Arthur Holly Compton (1892–1962)

Physicist, Philosopher and Citizen Scientist

Arthur Compton was born in Wooster, Ohio, on 10 September 1892, as the youngest of three sons to Elias Compton and Otelia Catherine Compton. His father was an ordained Presbyterian Minister and Professor of Philosophy at the College of Wooster. His mother taught in a school for some time, served on the board of managers of children's homes, and was named the 'American Mother of the Year' in 1939. Compton was brought up in a home with a mix of religious and academic atmosphere. All the three Compton brothers went on to receive their PhDs from Princeton University. Their sister Mary and brother-in-law C Herbert Rice were missionary educationists in India.

Arthur was interested in mechanical devices as a child and showed early interest in astronomy. He began experimenting with model planes and gliders at the age 16 and built a 27 feet wingspan glider entirely with his own hands and flew it. During this work, he invented a glider balancing mechanism and patented it. A year later, he published three articles on air flight [1]. He also photographed Halley's comet with his homemade camera at the age of 17.

Upon graduation from Wooster in 1913, he went to Princeton, where he received a master's degree in 1914 and a PhD degree in 1916 for his dissertation on the interaction of X-rays with matter. He developed a theory to connect the intensity of X-ray reflection from crystals to study the arrangement of electrons in line with Bragg's method for determining the arrangement of atoms. At this point in time, he thought of pursuing a religious career, but his father advised him to continue his work in science as it would allow him to serve humanity better. Compton himself believed that there was no conflict between science and religion and a man of science could also be a man of religious faith.

After a year of teaching physics at the University of Minnesota (1916–1917), Compton spent two years as a research physicist for the Westinghouse Lamp Company in East Pittsburgh, where he did original work on the sodium vapor lamp and developed instrumentation for aircraft for the Signal Corps.

Compton wanted to get back to academic research and utilized one of the first two National Research Council Fellowships awarded to work outside the USA. He chose to go to Cavendish Laboratory in England and wanted to work with Ernest Rutherford. At Cavendish, he finally worked with G P Thomson on X-ray scattering and the absorption of gamma rays. He observed that the scattered rays were more absorbed than the primary rays. The absorption of X-rays increased with the wavelength (except only at the absorption edges of the elements constituting the absorber), indicating an increase in wavelength on scattering. But he could not determine the increase accurately enough at that time.

Compton returned to the USA in 1920 and became the Chairman of the Physics Department at Washington University, St. Louis, where he continued his studies on the X-ray scattering. Using Bragg's crystal spectrometer, Compton made precise measurements of the wavelength of X-rays that had been scattered from a target. He found that the scattered rays were of two types, one with the same wavelength as that of the primary rays and the other with a longer wavelength. The increase in wavelength was proportional to the angle of scattering.

Compton's results could not be explained in terms of classical physics, and he took the bold step of applying quantum theory to explain the increase in wavelength. He viewed X-rays as particles (or quanta) and described the phenomenon as an elastic collision taking place between two particles, an electron and the light quantum, for which the name 'photon' was coined later by G N Lewis. As the photon gives up some of its energy to the electron, it has a lower energy after the collision, corresponding to a longer wavelength of radiation. Using the conservation laws for energy and momentum, he also found a formula connecting the change in the wavelength with the angle of scattering. He tested the predictions by bombarding different elements like graphite, paraffin and aluminum with X-rays and gamma rays and found a remarkable agreement between his measurements and the predictions [2]. Compton's quantum interpretation created a stir among physicists because it conflicted with the then prevailing classical ideas proposed by J J Thomson. Compton also predicted that the transfer of momentum from the photon to the electron would create recoil electrons which would be ejected from the atom simultaneously with the scattered photon [3]. The recoil electrons were observed soon thereafter by C T R Wilson in cloud chambers at Cavendish Laboratory and by W Bothe in Germany. The simultaneous ejection of electrons and scattered photons were observed through the coincidence technique developed by Compton and Simon and independently by W Bothe and H Geiger.

Compton published his results in 1923, which marked a turning point in physics. Compton effect provided a strong support to Einstein's theory (1905) that light behaves like a particle as well as a wave. It was Compton's experiments that finally convinced Niels Bohr to accept the reality of the photon. The wave-particle dualism of matter was finally incorporated in quantum mechanics by de Broglie's hypothesis in 1925. That others were close on his heels was borne by the fact that a few days after Compton's publication, a similar calculation was published independently by P Debye [4].

Compton accepted the position as a Professor of Physics at the University of Chicago in 1923, where he spent the next twenty-two years. For the great series of experiments on the Compton effect and their theoretical interpretation, he shared the Nobel Prize in Physics (1927) with C T R Wilson.

His work on the Compton effect overshadowed his other important results on X-ray scattering. One of them was the discovery of total reflection of X-rays from glass and silver mirrors when the glancing angles were small, usually within a few minutes of arc. This became an important method for determining the refractive index of materials for X-rays. Compton and R L Doan showed that a grating ruled on speculum metal could be used to observe a clear diffraction maximum of molybdenum K_α radiation. This allowed an accurate absolute measurement of X-ray wavelengths and also an accurate determination of lattice spacing of crystals. Accurate values of lattice spacing along with the density of the crystals allowed a new determination of the Avogadro number and led to the revision of the value of electronic charge. Another of Compton's important contribution in this field was the extraction of electron density distributions in the material from the observed X-ray diffraction intensities. He extended the method to obtain electron distributions in gases as well and measured them in He, Ne, Ar and Hg atoms. He used X-rays to investigate the phenomenon of ferromagnetism and showed that it arose as a result of electron spin alignment.

Today the Compton effect finds extensive applications in physics, chemistry and biology through the techniques of (i) Compton Profile Analysis (CPA), which gives information on electron momentum distribution in materials and (ii) Compton Scatter Densitometry (CSD) and Compton Scatter Imaging (CSI) of materials through the determination of electron density distribution.

Parallel to his academic work, Compton maintained contact with the industry and worked as a consulting physicist for General Electric Co., for many years. He gave lectures to the general staff and was effective in inspiring industrial researchers.

The other most important scientific activity of Compton after going to Chicago was his work on cosmic rays. Realizing their importance in cosmological theories, Compton and his students developed an array of Geiger counters as a cosmic ray telescope and convinced the Carnegie Institution to fund a world survey during 1931–1934. The globe was divided into nine regions, and roughly 100 physicists, carrying identical detectors, traversed the continents to measure cosmic-ray intensities. Among many notable physicists, an active member of the team was Compton's student, Piara Singh Gill, who later was one of the early practitioners of cosmic ray studies in India. Compton himself travelled approximately 40,000 miles with his family during the observations. The most significant conclusion of these studies was that the intensity of cosmic rays at the surface of the Earth steadily decreases as one goes from either pole to the equator (called the 'latitude effect'). This effect, unknown to Compton, had been discovered earlier by a Dutch physicist J Clay during his trip in 1927 from Holland to Java but was not widely disseminated. Compton's work, however, showed that it was the geomagnetic latitude and not the geographic latitude that was responsible for this phenomenon.

Compton's survey proved that the Earth's magnetic field deflected most of the incident cosmic rays, which was only possible if they were charged particles. He and Alvarez could show that the particles were positively charged. This activity brought out clearly the leadership quality and meticulous planning that were hallmarks of Compton throughout his career in which he donned various roles. At this stage, his reputation as a physicist spread far and wide and he was invited the world over. He and his wife spent a considerable amount of time in India, lecturing at the Forman Christian College, Lahore and carrying out cosmic ray observations in the Himalayas.

With the advent of World War II, Compton was appointed as the Chairman of a special committee of the National Academy of Sciences in 1941, to study the military potential of atomic energy. The committee's report led to the development of the Manhattan Project. In this report, Compton had estimated that it would take between three and five years to actually come up with a working weapon. The British scientists had also told their American counterparts that a bomb could be built in three years. The time from 6 December 1941 to 6 August 1945 was in fact, three years and eight months.

In 1942, he played a key role in the Manhattan Project which led to the development of the first nuclear weapon in the world. He gathered a remarkable group of scientists, engineers, and industry partners, at Chicago, that was known as the 'Metallurgical Laboratory', which later was extended to Oak Ridge and Hanford, Washington. Compton gave up all his other activities to organize and direct the Metallurgical Laboratory at the University of Chicago, which was responsible for the production of plutonium [5]. He was in charge when the first successful nuclear chain reaction with uranium was accomplished by Enrico Fermi and others on 2 December 1942 at the abandoned squash courts in University of Chicago. Compton had to take the decision himself to hold the test on the campus since for security reasons he could not ask the President of the University for authorization. This showed his boldness, which was obviously based on his complete confidence in the underlying science of chain reaction and the calculations of Fermi about the risks of the test going awry.

In 1945, he served, along with Lawrence, Oppenheimer, and Fermi, on the Scientific Panel that recommended the military use of the atomic bomb against Japan. Although Compton came from a deeply religious background, he was not a pacifist. About such issues, he had earlier written in the book *The Cosmos of Arthur Holly Compton* [6] that "As long as I am convinced, as I am, that there are values worth more to me than my own life, I cannot in sincerity argue that it is wrong to run the risk of death or to inflict death if necessary in the defense of those values." Compton in his book *Atomic Quest* gave a complete account of the activities of all his colleagues in the Manhattan Project [7]. As the war reached its end, Compton accepted the position of Chancellor of Washington University (1945–53) to the surprise of many of his colleagues. During his tenure, the Washington University formally desegregated its undergraduate classes and engaged their first woman professor. He was an inspiring teacher and his contagious enthusiasm, friendliness, and great mental power made his classes memorable experiences to the students who attended them.

Compton was one of a few famous scientists to venture into philosophical theories of free will, proposing a two-stage model. Many philosophers including Henri Poincare, Karl Popper and Roger Penrose had advocated alternate two-stage models that all argue that individuals have the freedom to choose from a possible set of events. He advocated the idea of human freedom based on quantum indeterminacy in 1931 [8] and wrote in the magazine *Atlantic Monthly* in 1955 [6] elaborating his views. He was one of the most visible public intellectuals of his time writing for the general reader about science, society and religion. He was on the cover of *Time* magazine in January 1936 and was an eagerly sought-after speaker for his lecturing skills in academia, business organizations, and religious groups.

Compton was in Pakistan in 1954 when the news broke regarding the suspension of J Robert Oppenheimer from the Advisory Board of the Atomic Energy Commission (AEC) during the era of McCarthyism. He immediately sent a letter to the Chairman of the Committee that recommended the suspension, defending the loyalty of Oppenheimer to the interests of USA in no uncertain terms based on his close association with Oppenheimer [9].

Compton won many honors apart from the Nobel Prize during his lifetime, which includes being elected to the National Academy of Sciences at the young age of 35. He was awarded the Rumford Gold Medal of the American Academy of Arts and Sciences (1927), Gold Medal of the Radiological Society of North America (1928), the Matteucci Gold Medal (1930), Hughes Medal of the Royal Society (1940), and Benjamin Franklin Medal of the Franklin Institute (1940).

He was Professor-at-Large from 1961, dividing his time between Washington University, the University of California at Berkeley, and Wooster College till his death at the age of 70 (15 March 1962) at Berkeley. He is remembered not only for his discovery of the effect bearing his name but also by a crater on the Moon named after him and his brother Karl. NASA's Compton Gamma Ray Observatory (April 1991–June 2000), was named in his honor. Compton was always involved with his surroundings and this is exemplified by his design of a gentle, elongated speed bump, called the 'Holly hump' to reduce traffic speeding on the roads of the Washington University campus.

Suggested Reading

[1] John J Compton, Arthur Holly Compton: The Adventures of a Citizen Scientist, *Perspectives on Science and Christian Faith*, Vol.62, No.1, 53, pp.53–60, 2010.

[2] Arthur H Compton, A Quantum Theory of the Scattering of X-rays by Light Elements, *The Physical Review*, Vol.21, No.5, pp.483–502, 1923.

[3] Arthur H Compton, *Nature*, 112, 435, 1923.

[4] P Debye, Physikalische Zeitschrift, 24, 161, 1923.

[5] S K Allison, *Arthur Holly Compton: A Biographical Memoir*, National Academy of Sciences, Washington, D.C., 1965.

[6] Arthur H Compton, *The Cosmos of Arthur Holly Compton*, New York: Alfred Knopf, 1967.

[7] Arthur H Compton, *Atomic Quest*, New York: Oxford University Press, 1956.

[8] Arthur H Compton, The Uncertainty Principle and Free Will, *Science*, Vol.74, No.1911, p.172, 1931.

[9] http://www.nuclearfiles.org/menu/library/correspondence/compton_arthur/corr_compton_1954-04-21.htm

Amit Roy
Honorary Professor
Department of Physics
Panjab University
Sector 14
Chandigarh 160 014, India.
Email: amitroy1948@gmail.com