FEBRUARY 1, 1932 *PHYSICAL REVIEW* *VOLUME 39*

ON AN ATTEMPT TO DEFLECT MAGNETICALLY THE COSMIC-RAY CORPUSCLES

BY L. M. MOTT-SMITH
THE RICE INSTITUTE

(Received December 16, 1931)

ABSTRACT

This paper reports the results of an experimental attempt magnetically to deviate the high-energy corpuscles associated with the cosmic radiation. With a magnetic analyser involving the use of Geiger-Müller electron counters and the magnetic field in the interior of a magnetized iron bar, it is found that no deviation of the corpuscles which cause the simultaneous discharges of the counters occurs. Calculation of the sensitivity indicates that an observable deviation would have been produced if the corpuscles were electrons of energy 2×10^9 *e*-volts or less or portons of energy 10^9 *e*-volts or less.

The difficulties involved in explaining this result are discussed and various possible interpretations are presented.

INTRODUCTION

IN THE present paper will be reported the results which have been obtained in the attempt magnetically to deviate the cosmic corpuscular radiation. The general character of the method has been described,[1] and preliminary results have already been presented.[2] The present experimental method was devised at about the same time independently by Rossi,[3] by Tuve,[4] and by the author. Results were first obtained by Rossi, who found that the greater part of the corpuscles passing through his apparatus if assumed to be electrons had an energy greater than about 10^8 *e*-volts. Recently a note by Rossi[5] has appeared in which he presents new results obtained by a more sensitive method which indicates energies greater than 10^{10} *e*-volts on the above assumption.

The starting point of this work was the work of Bothe and Kolhorster[6] who found that the cosmic radiation seems to consist principally of high energy ionizing particles. At that time it seemed natural to assume the particles to be electrons; and from their penetrating power it appeared that their energy had to be of the order of 10^9 *e*-volts. In order to obtain more definite information with regard to their energy an apparatus was set up which could give measurable deviation of electrons of this energy. Contrary to expectation, however, it turns out that no deflection is observed. It does not

[1] L. M. Mott-Smith, Phys. Rev. **35**, 1125 (1930).
[2] L. M. Mott-Smith, Phys. Rev. **37**, 1001 (1931).
[3] B. Rossi, Rend. Acc. dei Lincei **2**, 478 (1930).
[4] M. A. Tuve, Phys. Rev. **35**, 651 (1930).
[5] B. Rossi, Nature **128**, 300 (1931).
[6] W. Bothe and W. Kolhörster, Zeits. f. Physik **56**, 751 (1929).

seem possible to find a satisfactory interpretation of this result at the present time. However, some interesting questions are raised so that it seems worth while to present the experimental method and the results in detail.

Experimental

Method

The experimental method is based on the discovery by Bothe and Kolhörster that the high-energy particles associated with the cosmic rays can be studied by making use of their ability to cause the simultaneous discharge of two neighboring Geiger-Müller tube electron-counters.[7] This "coincidence method" is a very powerful means of studying these particles since this effect, save for chance coincidences, which can easily be allowed for, is practically entirely due to the cosmic radiation, and because it is possible to detect individual particles.

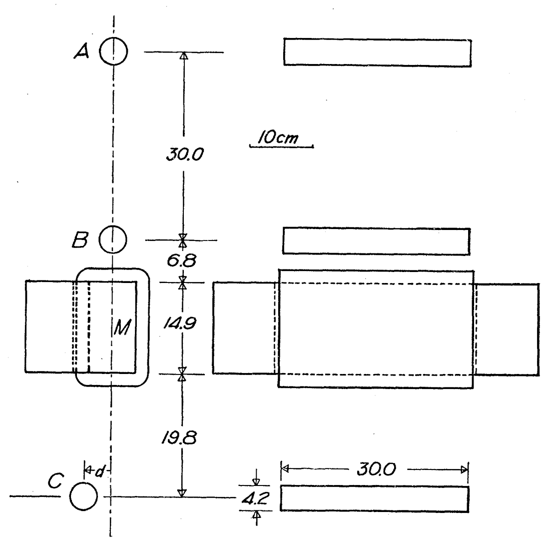

Fig. 1. Arrangement of apparatus.

For the purpose of magnetic analysis of these particles, Bothe and Kolhörster's method of counting coincidences between two counters was extended by the introduction of a third counter and recording the triply coincident discharges of the three. It was verified that the frequency of the triple coincidences under various geometrical arrangements of the three counters was exactly that to be expected on the assumption that the discharges are caused by the rectilinear passage of an ionizing particle through the apparatus, entirely in accord with Bothe and Kolhörster's position with regard to the meaning of the coincident discharges. (Evidence for this comes from the experimental results to be presented below.) The triple coincidence arrangement made it possible to set up a magnetic analyser because it allows a narrow beam of the particles to be picked out of the diffuse radiation by using

[7] H. Geiger and W. Müller, Phys. Zeits. 29, 839 (1928).

two of the counters as collimators. The two counters are indicated at A and B of Fig. 1, which represents the two vertical elevations of the apparatus. The third counter, C, placed below, serves to explore the beam defined by the first two. It will be evident that if only triply coincident discharges of the three counters are recorded any particles which reach the analysing counter without passing through both collimating counters are not registered and that consequently the two upper counters act exactly as a pair of slits in rejecting all particles which do not pass through them.

For studying the magnetic deviation of the particles a region of magnetic field is introduced just below the second counter. It was found that with the separation of the counters required to give what was believed to be sufficient resolving power, the length of the tubes had to be relatively great in order to give a counting rate high enough to render the experiment feasible. Since the magnetic field must be directed parallel to the axis of the cylinders and since a reasonably strong field over a path of the order of 10 cm was needed, it was difficult to produce a strong enough field throughout this large volume without very powerful electromagnetic equipment. Accordingly in this experiment the magnetic field in the interior of a block of magnetized iron is employed. That such a scheme would be feasible and convenient for deviating these very penetrating particles was first pointed out by Skobelzyn.[8] The closed core magnet used for this purpose is indicated at M, Fig. 1. In this manner it was possible to obtain a strong enough field so that a measurable deviation of electrons of 10^9 e-volts energy would be expected.

The experiment then consists in exploring the beam by observing the frequency of the coincidences at various displacements, d, of the lowermost counter and looking for a change in position or shape of the intensity maximum as the iron core is magnetized.

Details of apparatus

The Geiger-Müller counters. In as much as it was necessary to take counts continuously over a period of several weeks, it was essential that the G.-M. tubes should maintain constant characteristics during this period of time. Since difficulties might be experienced with leakage or slow changes of the

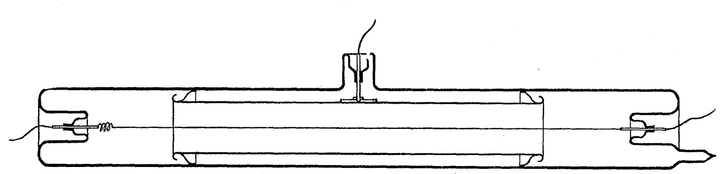

Fig. 2. Detail of Geiger-Müller counter.

gas in tubes not permanently sealed up, the tubes were enclosed in a glass envelope which could be sealed off. The details of construction will be evident from an inspection of Fig. 2. The tube is formed from sheet copper, with the usual "can" joint. Its ends were flared over to prevent strong electric fields at

[8] D. Skobelzyn, Zeits. f. Physik **54**, 686 (1929).

the sharp ends. The tube is supported in the Nonex glass container partly by two spring skirts bearing against the glass and partly by the side lead. The central wire is of tungsten 0.076 mm in diameter, supported from two tungsten seals one at each end of the envelope. A tungsten spring holds the wire taut. To prepare the tubes for operation they were baked out at about 350°C for several hours on the pumps in accordance with the usual high-vacuum technique. The central wire was then cleaned by electrical heating to incandescence for a few moments. After this treatment the tubes were allowed to cool, the pumps were shut off, and finally air was slowly introduced, passing through a liquid-air trap for removal of water vapor and radioactive emanations. The pressure chosen was 7.0 cm of mercury. The tubes were finally sealed off and were then ready for use.

A preliminary test of a tube constructed in this manner showed that its counting rate remained practically unaltered during about six weeks of continuous operation. Tests of the individual counting rates of the particular tubes used in the present experiment were not deemed necessary, though from experience with tubes of similar dimensions and construction the number of discharges per minute is estimated to be about 200 at sea level and with normal radioactivity of the surroundings.

The magnet. The "magnet" consists of a closed core of solid mild steel with a magnetizing winding of about 2000 turns on the leg through which the corpuscles passed. Its dimensions are given in Fig. 1. A magnetic induction of 17,000 was obtained with a current of 2.2 amperes. The induction was determined by means of a fluxmeter and single turn coil linking the core.

The coincidence selector and counter. For the present work it was essential to have an entirely automatic device for selecting the triple coincidences out of the single and paired impulses. Besides it was highly desirable to record and sum the triple coincidences automatically. Accordingly, Bothe's[9] automatic method of accomplishing these results for paired coincidences was extended to selecting and counting triple coincidences.[10]

The diagram of connections of the vacuum tube arrangement for selecting and recording the triple coincidences is shown in Fig. 3. The single impulses from the G.-M. tubes A,B,C are separately amplified by the three tubes T_1, T_2, T_3. The function of the interposed blocking condensers and grid leaks is to shorten the duration of the impulse and was shown by Bothe to be necessary if the selector is to give good resolution. The amplified impulses from two of the counters then actuate the grids of a double grid tube, T_4. As Bothe has shown, if the two grids of a double grid tube are maintained at a suitable negative potential with respect to the cathode, then the potential of either grid can be separately raised a considerable amount without causing current to flow in the plate circuit. On the other hand, if both grids are simultaneously raised, current flows in plate circuit. Accordingly, the impulses arriving at the grids of tube T_4 will only give a pulse of current in the output circuit of

[9] W. Bothe, Zeits. f. Physik **59**, 1 (1930).
[10] B. Rossi, Nature **125**, 636 (1930).

this tube when they occur simultaneously, or more precisely, when their overlapping is sufficiently large. The output of this tube is then combined with the single impulses of the third counter by means of a second double grid tube, T_6, which operates in exactly the same manner as T_4. Hence in the output circuit of this tube will only appear impulses due to triply coincident discharges. The tube T_5 is interposed between these two tubes (T_4 and T_6) in order to convert the negative impulse from the output of tube T_5 into a positive one, since it is evident that the operation of the double grid tube as a selector requires impulses which increase the potentials of its grids. The triple coincidence impulses are then amplified by the two stage amplifier T_8, T_9. The amplified impulses operate the relay R_1 and are finally recorded on the impulse counter. It was found, however, that the operation of the impulse counter was considerably improved by the introduction of the delay circuit, comprising the tube T_9 and the second relay, R_2, connected as shown. This circuit was necessary because during the very short time interval that

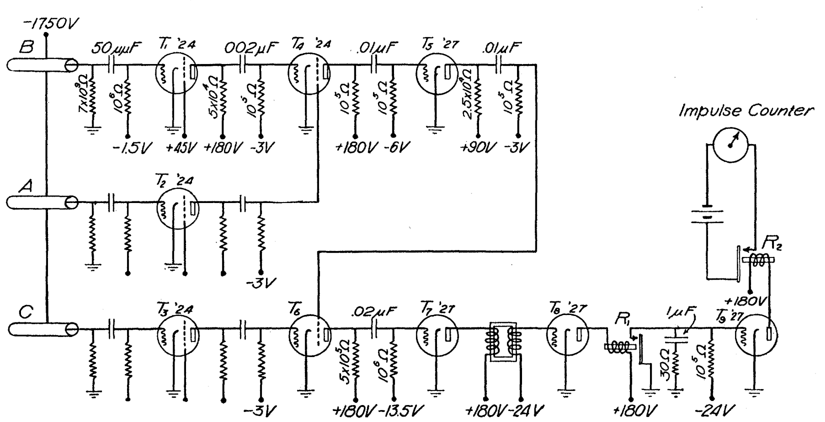

Fig. 3. Diagram of connections.

the relay R_1 remained closed it was not possible to pass sufficient energy to operate reliably the impulse counter.

The various details of the selector and counter, such as the method of coupling between tubes, the values of the plate and grid potentials, etc., will be evident from inspection of the diagram. The final adjustment to proper working condition was principally a matter of trial and error involving the adjustment of the amplification of the various amplifier tubes by altering the coupling resistances, and the setting of the steady grid potentials on the selector tubes. (The values of these quantities indicated on the diagrams are only approximately given for illustration; their correct exact values depend on the characteristics of the G.-M. tubes, the amplifier tubes, etc.) The final adjustment was governed by the criteria that if any one of the G.-M. counters is rendered inoperative no impulses should be registered, and that the triple coincidence counting rate should be the expected value based on the known intensity of the cosmic radiation and the geometry of the arrangement. In its final adjustment the selector gave no counts for a period of one hour when any one of the three counters was rendered inoperative by earthing the cylinder, under conditions when a count of about 30 impulses per hour would have been obtained if all three counters were operating. In addition, tests were made on the counting rate as the lower or central counter was moved out of alignment and in each case the counting rate was reduced to a small fraction (about 10 percent) of the rate with the three counters in alignment. It should be pointed out that no direct tests could be made to determine whether all the triple coincidences were being registered. In fact with all electrical coincidence selectors this doubt seems to be present. However, from the consistency of the results with various adjustments of the amplifier it is believed that an inappreciable fraction is lost, but in any case this question is of little importance for the present experiment since we are principally interested in the relative values of the counting rate under various experimental conditions.

Procedure and results

The investigation of the effect of the magnetic field consisted in two principal series of runs each extending over a period of six to eight weeks, during which time the apparatus was maintained in continuous operation. Between

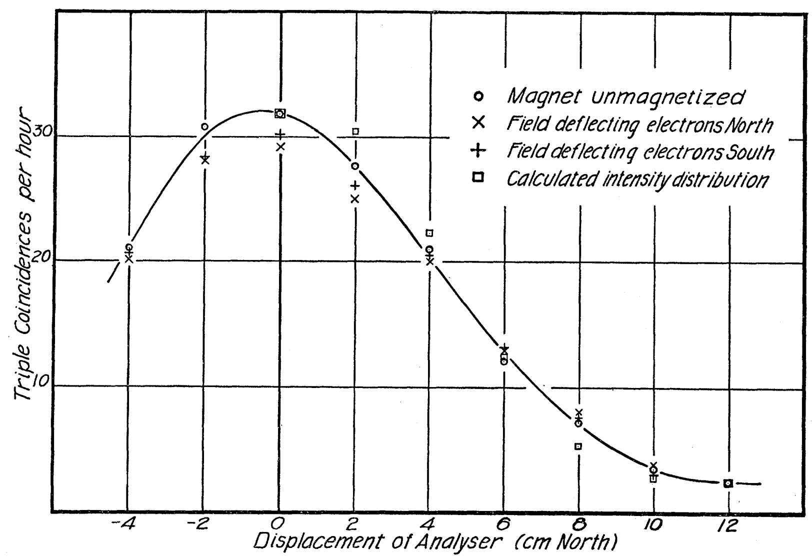

Fig. 4. Principal Data.

the two series the vacuum-tube rectifier which furnished the potential for the counters was replaced by a dry-cell battery because it was suspected that some fluctuation in counting rate was caused by unsteadiness of this potential. However, no evidence could be found showing that improvement in accuracy resulted from this change and accordingly the results from both series are averaged together. The individual determinations at each setting of the analysing counter and under various conditions of magnetization of the magnet usually were of about twelve to twenty-four hours duration, though in some cases runs lasting as long as forty-eight hours were made. During the course of the experiment the counts at the central position with the magnet unmagnetized as a standard condition were frequently repeated to test for possible secular changes in the counters or in the electrical system. No evidence of such effects was found.

The data are graphically represented in Fig. 4. The points in this figure are the averages of usually numerous separate runs at each of the various settings. These averages were of course taken by summing the total number of coincidences at each setting and dividing by the total time interval. The probable error of the individual points is estimated to be about 3 percent. In making this estimate it has been found necessary to take account of both the statistical error due to the random arrival of the corpuscles and of certain other sources of fluctuation also of a more or less random nature whose cause is not exactly understood but whose magnitude could be estimated by suitable statistical treatment of the separate runs at a particular setting. To indicate the method of estimating the probable error, and as a sample set of data, the results of the separate determinations at the central position with the magnetic field on, deflecting electrons north, are given in Table I. The number of separate counts for this position is not as large as that for certain other

TABLE I. *Sample of data*

Interval (hours)	Count (C)	Rate C/hour	Deviation (D)	CD^2	
19.32	588	31.5	2.1	2600	Average rate $=\frac{4454}{151.5}=29.4\ C/\mathrm{hr}$
17.79	494	27.8	−1.6	1300	Standard deviation $=\frac{(8400)^{1/2}}{4454}=1.4$
14.40	451	31.3	1.9	1600	Probable error $=0.67\times1.4=0.92$
12.00	360	30.0	0.6	100	% P.E. $=\frac{0.92\times100}{29.4}=3.1$
24.13	690	28.6	−0.8	400	Statistical error $=0.67(4454)^{1/2}=0.29$
39.90	1134	28.4	−1.0	1100	% S.E. $=\frac{0.29\times100}{29.4}=1.0$
24.00	737	30.7	1.3	1300	
151.54	4454			8400	

points but somewhat greater than that at a few others, so that it may be taken as an average sample. Taking the separate runs as individual observations, the probable error has been computed by the usual method. In making this calculation, since the counts are not all of the same number, the observations have been given weights proportional to the number of coincidences counted. As indicated in the table, the probable error for this set of counts is 3.1 percent and is taken to be the true probable error of the quantity in question. It will be noted that the statistical error is considerably smaller; only

1 percent in this case. Similar treatment of the rest of the data yields approximately this same figure or better. For example, the figures for the numerous runs at the central position, magnet unmagnetized, are: probable error computed in the above manner, 2.9 percent; statistical error, 0.7 percent.

The points at 10 and 12 cm north represent the count due to coincidences occurring by chance, because at the 10 cm position the analyser is just outside of the geometrical limits of the beam. The fact that the count at 12 cm is nearly the same as that at 10 cm indicates that there is very little scattering of the corpuscles in passing through the magnet.

On this figure have also been indicated the values of the counting rate which are expected assuming that the corpuscles pass rectilinearly through the apparatus, and that the entire cross-sectional area of each counter is effective. In calculating this curve the experimentally observed counting rate at the central position and the "chance" count for the point at 10 cm have been

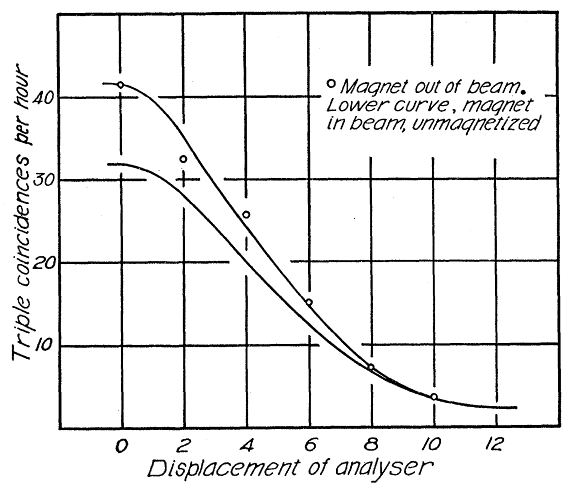

Fig. 5. Absorption due to magnet.

taken as given and the other points then computed. It will be noted that the calculated shape of the intensity maximum is slightly different from the observed. However, this difference is undoubtedly due to trivial causes such as inaccuracy in alignment and construction of the counters or lack of sensitivity of the counters for a corpuscle passing through very near the cylinder. It may be said that on the whole the experimentally observed intensity maximum is of the character to be expected under the above assumption.

A subsidiary set of runs was also made with the magnet removed from the beam for the purpose of observing the absorption due to the magnet as well as a possible widening of the beam due to the scattering of the radiation by the iron. The curve obtained for this condition is presented in Fig. 5. Only very rough determinations were made of the various points, with exception of that at the central position whose accuracy is as high as the data presented above. The curve for the magnet in position but unmagnetized has been repeated on this figure for purpose of comparison. One feature of interest in this determination is that we can obtain from it a check on the observation of Bothe and Kolhörster[6] and others that the absorption coefficient for the corpuscles responsible for the coincidences is nearly the same as the appropriate cosmic-ray coefficient determined by the electroscope measurements. The amount of absorption in passing through the magnet can be obtained from the two ordinates at the central position (41.5 and 31.8). Allowing for the chance count (3.0), we obtain, $I/I_0 = 0.75$. The expected change can be obtained from the water-equivalent thickness of the magnet and Millikan and Cameron's[11] cosmic-ray intensity curve. Assuming the mass law, the water equivalent of the magnet (15.1 cm of iron and 2.0 cm of copper) is 136 cm. From the curve we find, taking the ionization at 10.5 meters and at 11.9 meters, $I/I_0 = 0.81$, in good agreement with the observed value. The discrepancy is in the right direction to be explained by a failure of the mass law such as has been found by Millikan and Cameron[11] for their lead electroscope shield. It is also of interest to note that there appears to be little or no scattering of the radiation by the iron. If the part of the radiation (amounting to 25 percent) which is lost from the incident beam is removed mainly by scattering at small angles we should expect to find an appreciable broadening of the beam when the magnet is in position. It seems therefore that the corpuscles must be either absorbed or scattered at large angles. Though it would seem that interesting information with regard to the character of the radiation could be obtained by analysis of this observation it has not seemed worth while to attempt this until more accurate data on the scattering have been obtained.

Returning now to a consideration of the data of Fig. 4 it will be noticed that the values obtained when the magnetic field is present lie somewhat below those for no magnetization but that no significant shift or broadening of the intensity maximum on magnetization is observed. In the results which were previously reported, a similar lowering was observed but on account of the uncertainty of the measurements it could not be concluded that the presence of the magnetic field had any effect whatever on the shape of the curve. In the case of the present results it is probable that the observed lowering of the curve is significant. This effect is undoubtedly due to the presence of relatively low energy secondary particles. Such particles accompanying the cosmic radiation have been observed by Geiger.[12]

But what is perhaps of greater interest is that no significant displacement of the maxima for the two directions of magnetization is observed. To discuss the meaning of this result it is necessary to calculate the sensitivity of the apparatus. We first obtain the deviation experienced by an electron passing axially down through the apparatus. In making this calculation the force on the electron while in the interior of the magnetized iron is taken to be $e/c\,[v\times B]$, where e, v and c have their usual significance and B is the magnetic

[11] R. A. Millikan and G. H. Cameron, Phys. Rev. **37**, 235 (1931).
[12] H. Geiger, Proc. Roy. Soc. **A128**, 331 (1931).

induction. A few words in justification of this procedure may not be out of place. On the electromagnetic theory the induction represents the average value of the actual internal magnetic field. It is hardly conceivable that this average is made up of values so distributed that a majority of the electrons are able to pass through the iron without passing through the region where the field is large. Accordingly it seems that unless our notions of the nature of magnetic bodies are quite incorrect the above relation for calculating the deflection must give correct results, at least to a first approximation. For electrons whose velocity is so great that their moving mass is large in comparison to their proper mass, as will be true in the present case, the expression for $H\rho$ reduces to the simple form, $H\rho = 3.3\times10^{-3}V$, where ρ is the radius of curvature of the path in a field of strength H, and V the energy of the electron in equivalent volts. Putting in the value of H, 17,000 gauss, we obtain $\rho = 1.9\times10^{-7}$V. The deviation at the analysing counter produced by this curvature of the path is readily computed to be, $d = 420/\rho$.

It may first be assumed that all the electrons are arriving with the same velocity, in order to find a lower limit for this quantity. In this case, to a good approximation, the entire intensity maximum will be shifted to one side an amount equal to the calculated deviation for an axial electron. Although it is somewhat difficult to arrive at an exact estimate of how large a shift could have been observed, an inspection of the curve of Fig. 4 and the probable uncertainty in the points indicates that a displacement of 1 cm could not have escaped notice. (It should be remembered that the separation of the maxima for the two opposite senses of magnetization will of course be twice the calculated value). Introducing the value 1.0 cm it is found that the permissible ρ is 420 cm and the equivalent voltage $420/1.9\times10^{-7}$, or approximately 2×10^{9} volts. A similar computation for protons indicates that if the particles are protons their energy must be greater than about 10^{9} e-volts.

Discussion

If the radiation is indeed composed of electrons (or protons) a surprising feature of the present result is the apparent entire absence of deflectable ones, because on present ideas it would be expected that a considerable fraction of the radiation should consist of relatively low speed electrons. If nuclear effects are negligible, as has been always supposed when dealing with the absorption of high energy particles, it would seem that the principal causes of removal of electrons from the beam will be (1) complete loss of energy by production of ionization along the path and (2) by multiple scattering. When dealing with electrons whose energy is 1000 times that of an α-particle and whose momentum is of the same order it is evident that multiple scattering becomes a negligible factor in this process.[13] The principal factor in producing the absorption must be the loss of energy along a rectilinear path. Now the cosmic radiation is know to follow an approximate exponential law of absorption. In order to obtain such a law with this process of absorption it is

[13] See also calculations on the multiple scattering in the article of reference 6.

necessary to make the *ad hoc* assumption of an exponential distribution in number of electrons of given initial velocity. In addition it must be expected that a considerable fraction of the electrons composing the beam should have relatively low energy. This is readily seen without detailed calculation by the following consideration. It may be found, for example, from Millikan and Cameron's curve that 30 percent of the electrons passing through the magnet are destined to be absorbed in the next 2.5 meters water equivalent of absorbing material. The ionization along the path amounts to, say, 40 ion pairs per cm in air at atmospheric pressure, or 3×10^4 ions per cm of path in water, and 30 *e*-volts energy is lost on the average at each ionization. Hence the initial energy of the fastest of this fraction of the particles must be $30\times3\times10^4\times250$ or 2×10^8 *e*-volts. Were this the case a large magnetic effect would have been observed, since electrons of this energy or less would have been completely removed from the beam. A calculation based on these assumptions indicates that in order to account for the present result the loss of energy per cm of path must be of the order of 100 times greater than the above, and the initial energies correspondingly 100 times higher. This means that these electrons would have to produce at least 10,000 ions per cm of path. Though on latest theoretical ideas[14] the ionization along the path is found to increase as the energy of the electron becomes high, direct experimental evidence from the work of Skobelzyn[15] and of Mott-Smith and Locher[16] seems to show that the ionization due to cosmic corpuscles is only of the order of 30 ion pairs per cm of path. It follows that if the particles are electrons they must be removed from the beam in a manner analogous to that occurring in the case of photons. That is, the electrons must be removed not by a gradual loss of energy but by a single or at the most a few encounters entailing a large loss of energy. Attempts to find a possible process of this sort for electrons have so far failed. In fact it seems impossible to get rid of the enormous quantity of energy by any sort of mechanism. Disregarding possible theoretical difficulties, the most favorable assumption which it seems possible to make is that the electron, on having a sufficiently close encounter with a nucleus, enters it and remains attached, the greater part of its energy going into internal nuclear energy in the process. However, since momentum must be conserved the nucleus recoils with considerable velocity. Consideration of this process indicates that it would satisfy the requirements of the present experiment and not be in obvious contradiction with other experimental facts, though perhaps difficult to account for theoretically. (For example, the fraction of atoms altered by the capture of cosmic electrons is negligibly small during a period of, say, 10^9 years). However, a consequence of these ideas is that the bulk of the ionization due to cosmic radiation must be directly due to the recoil nuclei. Furthermore, the passage of such a nucleus through an electroscope will be relatively infrequent, so that it is required that the ionization should be observed to oc-

[14] J. F. Carlson and J. R. Oppenheimer, Phys. Rev. **38,** 1787 (1931).

[15] See reference 8.

[16] L. M. Mott-Smith and G. L. Locher, Phys. Rev. **38,** 1399 (1931).

cur in relatively large and observable spurts. This effect apparently has not been observed by any of the electroscope workers though it seeems that had it been present it could not have escaped notice. In addition a special test for this effect has been made here, by using a high pressure ionization chamber and short period electrometer, with negative result, so that this possibility has to be abandoned.

Accordingly it seems difficult to believe that the corpuscles responsible for the coincidences are electrons or protons unless the effective magnetic field in the iron is of a different order of magnitude than the value of the induction. And if this is the case, it means very drastic changes will be needed in theories of magnetization. It would be very desirable to test this possibility by repeating this experiment with an ordinary "air" magnetic field. However, very powerful electromagnetic equipment would be required to obtain the necessary sensitivity. (On account of the observed penetrating power, these particles must have energies of at least 10^8 *e*-volts.)

If the coincidences were caused by the passage of a photon through the counters, the present results are at once explained. However, on both theoretical grounds and by direct experimental evidence this possibility seems to be excluded. On the theoretical side it has been shown by Bothe and Kolhörster that photons cannot produce the coincidence effects. On the experimental side it has recently been shown by Mott-Smith and Locher[16] that the corpuscle which causes the coincidence makes an ion-track in the cloud-chamber, a fact which seems definitely to exclude the possibility that the corpuscle is a photon.

Another possible explanation is one which has been recently advanced by Pauli[17], and by Carlson and Oppenheimer[14], that these cosmic corpuscles are neutrons. In this case attempts to deviate them magnetically are necessarily futile. Evidence in favor of neutrons comes also from the calculations of Carlson and Oppenheimer on the relative ionizing power of electrons and neutrons. They find that while the ionization (number of ions per cm of path) by electrons of energies required to account for cosmic ray phenomena should be somewhat higher than that observed in cloud tracks of these particles by Mott-Smith and Locher, that of neutrons may be of the right order of magnitude. Though this possibility is in many ways attractive, it seems that evidence of a more direct nature will have to be found for the existence of neutrons before it can seriously be concluded that the cosmic-ray phenomena are due to them.

[17] W. Pauli, Presented in a speech at the meeting of the A.A.A.S., June 16, 1931.