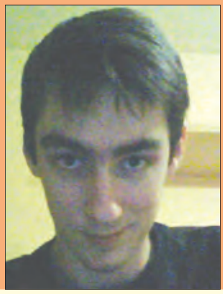
Review Article



A dual nature of light

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Have You ever Wondered Exactly What Light is?

No cheating. Have you ever looked at a beam of light and asked yourself that question? Some say it is nothing more than a wave, while others insist that light consists of lots of tiny elementary particles. However, is it possible that both of these statements prove to be true? A whole new branch of science, called quantum mechanics, deals with such issues and its latest research may shed some light on it. In physical terminology, a quantum is the minimum unit of any entity – in this case a quantum of light would be called a photon. So, are the photons able to behave like particles and still maintain their wave properties? For a better understanding of this case, try to imagine that dualism before moving on.

Particles of Light

Nowadays, most people would describe light as a wave, probably because it seems more intuitive. However, do you know that many great scientists of earlier centuries would not agree with that statement? One of the most famous physicists - Isaac Newton - who is well known for his description of universal gravitation and the three laws of motion also dealt with the issue of light. He claimed that it is no more than a cluster of unimaginably small particles, emitting energy. A simple experiment can prove his theory. The light (more precisely – the photons) falling on the metal plate releases electrons. These can then be captured by the second plate, which means that electric current, that can be measured, flows between these two objects. This phenomenon is called the photoelectric effect[1] [Figure 1] and is widely used in modern devices, such as photocells, solar batteries, digital cameras, etc. Light absorbed by these devices is used to produce electricity and generate an electrical charge. Of course Newton did not know any of this, or even the definition of an electron, which was discovered in 1897 – more than a hundred years after his death.

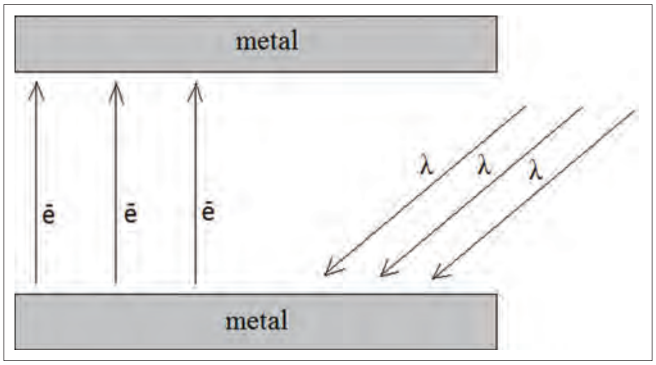

Figure 1: The photoelectric effect

A Diffracted Wave

From the time of Newton's postulates, people

[1]The person who discovered the photoelectric effect was none other than Albert Einstein. It was for this experiment that he gained the Nobel Prize in 1905 not for, what many believe, General relativity (which describes the influence of gravity on space-time) or Special relativity (which explains the behavior of physical bodies with a speed close to speed of light in vacuum).

thought light actually consisted of small particles. However, a breakthrough came in the early 19th century. An English polymath, Thomas Young, made a revolutionary discovery. He made an experiment, later named *The Double-slit Experiment*, which proved that light has the structure of a wave. Young used a source of a coherent light (waves in phase with each other) to illuminate a screen. Between that he placed a thin plate with two parallel slits cut into it. The wave nature of light causes its waves passing through both slits to interfere, creating an interference pattern of bright and dark bands on the screen.[2] This is very similar to waves which appear on water when one throws a rock. Similarly, if one throws two rocks, waves will interfere with each other and create a characteristic wave system.

The Unification of Theories

Since photons have shown they can behave both as particles and as waves, scientists had no choice but to agree on the wave–particle duality of light. The most common argument for its dual nature is *Compton Scattering* [Figure 2]. Put simply, it is all about the dispersal of a short light wave into free electrons and a longer wave.[3] Now it is also known that the shorter the wavelength is, the more energy is carried by the beam. In fact, colours of visible light are nothing other than the effect of different energy values – for example: blue light (short wavelength, high frequency) carries much more energy than a beam of red light (relatively long wavelength and, because the speed of light is always the same, lower frequency). Due to the dualistic nature of light, we may also say that its "red photon" has less energy than a "blue one".

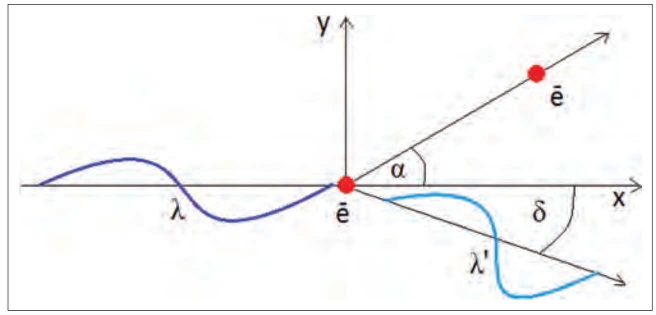

Figure 2: The Compton scattering

Not many years ago, more scientific research was carried out at Harvard University in the USA. Researchers managed to illuminate a container with an ultra-cold cloud of sodium atoms. When the beam was switched off, the gas mixture that recorded the properties of trapped light was pumped into the second container and exposed to a laser beam. Seconds later, the container glowed. Scientists say that this process may be used during manipulation of information transmission in future quantum computers, which would have a much greater computing power than conventional devices. Some say that the ability to record the properties of a wave and then regain it in other place may be the very first step to teleportation.

In summary, the photon's action can actually depend on the situation- it can behave as if it were a particle and as if it were a wave. According to quantum mechanics, the whole matter is characterized by this dualism. Each particle and even each object can be attributed to its characteristic wave function, resulting from the probabilistic nature of matter. On the other hand, each wave interaction can be described in terms of particles.

[2]In this experiment Young also exploited the phenomenon of wave diffraction. This means all waves bend around small obstacles, slightly changing the direction of propagation.

[3]In fact, a visible light beam is an electromagnetic wave of a specific length, possible to see with the naked eye. Shorter waves of the same structure (also comprised of photons) are, for example, X-rays or infrared. Compton scattering concerns X-rays of high frequency and electrons. An electromagnetic wave scatters on free particles, creating a shorter wave (less energetic) and knocking out the electron (which just gained the difference of the energies) in a specific direction. Photons are able to knock out electrons only because of their particle properties and we are able to measure their energy only by registering the frequency of the light wave. Compton scattering is widely used in technology and medicine, especially in radiology.

About the Author

Maciek Bąk is a Polish 19 year old and currently studies Biotechnology at Jagiellonian University. He is very keen on Genetics, Immunology and Quantum Mechanics. He went to private high school in Kielce.