These experiments emphasize again the fact that very large amounts of energy must be involved in the production of showers. Using Anderson's[10] value of the energy loss of electrons in lead, we see that at least half of the rays of the shower which emerge from the chamber have energies greater than 3×10^8 electron volts, and that the total energy in the showers which we observe must often exceed 3×10^{10} electron volts. It is also apparent that such penetrating powers as we observe are incompatible with the simple identification of the position of the maximum of a Rossi curve with the range of the shower particles.

An interesting consequence of these experiments is the quantitative agreement with the observations on the ionization produced in shielded and unshielded chambers in the stratosphere. As we go to higher and higher elevations, the contribution to the ionization of the extremely penetrating (primary) cosmic rays becomes smaller and smaller relative to the contribution of the secondary (shower) particles produced in the atmosphere. Thus we should expect that the percentage decrease in the ionization brought about by shielding the chamber should approach the value observed in the present experiments for the probability that a shower ray will be stopped in the shield. Bowen, Millikan, and Neher[11] have published a curve showing the variation with elevation of the decrease in ionization caused by a 6.5-cm lead shield, derived from their measurements and those of Compton and Stevenson.[12] The percentage decrease approaches the value of 68 percent as the elevation increases. The probability that a shower ray will be stopped in this shield thickness is 62 percent. Thus the observations are in accord with the interpretation suggested here.

The authors wish to express their gratitude to Professor W. F. G. Swann, in collaboration with whom a portion of these experiments were carried out, and whose interest and guidance throughout the course of this investigation have been invaluable.

[10] C. D. Anderson and S. H. Neddermeyer, Papers and Discussions, International Conference on Physics, London, 1934, I, p. 171.

[11] I. S. Bowen, R. A. Millikan and H. V. Neher, Phys. Rev. **46**, 646 (1934).

[12] A. H. Compton and R. J. Stevenson, Phys. Rev. **45**, 441 (1934).

MAY 15, 1936 PHYSICAL REVIEW VOLUME 49

Coincidence Counter Studies of Cosmic-Ray Showers

R. H. Woodward, *Harvard University*

(Received March 28, 1936)

It has been found that the production curves (counting rate against thickness of lead) of electron-produced and of photon-produced showers are similar and that the average penetrating power of the rays from electron-produced and from photon-produced showers is the same. Shower production curves have been obtained at four elevations and analysis of the curves shows that the absorption per nucleus of the shower-producing radiation (photons) is approximately proportional to the square of the atomic number. Coefficients for lead (0.33 cm^{-1}), iron, and air have been determined, and a comparison with theory is given. Also the penetrating power of the shower rays emerging from a block of lead has been measured and found to be independent of the elevation and of the thickness of the lead from which the rays emerge.

1. Introduction

The cloud chamber photographs of Anderson *et al.*[1] and Blackett and Occhialini[2] have shown that cosmic-ray showers consist of groups of from two to several score electrons which are accompanied by numerous low energy photons. The shower-producing rays are usually nonionizing, although the photographs of Stevenson and Street[3] show that ionizing rays may produce

[1] C. D. Anderson, R. A. Millikan, S. Neddermeyer and W. Pickering, Phys. Rev. **45**, 352 (1934).

[2] P. M. S. Blackett and G. P. S. Occhialini, Proc. Roy. Soc. **A139**, 699 (1933).

[3] E. C. Stevenson and J. C. Street, Phys. Rev. **48**, 464 (1935).

showers (possibly through the intermediary of nonionizing rays). Many of the shower electrons radiate from a single point. There is a high probability, however, that the production of one shower will be accompanied by the simultaneous production of other showers, the several shower foci usually being unconnected by tracks of ionizing rays. Either in the production of a shower or in a primary process nonionizing rays, photons, are created which themselves are capable of producing showers.

Geiger and Fünfer[4] have proposed a convenient nomenclature which we shall adopt in this discussion:

A-rays. The primary charged particles which lose energy through ionization and the radiation of B-rays (photons) in nuclear collisions. The latitude effect of showers[5, 6] requires that they be related to a primary corpuscular radiation.

B-rays. The shower producing photons.

C-rays. Shower electrons created in groups by B-rays.

D-rays. Low energy photons produced in the absorption of C-rays.

E-rays. Low energy electrons from photo and Compton collisions of the D-rays. The D- and E-rays account for the back scattering reported by Fünfer.[7] The distinction between A-, C-, and E-rays is not clearly defined. Their properties may be similar, and there may be overlapping of energies of different groups. Likewise the B- and D-rays may behave in similar fashions. But in general the classes are arranged in order of decreasing energy.

The study of showers by the coincidence counter method has been made by Rossi[8] and many others, and the results of these experiments have been discussed in detail by Geiger.[9] In general, curves of the type shown in Fig. 2 are obtained. Such a curve relating the counting rate N to the thickness X of material can be roughly expressed as the difference of two exponentials,

$$N = C(e^{-\mu X} - e^{-\nu X}). \tag{1}$$

Here μ may be considered as the absorption coefficient of the primary radiation and ν that of the secondary radiation or *vice versa*, and consequently there are two possible interpretations of the curve. The initial rise may represent the coming into equilibrium of a secondary radiation ($\nu \sim 0.7$ per cm of lead) with a more penetrating shower-producing radiation ($\mu \sim 0.3$ cm^{-1}), the absorption of which accounts for the fall of the curve beyond the maximum. The alternative interpretation is that the shower-producing radiation is rapidly absorbed ($\nu \sim 0.7$ cm^{-1}), while the secondary radiation is the more penetrating ($\mu \sim 0.3$ cm^{-1}). Direct measurements (see sections 2 and 4) of the absorption of the secondary rays emerging from a block of lead show that most of these rays are not penetrating, being absorbed to a large extent in two millimeters of lead. Furthermore it does not seem plausible that the secondary radiation, which on the average must be considerably less energetic, should be more penetrating than the primary radiation. For these reasons we prefer the former interpretation and in our discussion shall disregard the possibility of the latter.

2. A Comparative Study of Electron and Photon-Produced Showers

The production of cosmic-ray showers has been studied by the arrangement shown in Fig. 1. The counters in each of four groups were connected in parallel so that each group acts as a single counter. Iron blocks were placed below and at the sides of the lower counters to reduce the number of cross-scattered rays. The triple coincidence counting rates N_{123} between groups 1, 2, and 3, and N_{234} between groups 2, 3, and 4 were recorded simultaneously for various thicknesses of the lead in position A. A coincident discharge of groups 1, 2, and 3 requires ionization above the lead, whereas a discharge of groups 2, 3, and 4 is

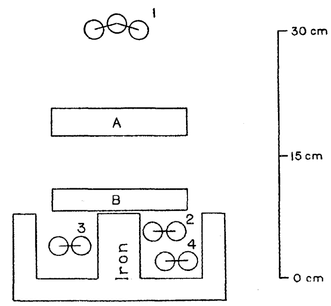

Fig. 1. Arrangement of counters.

[4] H. Geiger and E. Fünfer, Zeits. f. Physik **93**, 543 (1935).
[5] T. H. Johnson, Phys. Rev. **47**, 318 (1935).
[6] T. H. Johnson and D. N. Read, Abstract 2, New York Meeting of Am. Phys. Soc., Feb., 1936.
[7] E. Fünfer, Zeits. f. Physik **83**, 92 (1933).
[8] B. Rossi, Zeits. f. Physik **82**, 151 (1933).
[9] H. Geiger, Ergeb. d. Exakt. Naturwiss. **14**, 42 (1935).

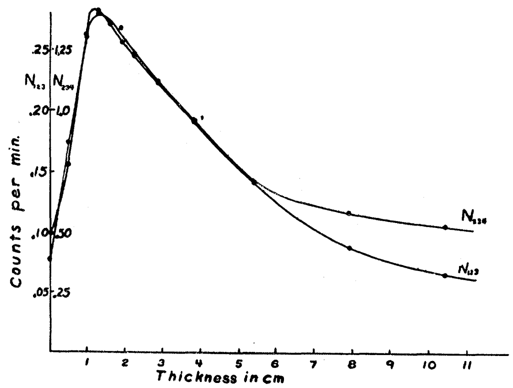

FIG. 2. Curves of shower production in lead.

independent of the nature of the radiation above the lead. As shown in Fig. 2, the variation of the counting rate N_{234} with thickness of lead is similar to that of N_{123}, the factor of five between the scales presumably depending on the geometry of the arrangement. Stevenson and Street[10] have shown that about 70 percent of the coincidences of type N_{123} due to showers produced in the lead actually arise from incident electrons. Most of the coincidences of type N_{234} involving no selection in favor of incident electrons are due to an incident photon radiation.[1] It is surprising, therefore, that the curves are so nearly similar, for in each case the shape of the curve and the position of the maximum are dependent upon the relative absorptions of the incident and secondary radiations. However, there is evidently a real difference in the curves at great thicknesses of lead. The significance of this difference will be discussed in section 3.

The absorption of the C-, D-, and E-rays which actually discharge the lower counters has been measured by placing plates of absorbing material of various thicknesses in position B, so that they absorb the rays produced in the block A but do not themselves produce many showers capable of discharging the triple sets of counters. Fig. 3 shows a schematic diagram of the arrangement together with a plot of four pairs of absorption curves which were obtained by placing various thicknesses of lead or aluminum in positions B under thicknesses 0, 0.476, 1.59, and 7.94 cm of lead at A. The thickness of aluminum is plotted on such a scale that equal distances along the abscissa represent equal numbers of extranuclear electrons per cm² in the lead and aluminum. The nature of the absorption curves is nearly similar for the two types (N_{123} and N_{234}) of coincidences discussed above, and only one set of curves is given. This indicates that there is no distinction between the photon and electron-produced showers as regards to penetrating power of the secondaries. The interpretation of the curves is complicated by the fact that the lead and aluminum in positions B are not pure absorbers; i.e., there are coincidences due to the production of showers and also there is possibly an increase of the efficiency of the photons (D-rays) in discharging the lower counters. These effects account for the peaks in the absorption curves, and corrections for them are unreliable. However, the initial rapid fall of the curves, which probably is not greatly influenced by these effects, shows that most of the shower rays are absorbed in two millimeters of lead. Also the curves show that the penetrating power of the shower rays does not change appreciably as the thickness of the lead block A is increased. The absorption per extranuclear electron is less rapid for aluminum than for lead, indicating that the absorption of shower rays depends not only on extranuclear electrons but also on the nuclei.

3. The Variation of the Rate of Shower Production with Elevation

The coincidence rate with no lead in positions A and B is a considerable fraction of the maximum change due to the introduction of lead, and it is

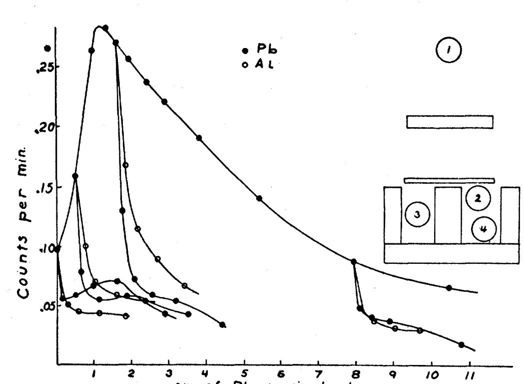

FIG 3. Curves of absorption in lead and aluminum of shower rays from lead. The thickness of aluminum is expressed in equivalent cm of lead on a scale of equal numbers of electrons per cm².

[10] E. C. Stevenson and J. C. Street, Phys. Rev. **49**, 425 (1936).

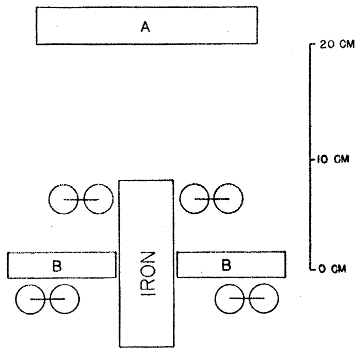

FIG. 4. Arrangement of counters.

not clear how corrections can be made for the variation of this "background"[11] rate with the introduction of lead at A and B. This difficulty, together with the fact that lead at B does not behave as a perfect absorber renders a quantitative treatment of the data obtained with the arrangement of Fig. 1 uncertain. The arrangement of counters shown in Fig. 4 was designed to minimize these difficulties. Quadruple coincidences between the four pairs of counters were recorded for various thicknesses of lead placed above the counters at A. The zero reading is too low to distort the measurements and the quadruple coincidence counting rate due to showers produced in the absorbing plates at B is negligible; i.e., no distortion of the absorption curves is observed. With this arrangement the previous measurements have been repeated at Cambridge and at three higher elevations. The results with the probable errors are tabulated in Table I and the principal curves are plotted in Fig. 5. All measurements were taken under canvas, and corrections were made for barometric fluctuations and for change of the efficiencies[12] of the counters with altitude and with thickness of lead. The accidental counting rate was negligible (order of 0.0001 per min.). The four curves are similar within the limits of experimental error. The increase of the rate of shower production with elevation is in satisfactory accord with other coincidence counter observations.[5, 13, 14] However it is in serious disagreement with the ionization chamber observations of C. G. and D. D. Montgomery.[15] They find that the frequency of cosmic-ray bursts increases by a factor of 26.6 from sea level to Pike's Peak (4300 m), whereas our coincidence rates increase by a factor of only 8.5 from sea level to Mt. Evans (4300 m). As a possible explanation for the discrepancy, we suggest that the small showers (an average of 3 or 4 rays per shower) recorded by the counter set increase with altitude less rapidly than the large bursts (estimated at 100 or more rays per burst) recorded by their ionization chamber. The results obtained at the same stations (Cambridge, Denver, Echo Lake, and Mt. Evans) by R. T. Young[16] with a small ionization chamber seem to support this explanation. He finds that while the small bursts (10 to 15 rays) increase by a factor of 9.0 between sea level and Mt. Evans, the large bursts (greater than 30 rays) increased by a factor of 22.

Gilbert[17] has reported that the peak of the shower production curve shifted from 1.6 cm of lead at sea level to 2.2 cm at an elevation of 3500 m. Although there is an indication of such a shift of the peak in our curves, it is certainly smaller, if it exists at all. Here again the explanation may lie in the different types of showers

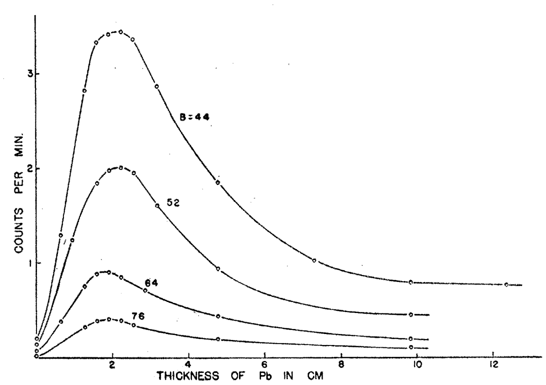

FIG. 5. Shower production curves at Mt. Evans (4300 meters), Echo Lake (3250 m), Denver (1620 m), and Cambridge (60 m).

[11] Supplementary tests have shown that not more than ten percent of this rate is due to accidental coincidences. The major part is no doubt due to showers from the air or light wooden roof above the counter set.

[12] J. C. Street and R. H. Woodward, Phys. Rev. **46**, 1029 (1934).

[13] B. Rossi and S. de Benedetti, Ricerca Scient. 5–II, 379 (1934).

[14] J. A. Priebsch, Zeits. f. Physik **95**, 102 (1935).

[15] C. G. Montgomery and D. D. Montgomery, Phys. Rev. **47**, 429 (1935).

[16] R. T. Young, Abstract 10, New York Meeting Am. Phys. Soc., Feb. 1936.

[17] C. W. Gilbert, Proc. Roy. Soc. **A144**, 559 (1934).

TABLE I. *Quadruple coincidence counts for various thicknesses of lead placed above the counters at A and for various altitudes.* Column 1 gives the position A in cm of lead; column 2, the position of B in cm of lead; columns 3, 6, 9, and 12 give the coincidence counts per minute, N; columns 4, 7, 10, and 13 give the probable error as defined by $0.67[\Sigma(\Delta N)^2/n(n-1)]^{\frac{1}{2}}$; columns 5, 8, 11, and 14 give the probable error as defined by $0.67c^{\frac{1}{2}}/T$.

Barometric Pressure Elevation		76 cm 60 meters			64 cm 1620 meters			52 cm 3250 meters			44 cm 4300 meters		
1	2	3	4	5	6	7	8	9	10	11	12	13	14
0.00	0.00	0.014	0.0017	0.0010	0.066	0.007	0.004	0.138	0.005	0.006	0.206	0.012	0.008
.63	.00				.39	.004	.012				1.28	.017	.033
.95	.00							1.23	.007	.005			
1.27	.00	.320	.0062	.0048	.75	.019	.014				2.82	.037	.035
1.59	.00	.388	.0064	.0054	.89	.017	.012	1.84	.032	.028	3.35	.020	.040
1.91	.00	.398	.0072	.0051	.91	.011	.012	1.98	.040	.025	3.38	.034	.027
2.22	.00	.398	.0065	.0064	.85	.011	.012	2.00	.026	.025	3.44	.038	.030
2.54	.00	.345	.0075	.0061				1.97	.019	.027	3.35	.040	.044
2.85	.00				.72	.018	.013						
3.18	.00							1.59	.017	.034	2.86	.054	.037
4.77	.00	.197	.0037	.0047	.43	.014	.012	0.93	.007	.028	1.84	.039	.030
7.30	.00										1.02	.017	.034
9.85	.00	.102	.0021	.0036	.20	.006	.007	.46	.030	.019	0.79	.009	.018
12.40	.00										.77	.007	.030
0.00	.63				.043		.006						
.00	5.08	.011		.0017	.030		.006	.071		.009	.105		.008
.63	.32										.62		.024
.63	1.59										.39		.021
.63	5.08										.19		.010
1.91	.16	.259		.0057	.60		.015						
1.91	.32	.161		.0042	.37		.012	.85		.028	1.54		.042
1.91	.63	.115		.0047	.19		.008	.60		.029			
1.91	1.11	.069		.0042									
1.91	1.59	.063		.0033	.14		.007	.39		.024	.63		.041
1.91	5.08	.013		.0015	.035		.004	.17		.010	.29		.016

recorded. Gilbert's arrangement of counters required three rays to produce a coincidence whereas ours required only two. It is evident from a comparison of the results of sections 2 and 3 that there is a shift of the peak due to the use of different geometrical arrangements. Probably this shift is not significant, for the distortion caused by the variation of the initial counting rate with the introduction of lead may well explain the entire difference. It is to be expected that the superposition of an initial decreasing curve upon the production curve will shift the peak to a smaller thickness.

The intensity of the single corpuscular radiation was measured by recording double coincidences between one of the upper pairs of counters in the arrangement of Fig. 4 and the pair below it. Corrections have been made for accidental coincidences. However, the coincidence rate due to showers probably is considerable, and, since the solid angle subtended by the counters is large, the observed counting rate is not truly representative of the vertical intensity. The ratio of the shower intensity to this measured corpuscular intensity increases markedly with altitude as shown in Table II, even though the factors mentioned above tend to make this increase less evident.

TABLE II. *Ratio of showers to corpuscular intensity at different altitudes.*

Barometric pressure (cm)	44	51	64	76
Relative shower intensity	8.5	5.0	2.25	1.00
Relative corpuscular intensity	3.6	2.5	1.46	1.00
Ratio of showers to corpuscular intensity	2.4	2.0	1.5	1.0

Although the theory as so far developed is unsatisfactory in treating multiple pair formation by photons, it is of interest to compare the theoretical predictions for single pair formation with the experimentally determined absorption of photons in shower production. Oppenheimer[18] has presented an argument which would lead to a lower limit for the nuclear cross section for pair formation by photon encounter.

[18] J. R. Oppenheimer, Phys. Rev. **47**, 44 (1935).

$$\sigma \sim (28/9)\alpha Z^2 \rho^2 \ln (1/\alpha^2 Z^{\frac{1}{3}}\epsilon), \quad \sigma \sim 0 \quad \text{for} \quad \epsilon > \alpha^{-2} Z^{-\frac{1}{3}}, \tag{2}$$

where

$$\alpha = e^2/\hbar c, \quad \rho = e^2/mc^2, \quad \epsilon = \text{Energy of photon}/mc^2.$$

As a basis of comparison we shall consider the absorbing power of a material as a function of its atomic number. Since the effect of the logarithmic factor is not large, a first comparison can be made by neglecting it. Then the absorption per nucleus of absorbing material should be proportional to the square of the atomic number, and for comparison, the atmospheric layers between stations have been expressed in equivalent cm of lead on the Z^2 scale. Fig. 6 is a logarithmic plot of the counting rate against the total equivalent thickness of lead. Each curve rises approximately linearly, falls approximately linearly, and then levels off. Presumably the linear portion of each curve beyond the peak represents the absorption of the B-radiation in lead. It is parallel to the corresponding portion of each of the other curves and approximately parallel to the line drawn through the peaks of the curves and representing the absorption of the B-radiation in air.[19] This

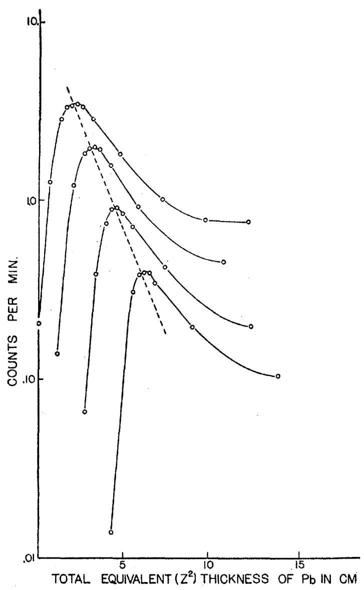

FIG. 6. Logarithmic plot of curves of Fig. 5. The atmospheric layers are expressed in equivalent cm of lead on the basis of an absorption per nucleus proportional to Z^2.

[19] W. F. G. Swann, Phys. Rev. **48**, 641 (1935), has proposed an alternative interpretation, based on the assumption that the increase of shower production with elevation may be attributed to an increase (with energy) of the probability that a primary ray (either directly or indirectly) will produce a shower rather than to an increase in abundance of shower-producing rays.

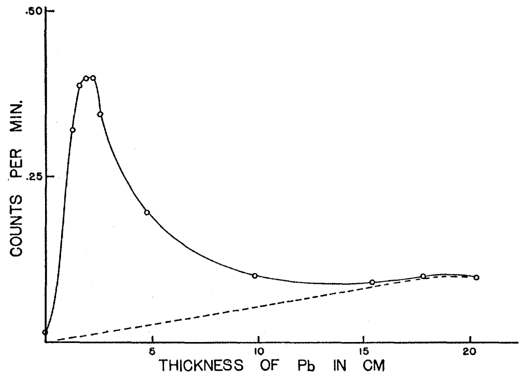

FIG. 7. Shower production curve at sea level extended to 20 cm of lead.

indicates that on the scale of the square of the atomic number the coefficients of absorption are roughly the same for lead and air. However, we do not wish to attach too much significance to the facts that the portions of the curves appear to be linear on a logarithmic plot and that the coefficients depend on the square of the atomic number. The shape of a logarithmic plot is very sensitive to the addition or subtraction of a constant value and the departure of the curves from linearity at great thicknesses of lead requires some explanation if this analysis is to apply. We considered the possibility that this departure might be due to rays which fall obliquely on the sides of the lead block and produce showers without traversing the entire thickness of the block. To test this we built up lead wedges on the sides to absorb rays coming in obliquely. Since the lead wedges produced no appreciable decrease in the counting rate, we concluded that this effect was too small to account for the departure of the curves from linearity. However, consideration of the experiments of Ackemann[20] and Hummel[21] leads to an explanation of the difficulty. By an experiment similar to theirs we have verified the existence of a second maximum at 18 cm of lead as shown in Fig. 7. The experiments of Kulenkampff[22] have given an explanation of the second maximum. He finds that it arises from a very penetrating B-radiation which produces a penetrating C-

[20] M. Ackemann, Naturwiss. **22**, 169 (1934).

[21] J. N. Hummel, Naturwiss. **22**, 170 (1934).

[22] H. Kulenkampff, Physik. Zeits. **22**, 785 (1935).

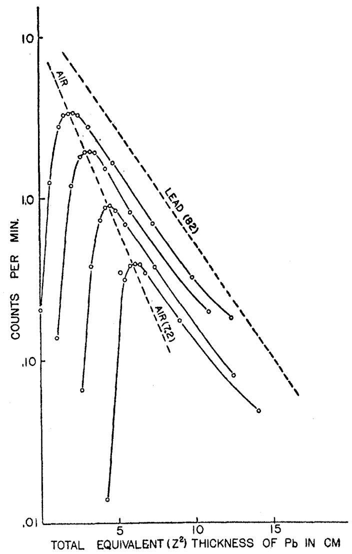

FIG. 8. Curves similar to the dashed curve of Fig. 7 have been subtracted from the curves of Fig. 6.

radiation. We suggest that the showers of the second maximum arise from this C-radiation, and that the variation with thickness of lead is represented by the dashed curve of Fig. 7.[23] We have assumed, as is strongly indicated by the curves of Fig. 5, that similar maxima would be found at higher elevations, bearing approximately the same ratio to the first maxima. Thus from each set of data we subtract the counting rate due to showers of this type, and obtain the curves of Fig. 8. Beyond the maxima the plots are now nearly straight and all have approximately the same slope, corresponding to an absorption coefficient of about 0.33 per cm of lead. This is to be compared with a coefficient of 0.53 per cm of equivalent lead for the absorption of the atmosphere. We estimate the probable error to be 0.04 cm^{-1} for each, which is considerably less than their difference. The ratio of the coefficients (μ air/μ lead $=1.6$) may be compared with the ratio of the logarithmic term for air and for lead given by Oppenheimer (Eq. (2)). The computed value for an energy of 300 MEV is 1.4. More recently an expression for the absorption coefficient for high energy photons has been suggested by Nordheim.[24]

$$\mu=\frac{Nz^2r_0^2}{137}\frac{28}{9}\ln\frac{137}{Z^{5/6}}\left(\frac{137mc^2}{\epsilon}\right)^{\frac{1}{2}}, \tag{3}$$

where $r_0=e^2/mc^2$ and N = number of atoms per cm^3. This expression gives a ratio of 5.0 for the logarithmic terms for air and lead. Although the experimental errors are large, the indication is that the dependence of the nuclear cross section on Z is somewhat stronger than that given in Oppenheimer's expression and weaker than Nordheim's. The experimental coefficient 0.33 per cm of lead is to be compared with 0.77 cm^{-1} predicted by Oppenheimer and 0.20 cm^{-1} predicted by Nordheim. The computations were made for an estimated average energy of 300 MEV.[25] The uncertainty in the estimated energy is large and might possibly account for the discrepancy either way.

To substantiate our conclusion that the absorption of high energy photons depends at least to a first approximation on the square of the atomic number, we have made measurements of the absorption of the B-radiation in iron at sea level. For this purpose we have placed at A

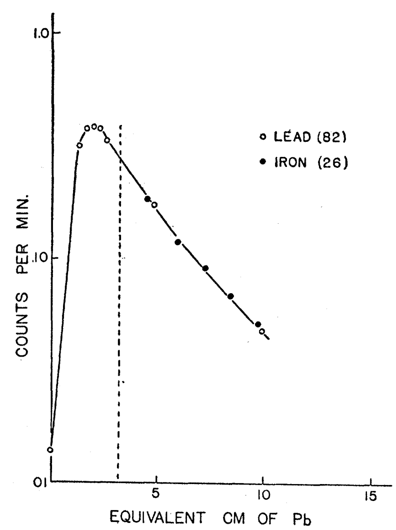

FIG. 9. Curves similar to those in Fig. 8 of the absorption of B-rays in lead and in iron (on top of 3.2 cm of lead).

[23] The difference between curves N_{123} and N_{234} (of section 2, Fig. 3) can now be explained as due to the contribution of showers of the type which cause the second maximum to the rate N_{234}, but not to the rate N_{123}, since this requires an ionizing ray above the lead.

[24] L. W. Nordheim, Phys. Rev. **49**, 189 (1936).

[25] This estimate is made from a consideration of the average number of rays per shower, reference 10, the average energy of the shower rays (C. D. Anderson and S. H. Neddermeyer, Int. Conf. Physics, London, October 1934), and the importance of secondary photons, reference 9, in the phenomenon.

(Fig. 4) 3.2 cm of lead, an amount sufficient to bring the C-radiation into equilibrium with the B-radiation. Iron placed on top of the lead acts essentially as an absorber of the B-radiation. The counting rates for lead and iron corrected for the second maximum and plotted against the total equivalent thickness of lead should lie along the same line, and it is found that within experimental error they do (Fig. 9). However, the correction for the second maximum here is rather uncertain. We take its position at 30 cm of iron as given by Kulenkampff[22] and assume that the magnitude of the first and second maxima for iron are in the same ratio as those for lead. For the case of iron and lead the deviation from the Z^2 relationship (i.e., the logarithmic term) is too small to be detected by this experiment.

4. Absorption of the Radiation Produced in Cosmic-Ray Showers

By placing plates of lead and aluminum in position B of Fig. 4 we have measured the absorption of the shower radiation from lead (probably a mixture of C-, D- and E-rays) in these two materials. Small corrections have been made for the initial counting rate (with no lead at A). It is found that within the experimental limits of the investigation the penetration of the rays is independent of the thickness of the lead at A and of the elevation. Since this is so, we have plotted curves for lead and aluminum (Fig. 10) which represent averages of all the data on absorption. Two curves are given for aluminum. For one the thickness is taken equivalent to lead on the Z scale and the other on the Z^2 scale. Since one of these curves lies above and the other below the lead curve, it is seen that the dependence upon Z is between the first and second power.

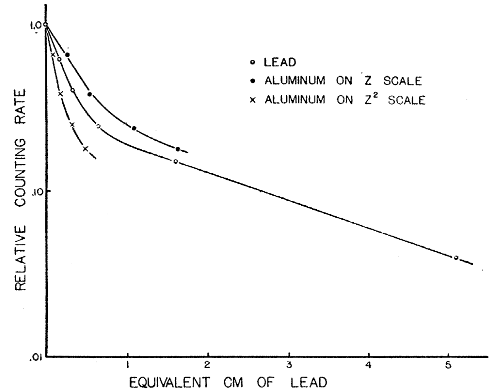

FIG. 10. Absorption of shower rays in lead and aluminum. The thickness of aluminum is expressed in equivalent cm of lead on the basis of an absorption per nucleus proportional to Z and Z^2.

The logarithmic plot shows that at least empirically the shower radiation can be considered as made up of two components with coefficients 5.0 and 0.4 per cm of lead. But, if the shower production curve is to be represented by Eq. (1), the absorption coefficient ν of the shower radiation is determined by the value of the coefficient μ of the B-radiation and the position of the peak, and is thus found to be about 0.7 per cm of lead. This does not agree with the coefficient of either of the components deduced from direct measurements. It will be noted that since the absorption takes place in both plates at B, the measured coefficient is too large by a factor of two. However, the absorption probably enters in the same way in block A and in Eq. (1). The coefficient 0.4 may possibly apply to a C-radiation capable of producing large numbers of soft D- and E-rays which are more effective in actuating the counters. Further cloud chamber studies are required to clear up this point.

In conclusion the author wishes to express his gratitude to Dr. J. C. Street, whose advice and inspiration have made this investigation possible. Also it is a pleasure to acknowledge the cooperation of Professor J. C. Stearns and of the University of Denver in affording laboratory facilities. Transportation of the apparatus was generously provided by the city of Denver through the courtesy of Mr. G. E. Cranmer and Mr. R. R. Vail.