Photon theory accounts for observations of the photoelectric effect

The photon theory of light explains features of the photoelectric effect that cannot be understood using classical concepts. The photoelectric effect is not observed below a certain threshold frequency because the energy of the photon must be greater than or equal to the work function of the material. If the energy of each incoming photon is not equal to or greater than the work function, electrons will never be ejected from the surface, regardless of how many photons are present (how great the intensity is). Because the energy of each photon depends on the frequency of the incoming light ($E = hf$), the photoelectric effect is not observed when the incoming light is below a certain frequency (f_t).

Above the threshold frequency, if the light intensity is doubled, the number of photons is doubled. This in turn doubles the number of electrons ejected from the metal. However, the equation for the maximum kinetic energy of an electron shows that the kinetic energy depends only on the light frequency and the work function, not on the light intensity. Thus, even though there are more electrons ejected, the maximum kinetic energy of individual electrons remains the same.

Finally, the fact that the electrons are emitted almost instantaneously is consistent with the particle theory of light, in which energy appears in small packets. Because each photon affects a single electron, there is no significant time delay between shining light on the metal and observing electrons being ejected.

Einstein's success in explaining the photoelectric effect by assuming that electromagnetic waves are quantized led scientists to realize that the quantization of energy must be considered a real description of the physical world rather than a mathematical contrivance, as most had initially supposed. The discreteness of energy had not been considered a viable possibility because the energy quantum is not detected in our everyday experiences. However, scientists began to believe that the true nature of energy is seen in the submicroscopic level of atoms and molecules, where quantum effects become important and measurable.

Did you know?

Einstein published his paper on the photoelectric effect in 1905 while working in a patent office in Bern, Switzerland. In that same magical year, he published three other well-known papers, including the theory of special relativity.

Why it Matters

Conceptual Challenge

1. Photoelectric Effect

Even though bright red light delivers more total energy per second than dim violet light, the red light cannot eject electrons from a certain metallic surface, while the dimmer violet light can. How does Einstein's photon theory explain this observation?

2. Photographs

Suppose a photograph were made of a person's face using only a few photons. According to Einstein's photon theory, would the result be simply a very faint image of the entire face? Why or why not?

3. Glowing Objects

The color of a hot object depends on the object's temperature. As temperature increases, the color turns from red to orange to yellow to white and finally to blue. Classical physics cannot explain this color change, while quantum mechanics can. What explanation is given by quantum mechanics?