THE DEMONSTRATION CORNER

A Simple Demonstration of the Photoelectric Effect

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INTRODUCTION

Following the work of Gustav Kirchhoff, James Maxwell, Heinrich Hertz, Wilhelm Hallwachs, Philipp Lenard, John Rayleigh, and James Jeans, Wilhelm Wien worked at finding out the distribution of energy radiated by a black body. Wien's energy radiation equation for a black body failed to agree with the observed values in the low frequencies (long wavelengths) region of the blackbody energy radiation spectrum (Wien's displacement law). Also, the Rayleigh-Jeans energy radiation equation for a black body failed to agree with the observed values in the high frequencies (short wavelengths) region. This failure is known as the ultraviolet catastrophe.

In 1900, Max Planck worked out a relatively simple energy radiation equation for a black body that described the distribution of radiation accurately over the entire range of frequencies. His equation was based on a crucial assumption: radiant energy is not infinitely sub-divisible. Like matter, it exists in "particles." These particles Planck called quanta, or in the singular, "quantum." He further suggested that the size of the quantum, also known as "photon," for any particular form of electromagnetic radiation, was in direct proportion to its frequency. In the visible spectrum, a photon of violet light would therefore contain more energy than a photon of red light. The small constant that is the ratio of the energy of a photon (E) and the frequency(ν) of the photon radiation is called Planck's constant and it is symbolized as h ($h = E/\nu$). It is now recognized as one of the fundamental constants of the universe. Planck's theory, known as Quantum Theory, was applied by Einstein in explaining the photoelectric efect.

DEMONSTRATION

Remove the knob of a gold-leaf electroscope and attach a zinc plate about 10 cm × 10 cm in dimensions[1]. The sharp corners of the plate should be turned into a circular arc to eliminate the possibility of leaking the charge through sharp points. The electroscope will function properly in whatever weather, if polystyrene insulation is used. A source of ultraviolet light, such as a quartz mercury lamp, or carbon arc, or a spark discharge between zinc or aluminum electrodes, or PSSC course ultraviolet light source, is arranged to illuminate the zinc plate[2]. The zinc plate must be cleaned by sandpaper (never by emery paper) immediately before using for the demonstration, so as to remove the oxide layer that forms on the surface of the plate because of exposure to the air[1].

Charge the electroscope positively. There should be no appreciable difference in the natural rate of leak determined both with and without illuminating the zinc plate by white light[3]. The plate is then charged with negative charge. Illuminate the plate with ultraviolet light; the leaf of the electroscope falls. This happens because electrons are ejected from the plate under the action of the ultraviolet light. Charge the plate again with negative charge. A glass plate is held a short distance from the source of ultraviolet light and the light is directed through the glass towards the plate; the deflection of the gold leaf does not change. This confirms that photons of the ultraviolet light were responsible in ejecting electrons from the zinc plate.

Other materials, such as aluminum or brass, may be used, but the effect is much smaller; all clean metals will show the photoelectric effect, to some extent, with ultraviolet light.

DISCUSSION

Einstein maintained that a minimum frequency of light (the threshold frequency), which corresponds to a minimum photon energy, is required to force an electron out of a given metal. Brighter light (more photons) would bring about the emission of more electrons. Light of higher frequency, however, would have more energetic photons and would bring about emission of more energetic electrons. Light that has a lower frequency than the threshold frequency would be made of photons with such little energy as to bring about no electron emission at all. The energy content of such low-frequency photons would be insufficient to break an electron away from the metal. Obviously, the threshold frequency would be different for different metals.

When the plate is charged positively and then illuminated by ultraviolet light, a few electrons may be ejected but the plate's attractive field pulls them back in[4]. On the other hand, if the plate is charged negatively and then illuminated with ultraviolet light, the leaf falls, and if the illumination is continued for a short time after that, one may see the leaf diverging again. Removing the light source and then testing the type of charge on the plate in a usual manner, one would find that the charge is positive. This is because, after a large number of electrons has been ejected from the zinc plate, the plate has a net positive charge for a short while, sufficient enough to be shown by the deflection of the gold leaf. This charge is then slowly neutralized by the natural absorption of electrons from the surrounding air.

If one of the glass faces of the electroscope is marked with angular calibration (projection electroscope), one can project the deflection of the leaf on a screen.

The photoelectric effect obeys the Einstein photoelectric equation:

$$h\nu = W + \tfrac{1}{2}MV^2$$

Energy of the incident photon.	=	Minimum energy required to remove an electron from its atom (threshold energy, or the work function).	+	Max. kinetic energy of the ejected electron.

Some electrons in a given metal will be more tightly bound to the metal than will others. These electrons will require more energy than the minimum to release them from the metal. Thus, for photons of a given frequency ν, there is a range of kinetic energies that the released electrons will have, with the maximum kinetic energy corresponding to electrons that were loosely bound and were ejected with only the minimum energy (W) being required.

REFERENCES

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