A TEST FOR POLARIZATION IN A BEAM OF ELECTRONS BY SCATTERING

By Carl T. Chase
New York University, University Heights

(Received September 13, 1929)

Abstract

This paper contains a final report on the researches commenced by Cox, McIlwraith, and Kurrelmeyer, and reported by them in preliminary fashion. High speed beta-particles from radium impinge on lead targets and are twice scattered at right angles. The doubly scattered electrons are counted by a point-discharge counter, the number counted at various azimuthal angles being studied, as the radium and upper target are rotated as a unit with respect to the counter and lower target. Experimental refinements have increased the total number of countable electrons and have eliminated the counts due to gamma-rays, which were very troublesome in the earlier experiments. Counts taken at four azimuthal angles separated by ninety degrees show no effect of the kind suspected by Cox, McIlwraith, and Kurrelmeyer, nor any effect of the kind which occurs when x-rays are twice scattered at right angles. More than forty-five thousand electrons were counted. The experimental error is less than one percent. It is concluded that high speed beta-rays are not polarized by scattering.

Introduction

By means of an experiment analogous to that in which Barkla showed that x-rays could be polarized by scattering at right angles, Cox, McIlwraith, and Kurrelmeyer[1] have looked for evidence of polarization in a beam of beta-rays from radium which had been scattered at right angles from a gold target, a second similar target serving as an analyzer. The electrons were detected by a point-discharge counter. In their report, which is of a preliminary nature, these authors call attention to an apparent positive effect, which is not, however, of the kind that occurs when a beam of x-rays is doubly scattered at right angles. In the case of x-rays, the intensity of the beam scattered from the second target is greatest when this beam is parallel to the beam incident on the first target, and least when the two beams are at right angles to one another. In the experiments referred to, the gamma-ray counts formed such a large part of the total count that counts were not taken in all positions of the second scattered beam with respect to the incident beam; in any one run counts were taken at two positions only, alternating between these two positions every five or ten minutes as long as the counter gave consistent results, a matter of a few hours. The counts due to gamma-rays differed widely in the different positions because of difference in path from radium to counter and difference in the amount of absorbing material in the path. This factor caused the data to show evidence of a polarization effect of the kind that x-rays would show. This was not men-

[1] Cox, McIlwraith, and Kurrelmeyer, Proc. Nat. Acad. Sci. **14**, 544 (1928).

tioned by the authors, but was spoken of by Davisson and Germer.[2] It is due entirely to the gamma-ray effect as just described, which was superposed on the electron count.

Because of this difficulty with gamma-rays, most of the data were taken in the two transverse positions, where the gamma-ray effect should be equal if the apparatus were as symmetrical as care could make it. This was done also to test an earlier observation that more scattered electrons were counted in one of the transverse directions than in the other. The results were not consistent, but most of the runs showed an effect of this nature. The present work aimed to check these observations under more controllable conditions, and was not deterred by the negative results of similar experiments,[2,3] more recently published, in which slow speed electrons from filaments were used. It was felt that the scattering of high speed electrons from radium should still be carefully investigated, especially in view of the observations of Cox, McIlwraith, and Kurrelmeyer.

Apparatus

The apparatus used is shown in section in Fig. 1, which is drawn to scale. Its main part is a brass cylinder, standing vertically in the figure. Brass

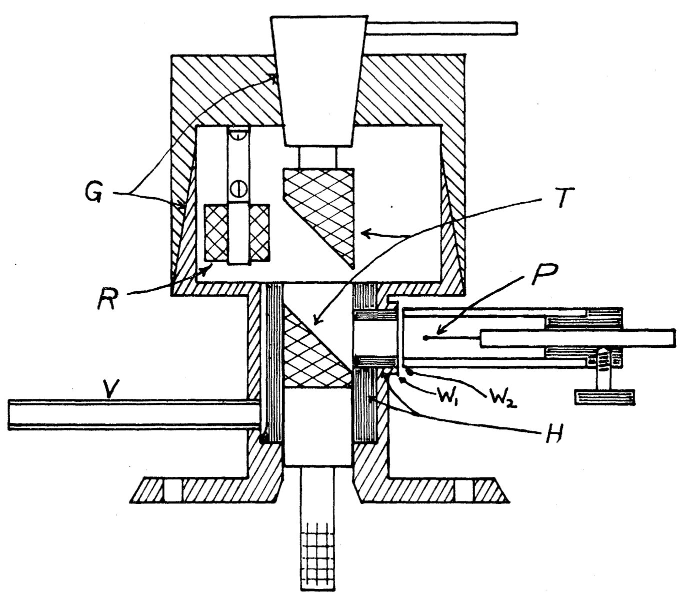

Fig. 1. Diagram of apparatus.

was used to prevent any effect of permanent magnetism. The two scattering targets T are made from lead cylinders, 1 cm in diameter, and cut at

[2] Davisson and Germer, Phys. Rev. **33**, 760 (1929).

[3] Wolf, Zeits. f. Physik **52**, 314 (1928);
Joffé and Arsenieva, Comptes rendus **188**, 152 (1929).

45° to their axis. The radium is at R, and the counter at P. The window W_1 is of mica, 0.03 mm thick, while W_2 is of aluminum foil, 0.01 mm thick. The apparatus is evacuated by means of the tube V.

Two adjustments can be made, provided for by the two ground joints G. The upper target can be rotated with respect to everything else by the plug and attached handle at the top. Or the whole upper part of the apparatus can be turned with respect to the lower part, carrying the radium and upper target together as a unit. The second adjustment allows the configuration of the path of the scattered electrons to be varied, while the first adjustment, that of the upper target alone, allows this target to be turned through 180° so that no electrons can be scattered to the lower target, a convenient method of determining how many of the counts recorded are due to gamma-rays.

H designates two tubes of hard rubber which form a lining to the lower part of the apparatus. These are to absorb the photoelectrons ejected from the brass walls by gamma-rays, and will be discussed more fully later.

Two radium sources were used. The first was a milligram of radium which had been used before by Cox, McIlwraith and Kurrelmeyer.[1] The second, to be discussed more fully, consisted of old radium emanation tubes containing radium D, E, etc., cut in half to avoid the absorption of the glass walls, and collected to form a sort of battery; seventy-five half-tubes were set into cylinders made from lead foil in order to define the electron beam, and bound in a bundle.

Continuous pumping kept the pressure in the apparatus below 10^{-4} cm of mercury, so that the mean free path of the electrons was long compared to the length of their actual path through the apparatus.

Procedure

Before giving the actual procedure, it may be well to state why the form of apparatus described above was used, and what its advantages are. When starting the present research, the writer used an apparatus similar to that used by Cox, *et al*, except that it was made of brass instead of steel, which had been used formerly, and the upper target could be turned out of the incident beam of electrons, allowing a count of the gamma-ray effect alone to be made. The dimensions were about the same as in the earlier outfit, but the targets were of lead instead of gold. A few runs showed, in the total count, an asymmetry of the same nature as had been observed by the earlier three, the effect being in the same direction and on the average of the same magnitude. To make things more certain, runs were then taken in which the gamma-ray effect was measured each time an electron count was made, in order to find what effect was due to the "net electrons." It was found immediately that the gamma-ray count was always of the order of magnitude of the total count, sometimes even more. In an attempt to get more electron counts per gamma-ray count, the present form of apparatus was developed. It has less material in the form of windows in the path of the electrons than did the earlier apparatus. By using the battery of radium tubes, as described, the high speed electrons from radium E, which product in the milligram of radium gives more of the faster electrons than any other, were kept, while the powerful gamma-rays of the earlier radium products were absent. What gamma-ray counts remained, from one-fourth to one-third of the net electron counts, were eliminated by the hard rubber lining to the lower part of the apparatus, absorbing the photoelectrons produced there by the gamma-rays. No photoelectrons could be produced in the glass wall of the counter. The total count was thus reduced to scattered electrons; when the upper target is turned through 180° so that no electrons can be scattered to the lower target, all counts disappear, and reappear immediately the target is returned to its usual position.

Another advantage of the present apparatus is the following. By increasing the number of countable electrons, the high potential applied between the foil and point of the counter could be kept at such a value that the counter would operate consistently for twelve hours or more, whereas in the previous work it had been necessary to raise this potential so high that the counter point was strained nearly to the breakdown state, causing a complete failure of the point in a short time. The writer found that, with the copious supply of electrons now available, with counter points made of platinum wire 2 mils in diameter ending in a fused ball some 4 to 6 mils in diameter and four or five mm from the foil, counters could be worked at such a voltage that a large electron count could be obtained without shortening the life of the counter below the time chosen for the length of one run, six hours of actual counting.

The procedure then was as follows. Counts were taken for five minutes at each of the four positions mentioned earlier, separated in azimuth by ninety degrees. (The azimuthal angle is that between the plane of incidence of the upper target and the plane of incidence of the second, or lower, target). The counting continued round and round until the run was over. The average count in each position was then found.

Runs were taken with the complete apparatus in several positions relative to the earth's magnetic field. The radium gun was removed and inverted. The milligram of radium was tried instead of the radium gun. A new counter point was used for each run. The whole counter was moved and rotated about its own axis. Every experimental variation that could be thought of was tried, and over 45,000 electrons were counted.

Results

The relative counts, in the series using the radium gun (no different results were obtained when using the milligram of radium) were as follows:

Azimuthal angle	Relative count
0°	1.000
90°	0.977
180°	0.958
270°	0.969

The azimuthal angle 0° corresponds to the configuration in which the electrons leaving the second target travel parallel to the beam incident on the first target, and in the same direction. The experimental error was less than one percent.

It will be seen that there is no indication of any effect of polarization either of the kind suspected by Cox, McIlwraith, and Kurrelmeyer, or of the kind occurring in Barkla's x-ray experiment. In looking for the latter effect, the counts at 0° and 180° must be averaged and compared with the average count at the two transverse positions. Further, none of the experimental variations produced any noticeable effect on the relative counts in the four positions studied.

Critique of the Result

One must conclude then that a beam of electrons is not polarized by scattering, even when the electrons have the high speeds of the beta-rays from radium E. It is hard to see how an asymmetry in the apparatus of Cox, McIlwraith, and Kurrelmeyer, or in the earliest apparatus of the present writer, could have produced the observed effect in such a large fraction of the number of runs, because of the care used in making the apparatus symmetrical, and in inverting the radium, etc. In the writer's case, this effect must have been entirely due to gamma-rays in which case the asymmetry must have been due to some asymmetry in the apparatus. Some data of Cox and his coworkers[4] seems to show that in their case more electrons were counted per gamma-ray than in the case of the author's earliest work. If any change had taken place in the relative proportions of the various radioactive products in the milligram of radium during the year that elapsed between the two sets of observations, this change could not account for an observed asymmetry in one case and not in the other, except that perhaps more electrons per gamma-ray were counted in one case. But in the final work herein discussed, electrons alone are counted and there is no effect. It may be remarked that the apparatus of Cox *et al* and that first used by the present writer, which gave similar results, were both made on the same lathe.

In the present work it was impossible to limit the beams to strictly parallel beams without seriously decreasing the number of countable electrons. The effect of the divergence of the beams has been investigated and appears to be too small to influence the nature of the result, as far as any asymmetry of either of the two kinds mentioned above is concerned.

A theory of the experiment has just been published by Mott,[5] who considers the double scattering of Dirac electrons by atomic nuclei. This theory, while not as yet entirely complete, predicts a difference between the counts at 0° and 180°. The data just given show that more electrons were counted at 0° than at 180°, but this has been ascribed to the somewhat freer path through the apparatus which the electrons have in the 0° position.

[4] Cox, McIlwraith, and Kurrelmeyer, unpublished, privately communicated.

[5] Mott, Roy. Soc. Proc. **A124**, 425 (1929).

Beam divergence might conceivably influence the result when comparing the counts at 0° and at 180°, due to the different configurations of path and the resulting differences in the various angles of incidence and of scattering. But it is improbable that a true polarization effect could have been masked in such a way, in as much as two radium sources, giving initial beams of different degrees of divergence were used, and the result was the same with each. Further experiments are now in progress, using a stronger source and parallel beams.

The author wishes to express his most sincere thanks to Professor Richard T. Cox of this laboratory for his interest and help in pushing this work to a successful conclusion, and to Mr. Frank E. Myers for constructing and maintaining in operation the vacuum tube amplifier necessary in the operation of the couter. He is also most grateful to Mrs. Edith H. Quimby of the New York Memorial Hospital for furnishing the radium tubes without which the success of the experiment would have been impossible.