In retrospect

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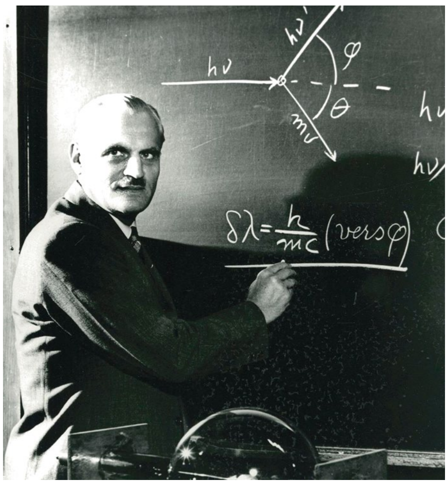
A century of Compton scattering



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Wave–particle duality is a fundamental tenet of quantum physics that physicists took a while to come to terms with. The wave nature of light had been long accepted, but it was only at the turn of the 20th century that a possible particle interpretation started to be considered. In 1923, Arthur Compton published the results of an X-ray scattering experiment that could only be explained by considering light as discrete particles. He later recalled, “when I presented my results at a meeting of the American Physical Society, it initiated the most hotly contested scientific controversy that I have ever known.” By the late 1920s, wave–particle duality was accepted and, in 1927, Compton won the Nobel Prize for his work.

In the original experiment, Compton used a molybdenum X-ray tube to direct X-rays onto a piece of graphite. The scattered X-rays were collected by a Bragg spectrometer: a rotating arm consisting of a calcite crystal and an ionization chamber. Using the known lattice spacing of calcite and the angle at which the X-rays were detected, Compton was able to calculate the wavelength of the scattered rays. If we assume light acts solely as a wave, a portion of the wave’s energy would be absorbed by the electron and it would oscillate at the same frequency as the light. The electron would then re-radiate the energy as scattered waves (in random directions) with the same wavelength. However, Compton observed that the scattered rays had longer wavelengths than the source rays. If we now consider light as a particle colliding with an outer shell electron, the light will impart some of its energy and momentum to the electron in the form of kinetic energy. In order for both energy and momentum to be conserved, the scattered light must have lower energy (longer wavelength) and be scattered at an angle with respect to the incident rays. Compton found that the wavelength shifts, while dependent on the angle of the incident ray, were not affected by the atomic number of the material. Unlike the photoelectric effect, the probability of Compton scattering is directly proportional to the number of outer shell electrons per gram of the scattering material, and is therefore mostly independent of atomic number (with the exception of elemental hydrogen, which has no neutrons).

Today, Compton scattering is a useful tool for physicists. In condensed matter, Compton scattering can be used to probe the electronic states in ferro- and ferrimagnetic materials. When the electromagnetic field of circularly polarized, high-energy rays interacts with the magnetic moment of the electrons, the rays are Compton scattered. If the crystal magnetization is then reversed and the scattered rays measured once more, one can determine the momentum distribution of the spin-up and spin-down electrons. In astrophysics, inverse Compton scattering is used to study black holes and galaxy clusters. In this case, low-energy rays scatter from high-energy electrons to produce high-energy X-rays or gamma rays. The energy shift can then be used to build up a picture of the astronomical bodies that surround us. For example, cosmic microwave background (CMB) rays are inverse-Compton-scattered by galaxy clusters and this shift in the CMB spectrum can be used to map the presence of such galaxies. Contrary to the original effect, in inverse Compton scattering, it is the electrons that lose energy as opposed to the photons.

Compton scattering also has practical applications in other fields. It is the dominant scattering process of gamma rays and high-energy X-rays in biological tissue and is therefore a key process in radiation therapy. When these rays are directed onto tissue, the energy imparted onto the electrons ionizes the molecules and causes damage to the tissue. This process is therefore very effective in destroying cancerous cells. Compton scattering is also an important process in diagnostic X-ray imaging; however, in this case it is an unwanted side-effect, degrading the image contrast and making bodily structures more difficult to see. In recent years, however, work has been ongoing to develop Compton cameras — a device originally developed by astrophysicists to detect gamma rays from astronomical bodies — to produce high-quality images for medical applications.

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Competing interests
The author declares no competing interests.