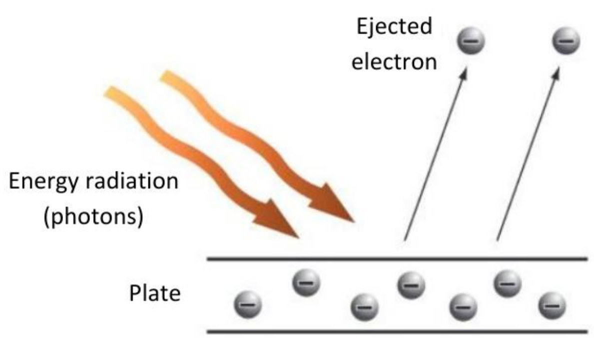
The Photon

What is a photon? A particle, a wave, or a bit of both? For the American physicist Richard Feynman, who received the 1965 Nobel Prize for his contribution to the theory of fundamental particles, 'no one knows and it's best not to think about it.' Let's take up the challenge...



Credit: https://laradioactivite.com

A look, a thought, a flash of light. The radio, chemistry, the hardness of wood, the fluidity of water. Life, in short. The photon (a name derived from the Greek word for light) comes into play at each stage, in each step, since it is the particle associated with the electromagnetic interaction, on which all these phenomena depend.

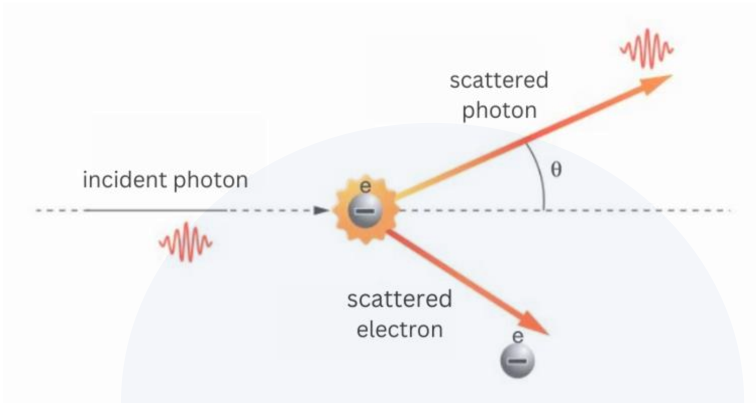
For a long time, the description of light oscillated between two seemingly opposite views: on the one hand, that of a wave similar to one moving across the surface of water; on the other, that of a set of tiny particles of well-defined energy. Some phenomena can be explained within the former framework, while others require the latter.

The photoelectric effect

When light illuminates a metal plate, electrons can be ripped off the metal. This phenomenon only occurs if the frequency of the light waves reaches a threshold value, independent of their intensity. This observation led Einstein to suppose that light consisted of particles, photons, whose energy was proportional to the frequency of the electromagnetic wave. The photoelectric effect thus results from collisions between photons and electrons, the latter being ejected from the metal only if the incident particles are sufficiently energetic.

A decisive breakthrough was made in 1900 when Max Planck used a 'mathematical artifice' to determine the radiation emitted by a closed cavity heated to a given temperature – a blackbody. The calculations that were made on the assumption of continuous energy transfers, a logical hypothesis at the time, did not reproduce the observations. Planck postulated that emission and absorption processes occurred via elementary units – quanta, whose energies are proportional to the frequency of the electromagnetic radiation – and he obtained correct results.

In 1905 Albert Einstein went even further: he used quanta to explain other phenomena, such as the photoelectric effect. Electrons can be stripped off a piece of metal when light is cast on it, but only if the light reaches a certain frequency,



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The Compton scattering

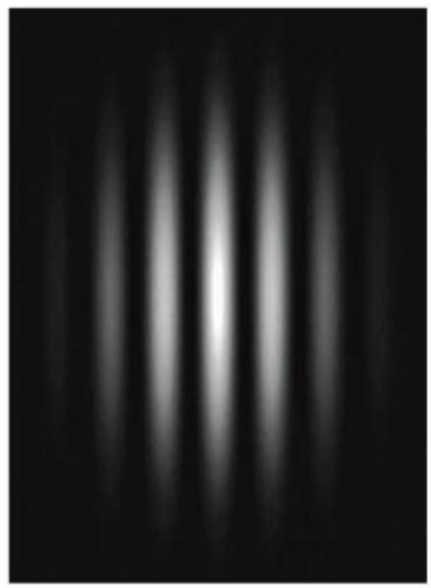
When a photon collides with an electron, it loses energy, which alters the frequency of the associated electromagnetic wave. Through calculations, the θ angle at which the photon deflects from its trajectory can be related to the amount of energy lost. In this experiment, the photon behaves like a particle.

independent of its intensity. A natural explanation for this observation can be found in the concept of photons: photons can break the cohesion of atoms if they individually provide a sufficient amount of energy.

This innovative idea (electromagnetic wave = photons) was eventually confirmed in 1922. Arthur Compton sent X-rays onto a metal plate – an experiment known as 'scattering' – and explained the results by the collisions of tiny billiard balls: photons on one side, electrons from atomic clouds on the other. The more energy photons lose, the more they are deflected; the variations of the wavelength measured follow exactly the expected law.

The photon is therefore a complicated object that can appear as either a wave or a particle, depending on how it is observed. The two facets of its personality are well described by quantum mechanics, which it originated. The photon has other surprising properties. For example, it has no mass, which explains why it travels in vacuum without slowing down or accelerating, at a speed no massive object can reach (around 300,000 km/s). In matter, the photon is slower because it collides with the atoms in the medium. As a result of its 'perfect' lightness, the photon is stable, i.e., it does not decay on its own. Despite its electrical neutrality, the photon is the electromagnetic interaction mediator: two charged particles attract or repel each other by exchanging photons.

For the physics of the infinitely small, a major consequence of the link between energy and wavelength is that the smaller the wavelength under study, the greater the energy needed to probe matter.



Credit: Wikipedia

Light interference fringes

Young's double slit experiment (1801): an opaque board with two small slits is placed between a source of monochromatic light and a screen whose illumination is observed. Alternating bright (resp. dark) bands correspond to constructive (resp. destructive) interference. In this experiment, light behaves like a wave.

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