= 0 °) and twice the Compton wavelength of the electron (for ? = 180 °) . He found that some X @-@ rays experienced no wavelength shift despite being scattered through large angles ; in each of these cases the photon failed to eject an electron . Thus the magnitude of the shift is related not to the Compton wavelength of the electron , but to the Compton wavelength of the entire atom , which can be upwards of 10 @,@ 000 times smaller .

" When I presented my results at a meeting of the American Physical Society in 1923 , " Compton later recalled , " it initiated the most hotly contested scientific controversy that I have ever known . " The wave nature of light had been well demonstrated , and the idea that it could have a dual nature was not easily accepted . It was particularly telling that diffraction in a crystal lattice could only be explained with reference to its wave nature . It earned Compton the Nobel Prize in Physics in 1927 . Compton and Alfred W. Simon developed the method for observing at the same instant individual scattered X @-@ ray photons and the recoil electrons . In Germany , Walther Bothe and Hans Geiger independently developed a similar method .

= = = X @-@ rays = = =

In 1923 , Compton moved to the University of Chicago as Professor of Physics , a position he would occupy for the next 22 years . In 1925 , he demonstrated that the scattering of 130 @,@ 000 @-@ volt X @-@ rays from the first sixteen elements in the periodic table (hydrogen through sulfur) were polarized , a result predicted by J. J. Thomson . William Duane from Harvard University spearheaded an effort to prove that Compton 's interpretation of the Compton effect was wrong . Duane carried out a series of experiments to disprove Compton , but instead found evidence that Compton was correct . In 1924 , Duane conceded that this was the case .

Compton investigated the effect of X @-@ rays on the sodium and chlorine nuclei in salt . He used X @-@ rays to investigate ferromagnetism , concluding that it was a result of the alignment of electron spins . In 1926 , he became a consultant for the Lamp Department at General Electric . In 1934 , he returned to England as Eastman visiting professor at Oxford University . While there General Electric asked him to report on activities at General Electric Company plc 's research laboratory at Wembley . Compton was intrigued by the possibilities of the research there into fluorescent lamps . His report prompted a research program in America that developed it .

Compton 's first book , X @-@ Rays and Electrons , was published in 1926 . In it he showed how to calculate the densities of diffracting materials from their X @-@ ray diffraction patterns . He revised his book with the help of Samuel K. Allison to produce X @-@ Rays in Theory and Experiment (1935) . This work remained a standard reference for the next three decades .

= = = Cosmic rays = = =

By the early 1930s , Compton had become interested in cosmic rays . At the time , their existence was known but their origin and nature remained speculative . Their presence could be detected using a spherical " bomb " containing compressed air or argon gas and measuring its electrical conductivity . Trips to Europe , India , Mexico , Peru and Australia gave Compton the opportunity to measure cosmic rays at different altitudes and latitudes . Along with other groups who made observations around the globe , they found that cosmic rays were 15 per cent more intense at the poles than at the equator . Compton attributed this to the effect of cosmic rays being made up principally of charged particles , rather than photons as Robert Millikan had suggested , with the latitude effect being due to Earth 's magnetic field .

= = Manhattan Project = =

In April 1941 , Vannevar Bush , head of the wartime National Defense Research Committee (NDRC) , created a special committee headed by Compton to report on the NDRC uranium program . Compton 's report , which was submitted in May 1941 , foresaw the prospects of developing radiological weapons , nuclear propulsion for ships , and nuclear weapons using uranium @-@ 235

or the recently discovered plutonium . In October he wrote another report on the practicality of an atomic bomb . For this report , he worked with Enrico Fermi on calculations of the critical mass of uranium @-@ 235 , conservatively estimating it to be between 20 kilograms (44 lb) and 2 tonnes (2 @.@ 0 long tons ; 2 @.@ 2 short tons) . He also discussed the prospects for uranium enrichment with Harold Urey , spoke with Eugene Wigner about how plutonium might be produced in a nuclear reactor , and with Robert Serber about how the plutonium produced in a reactor might be separated from uranium . His report , submitted in November , stated that a bomb was feasible , although he was more conservative about its destructive power than Mark Oliphant and his British colleagues .

The final draft of Compton 's November report made no mention of using plutonium , but after discussing the latest research with Ernest Lawrence , Compton became convinced that a plutonium bomb was also feasible . In December , Compton was placed in charge of the plutonium project . He hoped to achieve a controlled chain reaction by January 1943 , and to have a bomb by January 1945 . To tackle the problem , he had the different research groups working on plutonium and nuclear reactor design at Columbia University , Princeton University and the University of California , Berkeley , concentrated together as the Metallurgical Laboratory in Chicago . Its objectives were to produce reactors to convert uranium to plutonium , to find ways to chemically separate the plutonium from the uranium , and to design and build an atomic bomb .

In June 1942 , the United States Army Corps of Engineers assumed control of the nuclear weapons program and Compton 's Metallurgical Laboratory became part of the Manhattan Project . That month , Compton gave Robert Oppenheimer responsibility for bomb design . It fell to Compton to decide which of the different types of reactor designs that the Metallurgical Laboratory scientists had devised should be pursued , even though a successful reactor had not yet been built .

When labor disputes delayed construction of the Metallurgical Laboratory 's new home in the Red Gate Woods , Compton decided to build Chicago Pile @-@ 1 , the first nuclear reactor , under the stands at Stagg Field . Under Fermi 's direction , it went critical on December 2 , 1942 . Compton arranged for Mallinckrodt to undertake the purification of uranium ore , and with DuPont to build the plutonium semi @-@ works at Oak Ridge , Tennessee .

A major crisis for the plutonium program occurred in July 1943 , when Emilio Segrè 's group confirmed that plutonium created in the X @-@ 10 Graphite Reactor at Oak Ridge contained high levels of plutonium @-@ 240 . Its spontaneous fission ruled out the use of plutonium in a gun @-@ type nuclear weapon . Oppenheimer 's Los Alamos Laboratory met the challenge by designing and building an implosion @-@ type nuclear weapon .

Compton was at the Hanford site in September 1944 to watch the first reactor being brought online . The first batch of uranium slugs was fed into Reactor B at Hanford in November 1944 , and shipments of plutonium to Los Alamos began in February 1945 . Throughout the war , Compton would remain a prominent scientific adviser and administrator . In 1945 , he served , along with Lawrence , Oppenheimer , and Fermi , on the Scientific Panel that recommended military use of the atomic bomb against Japan . He was awarded the Medal for Merit for his services to the Manhattan Project .

= = Return to Washington University = =

After the war ended , Compton resigned his chair as Charles H. Swift Distinguished Service Professor of Physics at the University of Chicago and returned to Washington University in St. Louis , where he was inaugurated as the university 's ninth Chancellor in 1946 . During Compton 's time as Chancellor , the university formally desegregated its undergraduate divisions in 1952 , named its first female full professor , and enrolled record numbers of students as wartime veterans returned to the United States . His reputation and connections in national scientific circles allowed him to recruit many nationally renowned scientific researchers to the university . Despite Compton 's accomplishments , he was criticized then , and subsequently by historians , for moving too slowly toward full racial integration , making Washington University the last major institution of higher learning in St. Louis to open its doors to African Americans .

Compton retired as Chancellor in 1954 , but remained on the faculty as Distinguished Service

Professor of Natural Philosophy until his retirement from the full @-@ time faculty in 1961 . In retirement he wrote Atomic Quest , a personal account of his role in the Manhattan Project , which was published in 1956 .

= = Philosophy = =

Compton was one of a handful of scientists and philosophers to propose a two @-@ stage model of free will . Others include William James , Henri Poincaré , Karl Popper , Henry Margenau , and Daniel Dennett . In 1931 , Compton championed the idea of human freedom based on quantum indeterminacy and invented the notion of amplification of microscopic quantum events to bring chance into the macroscopic world . In his somewhat bizarre mechanism , he imagined sticks of dynamite attached to his amplifier , anticipating the Schrödinger 's cat paradox , which was published in 1935 .

Reacting to criticisms that his ideas made chance the direct cause of people 's actions , Compton clarified the two @-@ stage nature of his idea in an Atlantic Monthly article in 1955 . First there is a range of random possible events , then one adds a determining factor in the act of choice .

A set of known physical conditions is not adequate to specify precisely what a forthcoming event will be . These conditions , insofar as they can be known , define instead a range of possible events from among which some particular event will occur . When one exercises freedom , by his act of choice he is himself adding a factor not supplied by the physical conditions and is thus himself determining what will occur . That he does so is known only to the person himself . From the outside one can see in his act only the working of physical law . It is the inner knowledge that he is in fact doing what he intends to do that tells the actor himself that he is free .

= = Death and legacy = =

Compton died in Berkeley , California , from a cerebral hemorrhage on March 15 , 1962 . He was survived by his wife and sons , and buried in the Wooster Cemetery in Wooster , Ohio .

Compton received many awards in his lifetime , including the Nobel Prize for Physics in 1927 , the Matteucci Gold Medal in 1933 , the Royal Society 's Hughes Medal and the Franklin Institute 's Benjamin Franklin Medal in 1940 . He is commemorated in various ways . The Compton crater on the Moon is co @-@ named for Compton and his brother Karl . The physics research building at Washington University in St Louis is named in his honor . Compton invented a more gentle , elongated , and ramped version of the speed bump called the " Holly hump , " many of which are on the roads of the Washington University campus . The University of Chicago Residence Halls remembered Compton and his achievements by dedicating Arthur H. Compton House in Chicago in his honor . It is now listed as a National Historic Landmark . Compton also has a star on the St. Louis Walk of Fame . NASA 's Compton Gamma Ray Observatory was named in honor of Compton . The Compton effect is central to the gamma ray detection instruments aboard the observatory .