by the equation.

$$E=hf \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots \quad (1)$$

The photon carries energy (E) equal to (*hf*), where (*f*) is the frequency of light and the proportionality constant (*h*) is called Planck's constant is the constant derived by the German physicist "Max Planck" in the year (1900) to explain the wavelength distribution of black-body radiation, that is, electromagnetism and radiation emitted by a hot object [6].

The relationship can also be written in the equivalent form:

$$E = \frac{hc}{\lambda} \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots \quad (2)$$

Where c is the speed of light, and λ is the wavelength. This indicates that the energy of a photon is inversely proportional to its wavelength. Einstein assumed that a photon would penetrate matter and transfer its energy to an electron. When the electron moves through the metal at a high speed and finally exits the material, its kinetic energy will decrease by an amount (φ) called work, which represents the energy needed for an electron to escape from a metal. By conserving energy, this led Einstein to the photoelectric equation [6, 7].

$$E_k = hf - \varphi \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots \quad (3)$$

Where E_k is the maximum kinetic energy of the ejected electron or in another way the maximum kinetic energy Emax of an emitted electron is given by the following relationship:

$$K_{max} = hf - \varphi \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots \quad (4)$$

Where *f* is the frequency of the incident photon, φ is the work function, which gives the minimum energy needed to liberate an electron from the surface of a metal. The work function is expressed as:

$$\varphi = hf_0 \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots \quad (5)$$

Where f_0 is the threshold frequency for the metal; thus, the maximum kinetic energy of an emitted electron is:

$$K_{max} = h(f - f_0) \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots \quad (6)$$

Since the kinetic energy is positive, we need $f > f_0$ for the photoelectric effect to appear.
For a given frequency of incident radiation, the cut-off voltage depends on the intensity of the light, and at a given frequency of incident radiation, the cut-off voltage is related to the maximum kinetic energy of the photoelectron. If we consider *m* to be the mass and *v* to be the maximum velocity of the photoelectron emitted, then:

$$K_{max} = \frac{1}{2} m v_{max}^2 \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots \quad (7)$$

If q_0 is the charge of the electron and V_0 is the stopping voltage, then the work done from the cut-off voltage to stop the electron is eV0, we get the photoconductivity:

$$\frac{1}{2} m v_{max}^2 = q_e V_0 \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots. \quad (8)$$

The above relationship gives that the maximum speed of the photoelectron emitted is independent of the intensity of the incident light, Therefore Table 1. Illustrate that the work function of platinum metal as the highest (φ_0 = 5.65 eV) while the caesium metal as the lowest (φ_0 = 2.14 eV) [7-10].

Table 1. Work functions of some metals [7]

Element	Work Function (eV)	Element	Work Function (eV)
Cs	2.14	Al	4.28
K	2.30	Hg	4.49
Na	2.75	Cu	4.65
Ca	3.20	Ag	4.70
Mo	4.17	Ni	5.15
Pb	4.25	Pt	5.65

3.3. Radiation and Photoelectric Effect:

Other photoelectric effects are caused by radiation at high frequencies, such as X-rays and gamma rays. These high-energy photons can release electrons near the atomic nucleus, where they are tightly bound. When such an inner electron is ejected, a higher energy outer electron quickly drops to fill the void. The excess energy results in the emission of one or more electrons from the atom, which is called the Auger effect. Also seen at higher photon energies is the Compton Effect, which is created when an X-ray or gamma-ray photon collides with an electron.

Impact can be analyzed by the same principles that govern a collision between any two objects, including the conservation of momentum. The photon loses energy to the electron, a decrease corresponding to the increase in the photon's wavelength according to the Einstein relation ($E = hc/\lambda$). When the collision such as the electron and the photon part are at right angles to each other, the wavelength of the photon increases by a characteristic amount called Compton wavelength (2.43×10^{-12}) meters [8,9].

Since Becquerel put the first explanation for the effect of radioactivity, scientists have tried to explain this effect. In the early twentieth century, the scientist Frank Hertz noticed that the fall of light on a metal surface released a group of electrons, then; this findings could not be explained within the laws of classical physics, which say that light has a wave nature and does not carry any energy. Einstein adopted a different opinion, that light is particles with energy called photons, and proved that the fall of light on a surface of metal liberates a group of electrons if the energy of the photons is greater than the energy needed to disengage the electron and its atom, that theory is known as Einstein's theory of the photoelectric effect, which is what qualified him for the Nobel Prize. Then the scientist de Broglie came to say that light has a dual nature; it behaves like waves under certain conditions and particles in other conditions [9,10].

4. Practical applications of the photoelectric effect:

There are several applications of the photovoltaic effect in our practical life, the most important application, and also the largest, is its use in the production of electrical energy from sunlight using photovoltaic cells. These cells are made of a semiconducting material that generates electricity when exposed to sunlight [4]. The devices that use photovoltaic cells range from calculators to satellites orbiting the planet, there are countless solar energy applications. The photoelectric phenomenon was also used in imaging technology in the early days of television discovery. The photoelectric effect has also been used in chemical analyzes of materials based on the electrons they emit, allowing the study of electronic transitions between energy levels [2,3].

Photovoltaic cells are primarily used to detect light using an empty tube with a cathode (negative electrode) to emit electrons, and an anode (positive electrode) to collect the resulting current. Today, those light tubes have evolved into semiconductor photodiodes that are used in applications such as solar cells and optical fibers in communications. The light amplifying tubes are different from the photovoltaic tube, but they contain several metal strips called dynodes. Electrons are released when they hit the cathode, then the electrons fall on the first diode releasing more electrons that fall on the second diode, then on the third, fourth, and so on. Each diode amplifies the current; after about (10) diode, the current is strong enough to make optical amplifiers detect even single photons. Other applications of LEDs and optical amplifiers include study of nuclear processes, and the study of materials chemically based on the electrons emitted from them. Providing theoretical information about how electrons in an atom move between different energy levels [4].

4.1. Solar Photovoltaic Cell:

Solar cells are considered one of the most important applications on the phenomenon of the photovoltaic effect, which has achieved an amazing breakthrough in providing clean energy to the world, which is made of special silicon material, and works like batteries, when it is placed in sunlight, to play its role in storing energy, and reusing it in many areas, one of the most important is the provision of heating, as well as lighting as an alternative to electricity. Sunlight is composed of photons, which can be considered as discrete units of the energy stored in light. A cell with a p-n junction is made from semiconductor materials PV cell. When solar radiation strikes a solar cell, part of the photons can be absorbed by the cell, resulting in the production electron hole pairs in the cell. If an external circuit is formed, the voltage difference drives the electrons from the n-side to the p-side of the junction. Consequently, the electric current is formed in the external circuit as Figure 2. [4,5].

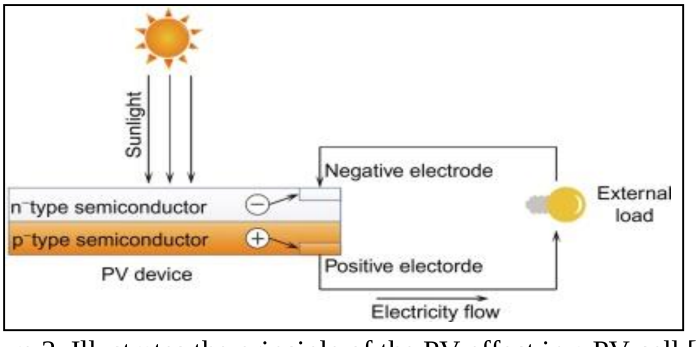

Figure 2. Illustrates the principle of the PV effect in a PV cell [4].

5. A new invention about what happens at the level of atoms:

The German researchers from Max Planck Institute for optics have measured the smallest unit of time ever recorded, while they were studying how long it took a photon of particle light to cross a hydrogen molecule. They reported that the photon crossed the molecule in about 247 zeptoseconds (A zeptosecond is equal to one trillionth of a billionth of a second, or one millionth of a femto-second). This is the shortest time span that has been successfully measured so far, the goal of researchers is measure shorter and shorter units of time [11,12]. The method used to measure in zeptoseconds involves what is known as the photoelectric effect. This scientific law explains how and why some metals give off electrons after light falls on their surfaces. The machines are used to investigate the structure of matter was equipment at the DESY national research center, which operates particle accelerators. The researchers made the measurement by releasing X-ray waves onto a molecule of helium, which is made up of two protons and two electrons. They set the energy of the X-rays so that one photon would be enough to expel both electrons out of the hydrogen molecule [11,12]. There has been earlier research on the speed at which molecules change shape. In 1999 by Zewail. Zewail, an Egyptian, was recognized for experiments that used laser light to study how atoms in a molecule move during a chemical reaction. His research involved femto-seconds, a unit of measurement meaning one quadrillionth of a second.

The German scientists say their research represents major progress from the earlier experiments. They also say they plan to build on their findings to measure even smaller units of time as showed in Figure 3. The experiment began by shooting beams of laser beams at a helium atom; The photoelectric effect was measured in full, and the data was analyzed, which enabled the research team to measure the time it takes for an electron to change its quantum state, and its transformation from restricted rotation around the atom, in a specific orbit, to the free state [12,13].

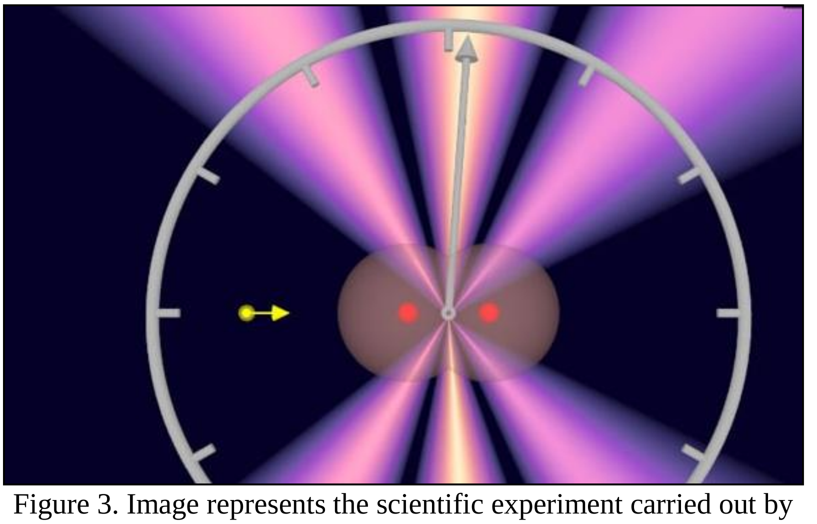

Figure 3. Image represents the scientific experiment carried out by German researchers who measured the smallest unit of time ever recorded [10-13].

6. Conclusion:

The article has concluded that, the effect of light when it falls on the surfaces of some materials, as it works on an electric current. That's the electrons revolve around the atom in specific orbits according to the energy of each electron, and when light falls on the electrons, they gain additional energy, which enables them to change their quantum state, move to another level, or even leave the atom completely, which is photoelectric effect. During the previous reviews, scientists have had a big obstacle, which is to know how one electron absorbs the energy of light particles or how to divide that energy into a number of electrons, and no one has been able to know enough details to study this matter, as the process of energy absorption occurs quickly, the emission of electrons from an atom takes no more than 15 atto-seconds (an atto-second is 1 trillionth of a second).

The study attempted to explain the emission of electrons from a metallic surface using the principles of classical physics. As simply way the branch of physics that does not use quantum mechanics or the theory of relativity, and classical physics is concerned with the study of the kinetic of objects and the forces that cause their motion considering that the measurements are certain and at fixed points. The classical physicists, that treated light as a wave, hypothesized that the oscillating electric field of light hitting the surface of a metal heats the electrons inside. They also believed that the brightness (Intensity) of a light wave is proportional to its energy. The study has summarized that the latest development on the how much energy is needed for an electron to change its quantum state, but they haven't been able to study what happens during the transition, and how long it takes and now; the scientists may be after new invention able to see and record the process of an electrons escape, during the liberate of the atoms.

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