Photoelectric Phenomenon Explanation and Applications

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May 09, 2022

Abstract

The history of the photoelectric effect dates back to the early 1840s. Since then, the dimensions of such a phenomenon have been expanded radically. This study explores the effects of the photoelectric phenomenon to come into a clear conclusion through analysing practical application. A total of 5 cases were studied ranging through different areas: photocells in daily use, photomultipliers use in light amplification, image sensors inner parts, the effect of photoelectric it has on spacecraft, and lunar dust. In conclusion, the photoelectric phenomenon is a powerful tool to explain the quantum field while having a great impact on the practical world.

Keywords: photoelectric, photoemission, photoelectricity

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Introduction

Emission mechanism

The photons of a light beam have a characteristic energy, which is proportional to the frequency of the light. In the process of photoemission shown in Figure 1, when a material's electron absorbs the energy of a photon, it will be ejected. However, if the photon energy is too low, the electron is unable to escape the material. Since an increase in the intensity of low-frequency light will only increase the number of low-energy photons, this change in intensity will not create any single photon with enough energy. Furthermore, the energy of the emitted electrons will not depend on the intensity of the incoming light of a given frequency, but only on the energy of the individual photons.

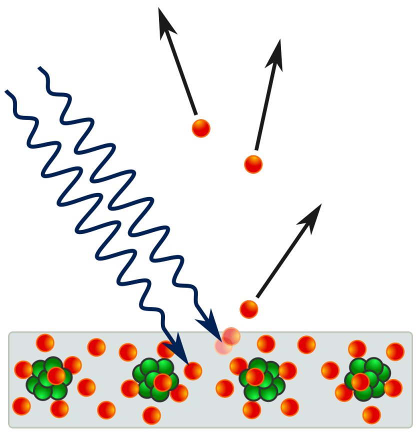

Figure 1

Diagram of photoelectric effect

Theoretical explanation

Einstein proposed a theory of photoelectric effect using Max Planck's hypothesis that light consists of small pieces of energy known as light quanta. Each piece carries energy hv of the electromagnetic wave. The constant h is known as Planck's constant. The maximum kinetic energy K_{max} of the electrons that were dispatched this much energy before abolition from atomic binding is $K_{max} = hv - W$, where W is the minimum energy required to remove an electron. It is called the work function of the surface and is denoted Φ in some references

(Mee, 2008). If the work function is written as $W = hv_o$ the formula becomes $K_{max} = h(v - v_o)$. $v > v_o$ is required for the photoelectric effect to occur. Above the threshold frequency v_o, the maximum kinetic energy of the photoelectrons as well as the stopping voltage in the experiment $V_o = \frac{h}{e}(v - v_o)$ rise linearly with the frequency, and have no dependence on other factors. Einstein's formula elucidated all the aspects of the effect, and had indisputable influences on the development of quantum mechanics (Thomas, 1991).

Analysis

Photocell

The photocell shown in Figure 2 produces a current in the circuit when light of sufficiently high frequency falls on the cell, but it does not allow a current in the dark. This device is used in streetlights: a photoelectric control unit in the base of the light activates a switch that turns off the streetlight when ambient light strikes it.

Many garage-door systems and elevators use a light beam and a photocell as a safety feature in their design. When the light beam strikes the photocell, the electric current generated is sufficiently large to maintain a closed circuit. When an object or a person blocks the light beam, the current is interrupted, which signals the door to open.

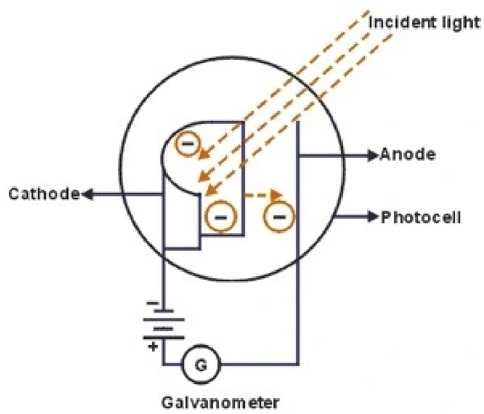

Figure 2

Schematics of a photocell

Photomultipliers

Photomultipliers shown in Figure 3 are extremely light-sensitive vacuum tubes coated with photocathode from inside. The photo cathode contains combinations of materials: cesium, rubidium, and antimony. These materials were selected to provide a low work function, so when illuminated even by the lowest levels of light, it readily releases electrons. By means of dynodes at ever-higher potentials, these electrons are accelerated and substantially increased in number through secondary emission to provide a readily detectable output current. Photomultipliers are still commonly used wherever low levels of light must be detected (Huber & Institute, 2010). It is usually integrated into lager systems such as streetlights, elevators, and garage doors. Furthermore, its effect is usually miniscule yet in highly sensitive systems it cannot be neglected.

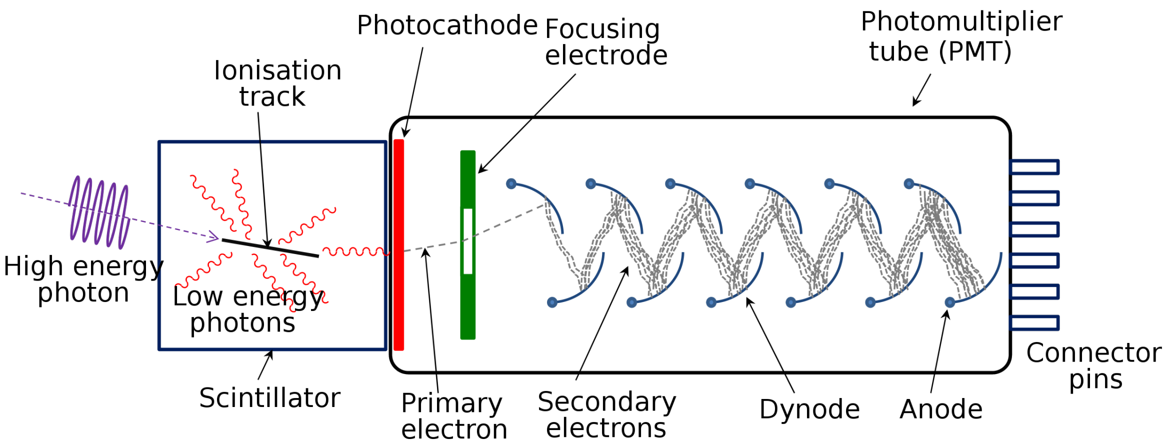

Figure 3

Schematic of a photomultiplier tube

Image sensors

Video camera tubes in the early days of television used the photoelectric effect. It used a screen photoelectrically charged to convert an optical image into electronic signals (Burns & Engineers, 1998). This, however, had many disadvantages (e.g. speed, size, etc), so modern cameras uses much more complex techniques, but the modern principles are the same in core (Liu & Xu, 2020).

Spacecraft

The photoelectric effect causes spacecraft exposed to sunlight to have a positive charge while other parts of it are in shadow. This will result in the spacecraft having an overall positive charge. Furthermore, the charge created by the photoelectric effect is self-limiting. A higher charged object doesn't give up its electrons as easily as a lower charged object does (Lai, 2012).

Moon dust

Light from the Sun hitting lunar dust causes it to become positively charged from the photoelectric effect. The charged dust then repels itself and lifts off the surface of the Moon by electrostatic levitation. This is visible as a thin haze and blurring of distant features. This was first photographed by the Surveyor program probes in the 1960s (Criswell, 1973), and most recently the Chang'e 3 rover observed dust deposition on lunar rocks (Stubbs et al., 2006).

Conclusion

The photoelectric effect is of a great importance, both theoretically and practically. Historically, its understanding lead to the foundation of quantum mechanics, which is the most affecting principle on our understanding of physics in the last century. In contrast, its daily practical application are of a wide variety, especially ones relating to the filed of astronomy.

References

Burns, R. W., & Engineers, I. O. E. (1998). *Television : An international history of the formative years*. Institution Of Electrical Engineers.

Criswell, D. R. (1973). Horizon-glow and the motion of lunar dust. In R. J. L. Grard (Ed.), *Photon and particle interactions with surfaces in space* (pp. 545–556). Springer Netherlands.

Huber, M., & Institute, I. S. S. (2010). *Observing photons in space*. Esa Communications.

Lai, S. T. (2012). *Fundamentals of spacecraft charging : Spacecraft interactions with space plasmas*. Princeton University Press.

Liu, W., & Xu, Z. (2020). Some practical constraints and solutions for optical camera communication. *Philosophical Transactions of the Royal Society A*, *378*(2169), 20190191.

Mee, C. (2008). *Physics : International a/as level.* Hodder Education.

Stubbs, T. J., Vondrak, R. R., & Farrell, W. M. (2006). A dynamic fountain model for lunar dust [The Moon and Near-Earth Objects]. *Advances in Space Research*, *37*(1), 59–66. https://doi.org/https://doi.org/10.1016/j.asr.2005.04.048

Thomas, A. (1991). *Quantum mechanics for applied physics and engineering*. Dover.