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The Photoelectric Effect Introduction The Quantum Theory was the second of two theories which drastically changed the way we look at our physical world today, the first being Einstein's Theory of Relativity. Although both theories revolutionized the world of physics, the Quantum Theory required a period of over three decades to develop, while the Special Theory of Relativity was created in a single year. The development of the Quantum Theory began in 1887 when a German physicist, Heinrich Hertz, was testing Maxwell's Theory of Electromagnetic Waves.

Hertz discovered that ultraviolet light discharged ertain electrically charged metallic plates, a phenomenon that could not be explained by Maxwell's Wave Theory. In order to explain this phenomenon termed the photoelectric effect, because both light and electricity are involved, the Quantum Theory was developed. The Photoelectric Effect Maxwell's work with the Theory of Electromagnetic Waves may seem to have solved the problem concerning the nature of light, but at least one major problem remained. There was one experiment conducted by Hertz, the photoelectric effect, which could not be explained by considering light to be a wave.

Hertz observed that when certain metals are illuminated y light or other electromagnetic radiation, they lose electrons. Suppose we set up an electric circuit. In this circuit the negative terminal ofa battery has been connected to a piece of sodium metal. The positive terminal of the battery is connected through a meter that measures electric current, and to another piece of metal. Both of these metal plates are enclosed in a sealed glass tube in which there is a vacuum. When there is no light illuminating the sodium plate, no current will flow, and therefore there is no reading on the meter.

A reading on the meter will only occur when electrons are liberated from the metal reating a flow of electric current. However, if the sodium plate is exposed to light, an electric current will tlow and this will register on the meter. By blocking the light from illuminating the sodium plate, the current will then stop. When the amount of light striking the plate is increased, the amount of current also increases. If various colours of light are tested on the sodium plate it will be discovered that violet and blue light causes current flow.

However, colours of light toward the other end of the spectrum (red) do not result in a flow of electric current when they illuminate the sodium plate. The electrons will only be emitted if the frequency of the radiation is above a certain minimum value, called the threshold frequency (fo). The threshold frequency varies with each metal. When the sodium plate was exposed to high frequency light, electrons were emitted and were attracted to the positive terminal, causing a flow of current. However, when a low frequency light was used no electrons were emitted and therefore there was no current.

Observations of the Photoelectric Effect 1 . Current flows as soon as the negative terminal is illuminated. 2. High frequency light causes electrons to be emitted from he sodium, however, a lower frequency light does not. 3. The energy of the emitted electrons does not depend upon the intensity (brightness) of the light, it is dependent on the frequency of the light. A higher frequency of light causes higher energy electrons. 4. The amount of current that flows is dependent upon the intensity (brightness) of the light. Prior to the 1900's light was considered to be wave-like in nature.

This was due to the success of Maxwell's Electromagnetic Theory. However, much of the phenomenon observed during the photoelectric effect was in contradiction to the Wave Theory of Light. For instance, the nergy contained in electromagnetic waves, and the amount of energy that would strike a sodium electron can be calculated. Such a calculation shows that an electron could indeed gain enough energy to be liberated from the sodium, but only after the sodium had been illuminated for several hours. However, this was not the case for photoelectricity, in which the electrons are freed instantly.

The Electromagnetic Theory sustains that light waves carry energy whether they are ot nigh or low frequency. Therefore, the frequency of light should not be a factor in the emitting of electrons. Once, again the photoelectric effect contradicts he Wave Theory. In the photoelectric effect only high frequency light can cause electrons to be emitted no matter how long the light is shined. The photoelectric effect was a major roadblock in the way of total acceptance of the Wave Theory of Light. Einstein's Theory In 1905, Albert Einstein published a revolutionary theory that explained the photoelectric effect.

According to Einstein, light and other forms of radiation consist of discrete bundles of energy which were later given the term Ophotons'. The energy contained in each photon depends on the frequency of the light in which they are found. The energy of the emitted hotoelectron can be determined using the equation E = hf, where h is Plank's constant, 6. 626 x 10 034 J/Hz. According to Einstein's theory an electron is ejected from the metal by a collision with a single photon in the process, all the photon energy is transferred to the electron and the photon ceases to exist. However, the result is the creation of a photoelectron.

Since electrons are held together in a metal by attractive forces, some minimum energy Wo (work function) is required to release an electron from the binding force. If the frequency (f) of the incoming light causes hfto be less than Wo, then the photons will ot have enough energy to emit any electrons. However, if hf is greater than Wo, then the electrons will be liberated and the excess energy becomes the kinetic energy of the photoelectron, allowing it to travel, creating an electric current. Einstein's theory uses the existence of a threshold frequency to explain the photoelectric effect.

A photon with minimum energy hf is required to emit an electron from the metal. Light with a frequency greater than the threshold frequency (fo) has more energy than required to emit an electron. The excess energy again becomes the kinetic energy of the electron, thus, Ek = hf - hfo. This equation is nown as Einstein's Photoelectric Equation. An electron cannot accumulate photons until it has enough energy to break tree; only one photon can interacts with one electron at a time. In Einstein's equation hfo, is actually the minimum energy required to free an electron.

Not all electrons in a solid have the same energy; most need more then the minimum (hfo) to escape. Therefore, the kinetic energy of the emitted electrons is actually the maximum kinetic energy an emitted electron could have. Einstein's theory can be tested by indirectly measuring the kinetic energy of the emitted electrons. A variable electric potential ifference across the tube makes the anode negative. Since, the anode rejects the emitted electrons from the cathode, the electrons must have sufficient kinetic energy at the cathode to reach the anode before turning back.

A light of measurable frequency f, is directed at the cathode. An ammeter measures the current flowing through the circuit. As the opposing potential difference is increased, the anode is made increasingly more negative. At some voltage, called the stopping potential, there is a zero reading from the ammeter because the electrons do not reach the anode. This is due to an insufficient amount of supplied nergy to the electrons. The maximum kinetic energy of the electrons at the cathode equals their potential energy at the anode.