New Evidence for the Existence of Penetrating Neutral Particles

FRANCIS R. SHONKA
University of Chicago,[1] *Chicago, Illinois*
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An experiment of the Rossi-Hsiung type was performed at an altitude of 14,200 ft. with a fourfold coincidence array of Geiger-Müller tubes in a vertical position. Thicknesses of 12.7 to 17.3 cm of lead served as absorber between the counters. Additional varying thicknesses were placed alternately above and between the counters, i.e., in positions A and B. For small thicknesses the ratio of the counting rates with the lead in position A to that for position B was very little greater than unity. This means very slight production of barytrons by photons at this altitude. For greater thicknesses (19 to 23 cm), however, the ratio A/B becomes 1.06 ± 0.02. Working at sea level, and having the bottom tube shielded with 25 mm of lead, Hsiung obtained the same results. Maass, using no shield for the tubes, found the ratio A/B equal to 1.2. The most reasonable interpretation of the fact that this ratio is greater than unity seems to be the production of barytrons by non-ionizing primaries. In view of the great thickness of lead required to give the maximum effect, these non-ionizing particles must be much more penetrating than photons. This high penetrating power suggests their identification with the neutrettos (neutral particles having mass and other properties similar to the barytron) postulated by Heitler.

INTRODUCTION

ONE of the major conclusions of Bowen, Millikan and Neher[2] from their recent high altitude cosmic-ray measurements was that the number of primary ionizing particles entering the atmosphere is too small to justify the hypothesis that the large number of penetrating cosmic-ray particles found at sea level comes from outside the atmosphere. They accordingly suggested that these penetrating rays may be produced in the atmosphere as secondaries from high energy primaries which are themselves absorbed before they reach the earth. A similar suggestion had been made by Compton[3] as an alternative interpretation of Hsiung's[4] experiment. This experiment, as other similar ones performed by Rossi[5] and Maass,[6] showed that at sea level no significant part of the penetrating radiation is being produced as secondaries from non-ionizing rays. It was apparent, however, that higher in the atmosphere such production of penetrating secondaries might nevertheless occur if the primary rays were quickly absorbed by the air.

With the discovery of new particles and additional experimental evidence, the question as to what percentage of the penetrating component of the rays observed at sea level may be of secondary origin has thus become increasingly important. This applies to all altitudes, but altitudes above sea level are particularly interesting, since there the primaries would be most abundant. With this in mind, a modified form of the Rossi and Hsiung type of experiment was performed at an altitude of 14,200 ft. at the Mt. Evans Observatory.

APPARATUS

The apparatus consisted of a fourfold coincidence array of Geiger-Müller tubes. These tubes were made of a copper cylinder 4.1 cm in diameter, 38 cm in length, and 0.05 mm wall thickness, sealed in glass. The central electrode was a 0.075-mm tungsten wire. The assembly of these tubes has been previously described.[7] The tubes had exceptionally good characteristics, including plateaus of over 1000 volts, obtained by a special cleansing and baking technique.

Each Geiger-Müller tube was surrounded by four plates of lead, 1.6 cm thick. These four plates formed the sides only of a rigid box, 5.71 cm×8.9

[1] Present address: Department of Physics, De Paul University, Chicago, Illinois.
[2] I. S. Bowen, R. A. Millikan and H. V. Neher, Phys. Rev. **53**, 217 (1938).
[3] A. H. Compton, Proc. Phys. Soc. London **47**, 747 (1935).
[4] D. S. Hsiung, Phys. Rev. **46**, 653 (1934).
[5] B. Rossi, Zeits. f. Physik **82**, 151 (1933).
[6] H. Maass, Ann. d. Physik **27**, 507 (1936).
[7] J. B. Hoag, *Electron and Nuclear Physics* (D. Van Nostrand Company, 1938), p. 432.

cm×55.9 cm, having no top or bottom. The lead boxes containing the tubes were then stacked on two channel iron shelves, separated by 47 cm, as shown diagrammatically in Fig. 1. The two channel iron shelves were supported one above the other by a framework of angle iron. For vertical fourfold coincidences, two of the lead boxes containing the Geiger-Müller tubes were placed on the lower platform of channel iron, and two on the upper one. Any desired separation of the counting tubes was obtained by placing plates of lead underneath the bottom-most tube. Additional plates of lead absorber were inserted between the boxes containing the tubes. When smaller thicknesses of lead were used between the tubes, correspondingly larger thicknesses were placed below the bottom tube. Thus the Geiger-Müller tubes were brought closer together and the rate of counting increased. It will be noted that the lead is piled in such a manner that all rays producing coincidences must pass through the same vertical thickness.

The high voltage source for the Geiger-Müller tubes was essentially the circuit described by Gingrich,[8] a modification of the Evans[9] circuit. The counting circuits[10] employed were of the Neher-Pickering[11] type. For the relay circuit a No. 57 tube was used. For the recording circuit an 885 Thyratron activated a circuit-breaking magnetic relay; the pulses were registered on a Veeder-Root counter. This recording system was capable of counting fifty evenly spaced impulses per second. By means of switches in the screen grids of the No. 57 tubes in the recording circuits, any desired combination of n-fold coincidences could be recorded. All of the circuits were built to operate on 110-volt 60-cycle current. This was obtained at the top of Mt. Evans from a 500-watt gasoline engine generator set.

With the tubes in a horizontal plane and shielded heavily with lead, the individual counting rates N_i, and the double and triple accidental coincidence rates A_{ij} and A_{ijk}, were recorded. Then by means of the Eckart-Shonka[10] formula the values of the time constants (τ_i) were calculated to be as follows: $\tau_1=2.38\times10^{-5}$, $\tau_2=2.17\times10^{-5}$, $\tau_3=1.85\times10^{-5}$, and $\tau_4=2.04\times10^{-5}$ minute. With these values of τ_i and the individual counting rates N_i, the accidental fourfold counting rate A_{1234} was found to be 0.004 counts per minute.

The efficiencies of the tubes for cosmic-ray particles were obtained by the method of Street and Woodward.[12] The resulting efficiencies were:

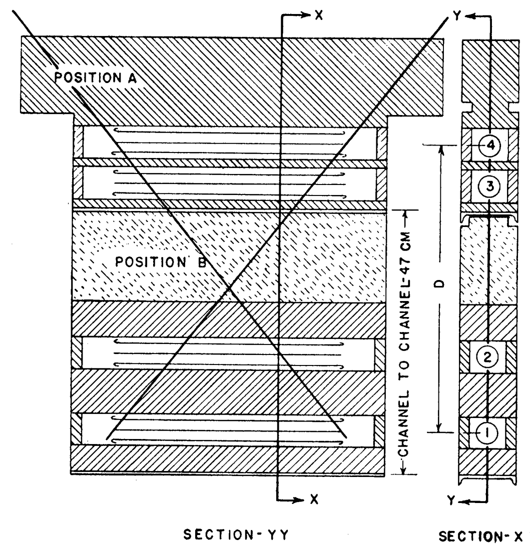

FIG. 1. Arrangement of tubes and absorbers.

tube I, 97.5 percent, tube II, 97 percent, tube III, 98 percent and tube IV, 98 percent.

Results and Interpretation

Readings were taken with the tubes in a vertical position, with the thickness of lead between the tubes varying from 12.7 to 17.3 cm. This lead served as the absorber for the soft secondary particles. In addition to this, various thicknesses of lead were placed alternately above and between the counting tubes, i.e., positions A and B (Fig. 1). In order to increase the rate of counting, larger solid angles were used with the smaller thicknesses of lead. Table I shows the results of these experiments. The tabulated values are corrected for accidental counts and efficiencies. The errors given are probable errors.

[8] N. S. Gingrich, Rev. Sci. Inst. **7**, 207 (1936).
[9] R. D. Evans, Rev. Sci. Inst. **5**, 371 (1934).
[10] C. Eckart and F. R. Shonka, Phys. Rev. **53**, 752 (1938).
[11] H. V. Neher and W. H. Pickering, Phys. Rev. **53**, 316 (1938).
[12] J. C. Street and R. H. Woodward, Phys. Rev. **46**, 1029 (1934).

In Fig. 2 the ratio of the counting rate with the lead in position A to that for position B is plotted against the thickness of the lead that is moved from A to B. The open circles are a graphical representation of Table I, and the full circles are the averages of the first five and last four points, respectively.

The most evident interpretation of the fact that A/B is greater than unity is that ionizing rays (presumably barytrons) capable of penetrating the 12.7 cm or more of lead between the tubes are produced as secondaries of non-ionizing primaries in the lead moved from A to B. Since most of the photons are absorbed in two cm of lead, only the small and hardly significant difference of 1.5 ± 0.5 percent observed with the shifting of the thinner layers of lead can be ascribed to the secondary barytrons excited by primary photons. The much greater difference of 6.1 ± 0.6 percent observed with layers of about 20 cm thickness should thus be ascribed to barytrons produced by neutral particles that are much more penetrating than photons. From the data shown in Fig. 2, it would seem that these rays penetrate 20 cm of lead without any considerable absorption.

An alternative interpretation of the data would be scattering of the barytrons which traverse the lead. When the lead is in position B, scattering of barytrons would reduce the counts by a larger factor than would scattering in position A. Though it appears unlikely that this effect is large enough to account for the difference observed in the two positions, the data on scattering are inadequate definitely to rule out this possibility.

Working at sea level with a threefold cosmic-

TABLE I. *Number of counts per minute for various thicknesses of lead at A or B.*

D in cm (See Fig. 1)	Cm of Pb between tubes	Cm of Pb at A or B	Counts per minute: Position A	Counts per minute: Position B	Ratio $\frac{A}{B}$
38.4	17.5	0.32	5.97 ± 0.05	5.90 ± 0.05	1.012 ± 0.012
38.4	17.5	0.95	5.99 ± 0.05	5.94 ± 0.05	1.008 ± 0.008
38.4	17.5	1.59	6.04 ± 0.05	6.08 ± 0.05	0.993 ± 0.012
38.4	17.5	1.91	6.01 ± 0.05	5.83 ± 0.05	1.031 ± 0.012
38.4	17.5	2.22	5.98 ± 0.06	5.91 ± 0.06	1.012 ± 0.012
38.4	17.5	5.71	5.69 ± 0.07	5.60 ± 0.07	1.016 ± 0.017
51.1	17.5	12.7	3.83 ± 0.07	3.67 ± 0.07	1.035 ± 0.024
54.5	15.9	19.68	3.48 ± 0.03	3.28 ± 0.03	1.061 ± 0.013
54.5	15.9	20.00	3.47 ± 0.04	3.23 ± 0.03	1.074 ± 0.013
54.5	14.3	20.32	3.41 ± 0.03	3.23 ± 0.03	1.056 ± 0.013
54.5	12.7	23.18	3.42 ± 0.03	3.23 ± 0.03	1.059 ± 0.013

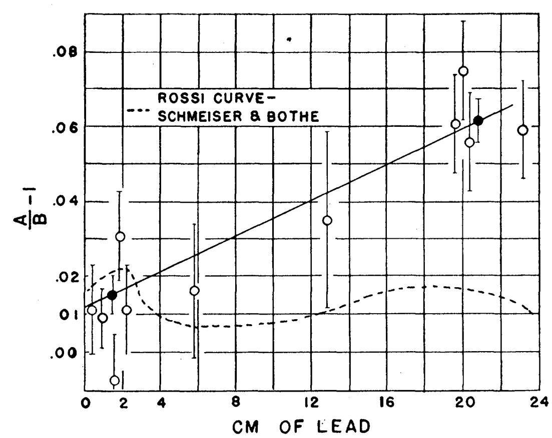

FIG. 2. Ratio of the counting rates with lead in positions A and B as a function of thickness of lead.

ray telescope, and having the bottom tube shielded with 2.5 cm of lead, Hsiung[4] found the ratio A/B to be 1.06 when alternating 20 cm of lead between positions A and B. Under similar conditions, Maass,[6] using unshielded tubes, alternated various thicknesses of iron between positions A and B and found the ratio A/B greater than unity with a maximum at about 30 cm of iron for which thickness this ratio was 1.2. It is possible, especially in the work of Maass, that some of the excess counts were caused by showers and scattering.

While the experiment on Mt. Evans was in progress, Schein and Wilson[13] took similar equipment in an aeroplane to an altitude of 25,000 feet. They alternated 2.2 cm of lead between the second and third tubes of a fourfold system (position B) and above all four tubes (position A). At 25,000 feet, they find the ratio A/B equal to 2.1 ± 0.44. This increase is probably due to barytrons produced by photons. Heitler[14] calculates that about one in 40 photons will be spent by producing a barytron. This would be adequate to account for their observed increase of counts in position A.

The small magnitude of the increase in the counting rate in position A for small thicknesses of lead is to be expected on the basis of Heitler's[14] calculations, since, if the production of soft shower particles by photons is 40 times as frequent as the production of penetrating second-

[13] M. Schein and V. C. Wilson, Phys. Rev. **54**, 304 (1938).
[14] W. Heitler, Proc. Roy. Soc. **166**, 529 (1938).

aries, the effect would be too small to be detected at lower altitudes. Thus the effect observed by Schein and Wilson[13] with 2.2 cm of lead at 25,000 feet altitude is different from the effect observed with ten times greater thickness in the experiments, such as the present ones, made at lower altitudes.

On the basis of the results of Maass,[6] Heitler[15] postulates the existence of a neutretto (a neutral particle having mass and other properties similar to the barytron) which could be transformed into a negative barytron by colliding with a neutron or into a positive barytron by colliding with a proton. Because of the great thickness of lead absorber used in this experiment, the probability of registering soft secondary and scattered rays was less than in the work of Hsiung[4] and Maass.[6] Thus the results presented in this paper offer more definite evidence for the existence of a penetrating neutral ray than do the results of previous experiments.

[15] N. Arley and W. Heitler, Nature **142**, 158 (1938).

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The author wishes to express his appreciation to Professor A. H. Compton for suggesting this problem and for his continued assistance. Grateful acknowledgment is made to the Massachusetts Institute of Technology and the University of Denver for the use of the facilities of the Mt. Evans Observatory; to Dr. J. C. Stearns, through whom arrangements for the use of the Observatory were made; and to the Denver City Parks for the transportation of the fuel supplies.

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The Gamma-Radiation from Boron Bombarded by Deuterons

E. R. Gaerttner,* W. A. Fowler and C. C. Lauritsen
Kellogg Radiation Laboratory, California Institute of Technology, Pasadena, California
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By a method already described, the gamma-ray spectrum from B+D has been obtained by observing the positron-electron pairs ejected from a thin lead lamina (0.033 cm) and the recoil electrons from a carbon lamina (0.12 cm). Gamma-ray components with quantum energies 1.5 ± 0.2, 2.2 ± 0.3, 4.4 ± 0.3, 6.9 ± 0.4 and 9.1 ± 0.4 Mev are indicated with relative intensities $>2.5 : 2.5 : 1.0 : 0.3 : 0.1$. An attempt is made to correlate the energies and relative intensities of the observed gamma-ray components with those of the proton and neutron groups.

Introduction

The recoil electrons ejected from the thick glass wall of a cloud chamber by the gamma-radiation from boron bombarded with deuterons were studied by Crane, Delsasso, Fowler and Lauritsen,[1] and indicated two lines at about 2.4 and 4.2 Mev and a number of weak components of higher energy. An improved method for determining gamma-ray energies from the secondary electrons and pairs ejected from thin laminae has already been described in detail in earlier publications.[2,3] This method has been extended to the study of this radiation, and if due allowance is made for the lower resolving power of the earlier experiments, the original results are not in contradiction with those reported here.

Except for a few minor changes the experimental procedure employed was essentially the same as that described in reference 2. In order to select those recoil electrons which were ejected nearly in the forward direction by the gamma-rays the distance from the target to the scatterer

* Horace H. Rackham Post-Doctoral Fellow. This work was completed during the tenure of his National Research Fellowship.

[1] Crane, Delsasso, Fowler and Lauritsen, Phys. Rev. **46**, 1109 (1934).

[2] Delsasso, Fowler and Lauritsen, Phys. Rev. **51**, 391 (1937).

[3] Fowler, Gaerttner and Lauritsen, Phys. Rev. **53**, 628 (1938).