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Compton Effect: Historical Background

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A review of the chain of experiments whose results were finally explained by Compton's discovery of the Compton effect shows that these experiments were not solely in the field of x rays. The studies of the scattering of high-energy gamma rays of radium had presented physicists with the puzzle that scattered gamma rays were distinctly less penetrating than were those that had not been scattered, and that the amount of this "softening" of the scattered gamma rays was dependent on both the initial "hardness" of the gamma rays and on the scattering angle. Many of the experimental facts of the Compton effect were well known from the studies of scattering of gamma rays some years before the effects were observed with x rays. Compton's interest in the problem was apparently greatly stimulated by his own experiments on the scattering of gamma rays.

However, since the first detailed and convincing experimental verification of several of the consequences of Compton's hypothesis came from experiments with x rays, one may not be aware of the important role played by gamma-ray experiments in the steps leading to the discovery.

As one looks at the list of experimental physicists whose works have merited the recognition of a Nobel Prize, one is quick to recognize that many of these experiments which were milestones when they were first performed, are now often found in undergraduate and in graduate laboratories in regular physics courses. The point is clear from a list of just a few such experiments: the Zeeman effect, e/m of electrons, the Laue patterns, the Bragg spectrometer, the oil drop and the h/e experiments of Millikan, the Franck–Hertz experiment, the study of the Richardson equation, the cloud chamber, the study of nuclear resonance, the Mössbauer effect and, perhaps, others.

Although the Compton effect stands as a landmark in modern physics, it is not often thought of as being an experiment suitable for the student laboratories. The reasons for this may stem partly from a misunderstanding of the chain of events that led to Compton's discovery.

The well-known facts of the discovery are not subject to misinterpretation. Arthur Holly Compton was working with x rays, and was studying their scattering at different angles and by different materials. A Bragg crystal spectrometer was used to analyze the wavelengths present in the scattered radiation, and it was found that part of the scattered radiation was shifted to longer wavelengths (relative to the incident wavelengths) in a manner that was independent of the atomic number of the scattering material and which depended only on the angle θ through which the x rays were scattered. Compton proposed a quantum theory of scattering from which he was able to derive the relation between the scattered wavelength λ and the incident wavelength λ_0

$$\lambda - \lambda_0 = (h/m_0c)(1-\cos\theta) = 0.024(1-\cos\theta)\ \text{Å}, \quad (1)$$

as well as other relations for the energy of the scattered electron, etc. Compton recently published his recollections of the discovery and of the steps leading up to its complete experimental verification.[1] It may be a common misunderstanding to think that since the Compton effect is basically an x-ray phenomenon, it is quite difficult to observe because it requires an x ray set as well as a Bragg spectrometer. Simple arithmetic tends to support this concept of difficulty, for if one uses, as Compton did, the molybdenum K x-ray lines whose wavelength is approximately 0.71 Å, then the radiations scattered at 90° should be shifted by 0.024 Å to approximately 0.73 Å, which is about a 3% change in wavelength. The idea of the difficulty of the experiment is further supported by an examination of Fig. 1 which is taken from Compton's work. One sees here that the whole range of the effect takes place in less than 1° of deflection by the Bragg spectrometer. If asked if there are modern tech-

[1] A. H. Compton, Am. J. Phys. **29**, 817 (1961).

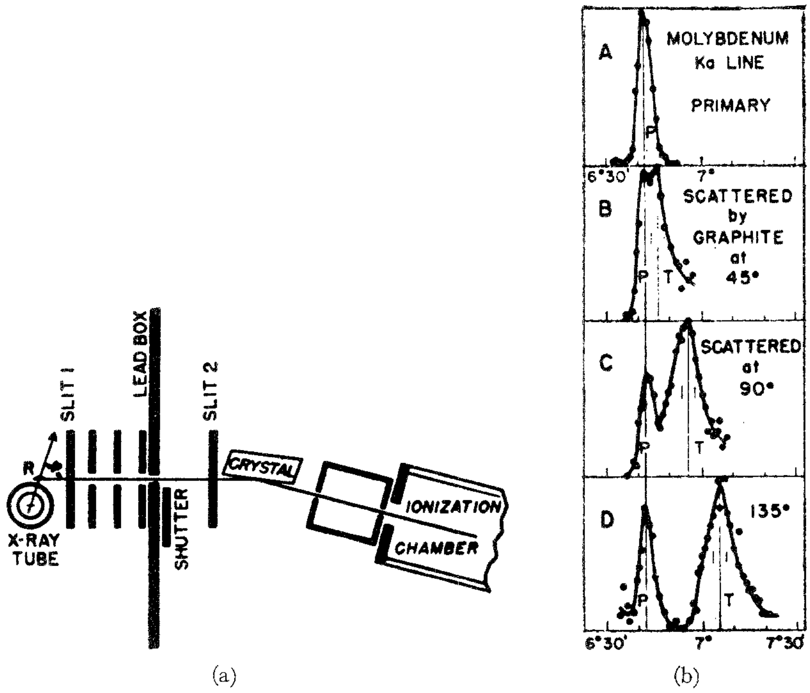

FIG. 1. Apparatus and sample results of Compton's experiment on the wavelength shift of scattered x rays.

niques which might make the observation of the Compton effect more suitable for a student laboratory, one may suggest that the present availability of isotopes, such as cobalt 60, should make the problem much simpler than that faced by Compton. The two gamma rays emitted by Co^{60} have energies of 1.33 MeV and 1.17 MeV which might crudely be thought to be monochromatic radiation with an average energy of 1.25 MeV with a corresponding wavelength of 0.010 Å. The 90° wavelength shift of 0.024 Å would give a wavelength change on scattering from 0.010 Å to 0.034 Å or a shift of nearly 250%. Such a change could be seen by the most crude of techniques, i.e., the absorption of gamma rays in lead. It was felt that the use of gamma rays from radioisotopes could thus give today's student the chance to see an effect which required elaborate and difficult techniques when it was first studied with x rays.

A review of the literature revealed, in the background to Compton's work, a picture quite different from that which was expected. In particular, the literature shows that the puzzling wavelength shift in the scattered radiation was first seen and studied in the scattering of the high-energy gamma rays from radium. The change in wavelength of scattered x rays is proportionally a much smaller effect than the change in the scattering of gamma rays and hence the development of an empirical understanding of the effect seems to have centered around the gamma-ray experiments until a rather high state of development had been reached in the techniques of x-ray experiments. Several things pointed however to the use of x rays and the Bragg spectrometer for final quantitative experimental description of the effect. The Bragg spectrometer was the only real quantitatively analytical tool available for the study of short wavelength electromagnetic radiation. It worked well for x rays, and by its use physicists had gained a good understanding of the spectral composition of x-ray beams. No such analytical tool had been developed for the problems of understanding the spectral composition of the radiations from radioactive substances, hence it was not an attractive proposition to use beams of gamma rays of unknown spectral composition to study the spectra of the scattered gamma radiation. In the period immediately before and after World War I it was more urgent that physicists should seek to learn about the spectral composition of gamma rays from radium and from other sources before they attempted to use these radiations to quantitatively gain an understanding of the scattering problem.

A brief review of some of the works that led up to Compton's discovery may be of interest, in order to point out the important role played by the gamma-ray scattering experiments.

The discovery of x rays by Roentgen and the discovery of radioactivity by Becquerel came very close to one another in the years 1895 and 1896. The exact nature of x and presumably of gamma rays was not established with certainty until the work of Friedrich, Knipping, and Laue in 1912[2] and the work of the Braggs in 1913.[3] However, in this intervening time, the scattering of both x and gamma rays were intensively studied. Eve of McGill University[4] made studies with the penetrating rays from radium, in which he studied the scattered radiation from various materials as they were irradiated by a beam of gamma rays. His Fig. 1 shows the usual scattering experiment in which a source irradiates a sheet of material which scatters radiation to a detector, the detector being shielded from the direct rays from the source by a thick lead shield. He demonstrated a straight-line plot of the logarithm of the scattered intensity vs the thickness of absorbers placed in the scattered beam, and he concluded, "It appears that in this case the secondary rays are more homogeneous than the rays which cause them, since the coefficient of absorption is not constant for the primary β or gamma rays." In 1908, Kleeman[5] compared the properties of the primary rays from radium and the secondary or scattered rays from materials irradiated by the gamma rays from radium. He concluded, "Thus zinc [and also carbon] radiates a greater proportion of rays which are well absorbed by lead than lead itself [does]." and, "It will be seen that, on the whole, the coefficients of absorption of the secondary rays are much greater than those of the primary rays." Madsen[6] continued experiments with radium radiations, and among his conclusions were the statements, "Secondary gamma radiation appears on both sides of a plate which is penetrated by a stream of gamma rays. There exists a marked lack of symmetry between the amount of secondary radiation which proceeds from the two sides. A lack of symmetry exists in the case of some substances between the quality of the radiation on the two sides." The word "quality" refers to degree of penetration of absorbers, to the hardness, or to the wavelength of the radiations.

This work was followed by the first of several by Florance[7] in which a number of new ideas were used in the experimental observations. Florance placed an electroscope on an arm that would allow the electroscope to move on the arc of a circle at a constant distance from the scatterer, and some of the basic ideas of good and poor geometry were apparently in his mind as he discussed the effects of secondary radiations on the measurements of primary intensities. It was necessary that he think about these problems because he reported his radium source to be 300 mg which gave him sufficient intensity to allow small effects to be seen. He reported, "A few experiments were carried out on the radiation emitted from the surface of the plate against which the primary rays strike." In his summary he itemized the following observations. "Secondary gamma rays are emitted from both sides of a plate exposed to gamma rays. The 'incident' secondary (scattered through angles greater than 90°) is in all cases softer than the 'emergent' secondary (scattered through angles less than 90°). There is, moreover, a gradual change from the quality of the primary to that of the secondary emergent and then to that of the secondary incident. The quality therefore depends on the position of the electroscope." Thus in 1910 the angular dependence of the wavelength of the scattered radiation had been at least qualitatively established. The other summary conclusions of Florance are very easy to understand in terms of our present understanding of what he was observing. Sections of his final conclusions merit quotation in some detail for their accurate description of experimental phenomena. "In the foregoing results there is nothing to suggest that the secondary gamma radiation is a true secondary excited in the material of the radiator by a transformation of the primary rays. In such

[2] W. Friedrich, P. Knipping, and M. Laue, Ber. Akad. Wiss. **303**, (1912); Ann. Phys. **41**, 971 (1913).

[3] W. H. Bragg and W. L. Bragg, Proc. Roy. Soc. (London) **A88**, (1913); **A89**, 246 (1913).

[4] A. S. Eve, Phil. Mag. **8**, 669 (1904).

[5] R. D. Kleeman, Phil. Mag. **15**, 638 (1908).

[6] J. P. V. Madsen, Phil. Mag. **17**, 423 (1909).

[7] D. C. H. Florance, Phil. Mag. **20**, 921 (1910).

a case, it would be expected that each element would give out a characteristic radiation. (This was still prior to the discovery of x ray diffraction and the subsequent analytical work of Moseley.) Experiments show that with proper conditions, every substance can be so chosen as to give a similar type of (secondary or scattered) radiation." "The quality of the secondary gamma radiation shows no sudden change from that of the primary. There is simply a gradual softening the more the secondary radiation is deflected from its original direction. The gradual softening is the same for every radiator." From this he proceeds to conclude, "The primary gamma rays possess a wide range of penetrating power. The softening of the secondary radiation that has been observed is the result of the heterogeniety of the primary rays. The softer radiation is more scattered than the harder radiation; as the radiator is increased in thickness, more of the harder gets turned aside, and in consequence we get both the hardening of the primary and of the secondary." In 1912, Sadler and Mesham[8] made careful studies with x rays, performing a double scattering experiment. The supposed heterogeneity of x rays and of gamma rays always served to cloud the results of direct scattering experiments in which the study of absorption coefficients continued to be the main analytical tool that was available for the determination of the quality (wavelength) of the radiations. In the experiment of Sadler and Mesham, the first scattering from copper was to yield a relatively homogeneous beam of K characteristic x rays and it was with this supposedly homogeneous beam that their experiments were done. They concluded, "There was strong evidence that the radiations excited in carbon (by x rays) was heterogeneous and distinctly *less penetrating* than the primary exciting beam." They itemize the following three conclusions:" (1) A homogeneous beam (of x rays) when scattered by a substance of low atomic weight is transformed into a softer type of radiation. (2) The harder the exciting beam the greater is the intensity of the scattered radiation. (3) The harder the exciting beam, the more profound is the change in quality between the incident and the scattered radiations." Gray[9] was one of the first to question the idea that selective (energy dependent) scattering of a heterogeneous beam gave an apparent shift in the wavelength of the scattered radiation. Gray wrote, "The writer came to the conclusion that gamma rays could be directly scattered (classically with no wavelength change), but further consideration of the experiments of Madsen and Florance showed that the classical interpretation of the scattering of gamma rays given was probably not sufficient, as it appeared that when the intensity of the primary rays was diminished by lead, the softer scattered rays were not cut down so quickly as one would expect." "It seems quite probable that the change in quality is small for very soft x rays." "The quality and quantity of the scattered radiation is approximately independent of the nature of the radiator." Thus at the time of the appearance of x-ray crystal diffraction as a tool for studying the composition of x-ray beams, many of the essential features of the Compton effect were known, and these features were first recognized in the study of the scattering of gamma rays and the scattering of x rays. Even though Moseley quickly demonstrated the great analytical capabilities of the new Bragg crystal spectrograph, this tool was not brought into the study of the scattering problem for some years, and in the meantime some of the old ideas continued to persist. In 1914, Florance, who was then asistant lecturer and demonstrator at the University of Manchester wrote,[10] in spite of the earlier work of Sadler and Mesham, "The general view at the present time regarding the scattered x rays is that they are of the same penetrating power as the primary x rays." However, he did no longer hold the view that energy dependent classical scattering of a heterogeneous beam gave rise to the apparent softening of the scattered rays, for he also said, "It is necessary to adopt the first view, i.e. that the primary gamma rays during the process of scattering lose energy and are in consequence modified in type." A short time later Florance wrote,[11] "The penetrating power of this scattered radiation may become modified in its final passage through matter, but the penetrating power of the scattered radiation depends essentially on

[8] D. A. Sadler and P. Mesham, Phil. Mag. **24**, 138 (1912).
[9] J. A. Gray, Phil. Mag. **26**, 611 (1913).
[10] D. C. H. Florance, Phil. Mag. **27**, 225 (1914).
[11] D. C. H. Florance, Phil. Mag. **28**, 363 (1914).

the angle of scattering and not on the material of the radiator."

World War I interrupted these works at a time when the problem seemed to be fairly well understood, mainly from experiments with gamma rays, and at a time when the Bragg spectrometer, the tool that was to be invaluable in the solution of the problem, had already demonstrated its great versatility.

Following World War I, J. A. Gray[12] made a new series of measurements with gamma rays from radium. He pointed to the past troubles and to the way to resolve the experimental difficulties, "When we wish to compare the qualities of two different beams, we should obtain their spectra, but this is often impracticable especially for spectra from radioactive nuclei. In experiments on the scattering of x rays, such a comparison has invariably been made by absorption measurements." He described his own experiments and then concluded, "The results we have obtained would be explained if we could always look on a beam of x- or gamma-rays as a mixture of waves of definite frequencies, and if rays of a definite frequency were altered in wavelength during the process of scattering, the wavelength increasing with the angle of scattering." However, he was still aware of the persistence of some of the classical ideas, for he also wrote, "The views of most writers about the quality of scattered x rays have been well summed up by G. W. C. Kaye in his book on 'X-rays.' 'All substances, when exposed to a beam of X-rays themselves give out X-rays, which are identical with the primary rays in quality, and can, in fact, be conveniently regarded as so many unchanged primary rays which have been merely scattered or deviated by the substance.' "

This problem attracted the attention of A. H. Compton, who went to the Cavendish Laboratory in England for a period to work on it. He repeated, with refinements, some of the definitive experiments using absorption techniques to try to deduce spectral information about direct and scattered radiations from radium. He also began a serious study of the theoretical interpretations of the problem.[13] "It is the purpose of the present paper to investigate the nature and the general characteristics of secondary *gamma rays*, and to study the mechanism whereby comparatively soft secondary radiation is excited by relatively hard primary radiation." Again, absorption techniques seemed inadequate for a resolution of the problem, for he concluded, "It seems premature to attempt any detailed explanation of the failure of the usual electron theory (of scattering) until more definite information is available with regard to the wavelength of the hard gamma rays." In the paper that followed this, Compton reported on an investigation he had done at the Cavendish laboratory to attempt to learn more about the gamma-ray spectrum of radium. Here again one notes the double dilemma which faced those physicists who sought to understand the phenomena which took place in the scattering of gamma rays. The classical theory of scattering was developed by J. J. Thomson and was based on the traditions of Maxwell. The respect felt for Thompson may have caused some reluctance among physicists to explore scattering theories that departed from Thomson's classical theory. The reluctance may have been all the greater because the puzzling evidence was in large part from the study of gamma-ray scattering, and little or no spectral information was available on the composition of the gamma-ray beams. This was especially true because, as Compton noted, there was a need for "more definite information—with regard to the wavelength of the hard gamma rays" (of the radioactive materials used in the various experiments to test the scattering theories).

Upon this return to St. Louis, Compton appears to have worked steadily on the problem. An abstract[14] summarizes the problem and some points of interpretation. A second abstract[15] shows that the Bragg crystal principle is at last being brought into the study. "More recent experiments have shown that this phenomenon is not confined to heterogeneous X-rays, but occurs also when the rays incident upon the radiator have been reflected from a crystal. The most obvious interpretation of these results was that in addition to scattered radiation there appeared in the secondary rays a type of flourescent radiation, whose wavelength was nearly independent

[12] J. A. Gray, J. Franklin Inst. **190**, 633 (1920).
[13] A. H. Compton, Phil. Mag. **41**, 749 (1921).
[14] A. H. Compton, Phys. Rev. **18**, 96A (1921).
[15] A. H. Compton, Phys. Rev. **19**, 267A (1922).

of the substance used as a radiator, depending only upon the wavelength of the incident rays and the angle at which the secondary rays are examined." Compton also brought forth another possible interpretation, "If we suppose that the incident beam (of X-rays) ejects electrons moving forward with a kinetic energy hc/λ, where λ is the wavelength of the exciting ray, and if the ejected electron is oscillating at such a frequency that as observed in the direction of motion, the wavelength is λ, on account of the Doppler effect, the wavelength of the radiation at right angles with the primary beam will be very close to that of the fluorescent rays observed in these experiments." The February 1923 issue of the *Physical Review* carries the minutes of the Chicago meeting of the American Physical Society, 1 and 2 December 1922, in which abstract No. 32[16] carries Compton's solution to the problem in a paper entitled, "A Quantum Theory of the Scattering of X-rays by Light Elements." In the abstract he says, "The hypothesis is suggested that when an X-ray quantum is scattered it spends all of its energy and momentum upon some particular electron. This electron in turn scatters the ray in some definite direction. The change in momentum of the X-ray quantum due to the change in its direction of propagation results in a recoil of the scattering electron. The energy in the scattered quantum is thus less than the energy in the primary quantum by the kinetic energy of recoil of the scattering electron. The corresponding increase in wavelength of the scattered beam is

$$\lambda_\theta = \lambda_0(1 + 2\alpha \sin^2\theta/2), \quad \text{where} \quad \alpha = h/mc\lambda_0."$$

Compton made a full published report on the experiments and the theoretical interpretation shortly thereafter.[17] "It has long been known that secondary gamma rays are softer than the primary rays which excite them, and recent experiments have shown that this is also true of X-rays. By a spectroscopic examination of the secondary X-rays from graphite, I have, indeed, been able to show that only a small part, if any, of the secondary X- radiation is of the same wavelength as the primary." He proceeded then not only with the demonstration of the wavelength increase for scattered x rays, but also went back to his own data taken in England on the scattering of the gamma rays of radium and showed that they too supported the quantum theory of scattering. Compton's recent article[1] includes several interesting highlights of the period following the discovery. In recognition of this work, the Nobel Physics Prize of 1927 was awarded to A. H. Compton. The prize of 1927 was shared with C. T. R. Wilson for Wilson's discovery of the cloud chamber, for its application to several physical problems, and in particular for Wilson's verification of the Compton effect through cloud-chamber pictures.

It is of interest to examine the Nobel Prize citations for the year 1927.[18]

"Professor M. SIEGBAHN, member of the Nobel Committee for Physics, spoke to the following effect":

"The Royal Academy of Sciences has awarded this year's Nobel Prize in Physics to Professor ARTHUR HOLLY COMPTON of the University of Chicago for the discovery of the phenomenon named after him the Compton effect, and to Professor CHARLES THOMSON REES WILSON of the University of Cambridge for his discovery of the expansion method of rendering visible the tracks of electrically charged particles.

"Professor COMPTON has won his prize by work in the field of X-radiation. Soon after RÖNTGEN's discovery it became known that matter exposed to X-rays emits radiations of different character. Besides an emission of electrons, corresponding to the photoelectric effect known also in the optical region of radiation, there is also a secondary X-radiation. Even before the methods of X-ray spectrometry were known, these secondary X-rays were proved by the investigation of their absorption to be of a twofold nature. It was BARKLA who, through his fundamental researches, proved that the secondary X-radiation consists partly in a scattering of X-rays, which he thought to have the same penetrability as the original radiation, and partly in a specific X-radiation which was characteristic of the chemical atom and which was more easily absorbed.

"When X-rays fell upon matter with small atomic weight, as for example graphite, BARKLA was not able to detect the mentioned characteristic X-radiation, but only a scattering; and consequently the secondary rays ought to have the same properties as the original X-rays. BARKLA, however, in the course of his investigations of the absorption, had already been able to show that in this case also the secondary X-rays—at least partly—are more easily absorbed than the original radiation and therefore have a greater wavelength. BARKLA thought this to be a new characteristic X-radiation.

"This is the point where COMPTON comes in and affects the development of science. He made exact spectro-

[16] A. H. Compton, Phys. Rev. 21, 207A (1923).
[17] A. H. Compton, Phys. Rev. 21, 483 (1923).
[18] "*Les Prix Nobel en 1927*" (P. A. Norstedt & Söner Stockholm, 1928).

metrical investigations of the secondary X-radiation from matter with small atomic weight: in other words, he undertook to investigate exactly the scattered X-radiation. After some preliminary work, he found an experimental method that gave results which were as exact as they were astonishing.

[Compton's discovery was outlined and Compton's theory to describe the effect was presented with emphasis on the point that the theory predicted the simultaneous appearance of a scattered electron and of a scattered photon of reduced energy.]

"Thus this theory predicts recoil electrons with a velocity generally much smaller than that of the above-mentioned electrons which correspond to the photo-electric effect. It was a triumph for both parties when these recoil electrons were discovered by WILSON's experimental method both by WILSON himself and, independently, by another investigator. Hereby the second chief phenomenon of the Compton effect was experimentally verified, and all observations proved to agree with what had been predicted in COMPTON's theory.

"Finally, the fact deserves to be emphasized that the Compton effect has proved to be of decisive influence upon the absorption of short-wave electro-magnetic—especially radio-active—radiation and of the newly discovered cosmic rays.

"Professor WILSON has been awarded his prize for the discovery of a purely experimental method, which dates back from as long ago as 1911. It is based upon the formation of clouds, which develop when sufficiently moist air is suddenly expanded. [The application of the method to the study of alpha and beta ray tracks is described, and then Professor Siegbahn continued:] "The problem is a little more complicated when the nature and the details of the ionization caused by X-rays [i.e., the Compton scattered electron and photoelectric interaction of the Compton scattered photon in the gas of the chamber] have to be analysed; and the perfect method for such investigations was not described until in a paper of 1923. The extremely delicate regulation of small time intervals which is necessary in such researches is attained by the use of three pendulums of adjustable period, which are all released simultaneously. The pendulum which comes down first opens a communication with a vacuum, and the resulting suction is used, by a mechanical device, to produce a sudden expansion of the gas that is being examined. The second pendulum releases an electric spark, which passes through an X-ray tube, oscillatory sparks being excluded; and thus the anticathode is brought to send an X-radiation of extremely short duration through the gas before the lenses of a stereoscopic camera. The third pendulum releases another electric spark, which passes through mercury vapour and momentarily illuminates the clouds. By means of sliding weights on the different pendulums, just as on an ordinary metronome, WILSON was able to bring it about that the X-rays were sent through the gas at the moment when the expansion was complete, and the illuminating spark just as long afterwards as was needed for a sufficient formation of droplets round the ions, but before the droplets had time to be dislocated by currents in the gas, which might have deformed the tracks visible on the photographic pictures.

[In summary it was said] "Of late years new and scientifically important results have been attained which could not have been gained by other methods. The consequence of this is that the discovery, although it was made so long ago, satisfies the provisions for the award of the Nobel Prize. It would not be of much use to describe these results on this occasion, as the understanding of them presupposes full knowledge of the structure of the atom. I will merely call to mind that in 1923 WILSON gave the experimental proof of the existence of the recoil electron tracks that had been postulated by COMPTON for his explanation of the change in wave-length of scattered X-rays, and that his method has rendered possible the closer examination of these tracks."

In his acceptance of his award, Professor Wilson said, "I am very glad to be associated with my friend Professor Compton in the award of the Nobel Prize for Physics. Compton was one of the workers at the Cavendish Laboratory a few years ago and in virtue of that we in Cambridge look upon him as one of ourselves."

Compton's Nobel Prize lecture of 12 December 1927 was entitled "X-Rays as a Branch of Optics" and in it he discussed, "The Refraction and Reflection of X-Rays", "The Diffraction of X-Rays," and "The Scattering of X-Rays and Light". In this lecture he described the cloud chamber pictures in which the scattered electron is identified and its angle with the direction of the initial x-ray beam is observed. If the scattered photon happens to interact in the chamber to produce a photoelection, then the vector from the point of scattering to the start of the photoelectron track identifies the angle the scattered photon makes with the incident direction of the x-ray beam. These angles were observed to be in accord with the predictions of his theory. "This experiment is of especial significance, since it shows that for each recoil electron there is a scattered photon, and that the energy and momentum of the system photon plus electron are conserved in the scattering process."

This brief examination of some of the highlights of the studies that led to Compton's quantum theory of scattering should make it clear that the laboratory demonstration of the Compton effect through the scattering of high-energy gamma rays as described in the papers that follow, is not at all a modern technique but is in fact the line of experimentation which started in 1904 and which played a very important role in leading to the discovery in 1923, and the very common association of Compton effect and x rays (to the exclusion of gamma rays) is inappropriate. By taking advantage of the availability today of cobalt 60 or other sources of hard gamma rays, we are not using a new technique that was unavailable to Compton, we are rather going back to the original type of investigation that played such an important part in the steps that led to Compton's discovery.

The final preparation of this manuscript was completed while the author was a guest at the Nobel Institute of Physics in Stockholm.

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Compton Effect: A Simple Laboratory Experiment

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An experiment is described in which the magnitude and angle dependence of the wavelength shift of Compton scattered photons can be determined. The equipment necessary for the experiment is simple and inexpensive. The experiment is a modified version of the "absorption curve" type of study which as early as 1904 (nearly 20 years prior to Compton's discovery) showed the wavelength shift of scattered gamma-ray photons.

THE goal of the experiment described here was to achieve a conclusive demonstration of the Compton effect with equipment that is modest in cost and construction.

It was desired to use gamma rays rather than x rays because of the ease of obtaining radioisotopes such as cobalt 60 or cesium 137 whose emissions are reasonably monoenergetic. These gamma rays have high energies and a corresponding short wavelength. Since the Compton wavelength shift at any scattering angle is independent of the wavelength of the incident photons, the higher the energy of the incident gamma rays, the greater is the percentage shift in the energy and wavelength of the scattered radiation. For instance, the gamma rays of cesium 137 undergo a wavelength shift of 130% at 90° scattering, and those of cobalt 60 are shifted by approximately 250% in 90° scattering. This shift is so extreme that it may be studied by the use of the most crude of techniques, i.e., by the use of the method of studying the absorption coefficients of the direct and scattered beams.

These points are indicated in Table I which compares the cesium 137 and cobalt 60 experiments with the molybdenum K_α experiment of 40 years ago. The table indicates the energy and wavelength of the incident beams in each case, as well as the energy and wavelength of the 90° scattered beams. The last items given are the absorption coefficients in lead of the direct and scattered beams. The table makes it clear

Table I. Comparison of sources for Compton-effect experiments.

	A. H. Compton	Cesium 137	Cobalt 60
E_γ (MeV)	0.0175[a]	0.661	1.25[b]
λ (Å)	0.71[a]	0.01875	0.00991
$\Delta\lambda_{90°}$ (Å)	0.02426	0.02426	0.02426
λ Scattered 90° (Å)	0.734	0.0430	0.03417
$\Delta\lambda/\lambda \times 100$	3.4%	130%	245%
$E_{\text{Scattered }90°}$ MeV	0.0169	0.288	0.362
μ_{Direct} cm^2/g	~120	0.105	0.0502
$\mu_{\text{Scattered }90°}$	~140	0.405	0.2245
$[(\mu_D - \mu_{90°})/\mu_D] \times 100$	16%	295%	347%

[a] Molybdenum $K\alpha$.
[b] Average of 1.17 MeV and 1.33 MeV.