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Cloud-Chamber Study of the Second Maximum

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A 12-in. G-M tube controlled cloud chamber was used to study the second maximum of the shower transition curve for lead. Stereoscopic pictures were taken to study the angular divergence of the pairs produced. Over 14 000 photographs were analyzed for a range of lead thickness from 10 to 23 cm. The frames with pairs were reprojected and the angular divergence of the tracks measured with a protractor. The experimental results appear to indicate a second maximum at a thickness in the neighborhood of 17.5 cm lead.

1. INTRODUCTION

IF the frequency of shower production resulting from cosmic rays is measured below an absorber, for instance lead, and if the frequency is plotted against the thickness of absorbing material, a curve will be obtained which rises to a maximum at about 1.5 centimeters of lead and diminishes with corresponding rapidity, until at a thickness comparable to 4 or 5 centimeters it attains a condition in which the curves decrease slowly with the thickness of absorber. Such curves are called "Rossi" curves. Ackemann and Hummel[1] observed such curves with the additional feature of a second maximum in the neighborhood of 15–18 centimeters of lead. The existence of the so-called second maximum has been questioned. For example, Schwegler,[2] Morgan and Nielsen,[3] Auger, Maze, Ehrenfest, and Freon,[4] Altmann, Walker, and Hess,[5] and Weaver[6] failed to observe the second maximum. On the other hand, the second maximum has been observed by Priebach,[7] Swann and Ramsey,[8] Bothe,[9] Clay,[10] and Broussard and Graves[11]; also Nielsen and Morgan[12] found the second maximum with one counter arrangement and failed to observe it with another arrangement. In the determinations discussed, only Broussard and Graves used a cloud chamber; the others used different arrangements of G-M tubes.

Chaudhury[13] discussed the controversial existence of the Rossi second maximum of cosmic rays in the light of her experiments with lead using triple coincidence arrangements of counters under different geometrical conditions, and obtained definite evidence of the existence of a second maximum at about 18 centimeters lead with a third maximum at about 23 centimeters lead. Except for a drop in coincidence rate at about 20 centimeters of lead, both these maxima might be considered as a single maximum from 16 to 24 centimeters, similar to the work reported by others. From her careful analysis of the investigations made by other workers, it appeared that the failure of some workers to confirm the existence of these maxima might be due to differences in geometry of the counter banks. With counter banks too close together, the possibility of counting side showers originated outside of the lead is increased. With too wide a separation, showers having narrow angles are favored. Some of these difficulties of geometry can be removed by the use of a cloud chamber which allows the origin of the event to be localized. With such a chamber, the coincidence banks can be placed close enough together to avoid favoring narrow angle showers, while coincidences caused by oblique showers can be recognized and discounted.

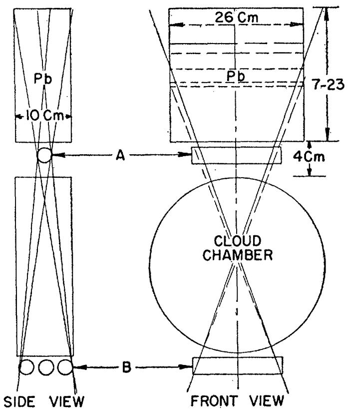

FIG. 1. G-M tube and cloud-chamber geometry.

To investigate the existence of the second maximum in the cosmic-ray transition curve for lead, a large Wilson cloud chamber was constructed and operated continuously over a $2\frac{1}{2}$-month period to obtain sufficient data to be statistically sound. The arrangement of the triggering counter tubes, the lead used as the penetrating material and the chamber is shown in Fig. 1. This experiment was performed in the basement of the Physics Building at Louisiana State University, Baton Rouge, Louisiana.

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TABLE I. Cloud-chamber data on pair and shower production as the thickness of Pb absorber is varied. The frequency is given in number of events per hour.

Thickness of Pb absorber (cm)	Total active time of chamber (hours)		Penetrating pairs Angular divergence ≤20°	Penetrating pairs Angular divergence >20°	Total (all pairs)	Showers (>2 particles)	Total events	Total intensity
7.0	7.0	No. of events	20	26	46	28	74	372
		Frequency	2.86	3.72	6.58	4.0	10.6	53.2
10.4	7.8	No. of events	15	30	45	9	54	373
		Frequency	1.93	3.85	5.77	1.16	6.9	48.0
14.0	9.8	No. of events	30	20	50	9	59	424
		Frequency	3.06	2.04	5.1	0.92	6.0	43.2
15.2	39.1	No. of events	73	121	194	31	225	1698
		Frequency	1.87	3.1	4.95	0.79	5.8	45.5
16.3	32.5	No. of events	51	111	162	26	188	1404
		Frequency	1.57	3.42	5.0	0.8	5.75	43.3
17.5	48.9	No. of events	148	137	285	57	342	2234
		Frequency	3.0	2.33	5.82	1.17	7.0	45.6
19.0	54.0	No. of events	109	127	236	69	315	2506
		Frequency	2.02	2.36	4.39	1.28	5.8	46.5
20.5	46.2	No. of events	76	103	179	44	223	2104
		Frequency	1.64	2.24	3.89	0.96	4.8	45.7
21.5	4.0	No. of events	10	2	12	4	16	193
		Frequency	2.5	0.5	3.0	1.0	4.0	48.3
23.0	12.6	No. of events	15	19	34	12	46	640
		Frequency	1.19	1.56	2.7	0.95	3.7	50.7

2. EXPERIMENTAL TECHNIQUES

The counter-controlled, rubber-diaphragm type Wilson cloud chamber had an inside diameter of about 12 in. and a depth of 4 in. Referring to Fig. 1, G-M tube *A* was a 6-in. active length, 1-in. diam, 30-mil Cu wall, gamma-ray tube; G-M tube bank *B* consisted of 3 similar tubes with an active length of 12 in. The absorbing lead was placed immediately above the G-M tube *A*. A coincidence between *A* and any one of the tubes of bank *B* would fire the chamber. Stereoscopic pictures were taken in order to study the angular divergence of the pairs produced.

For a particular series of runs, with a selected thickness of lead above the chamber, the total number of

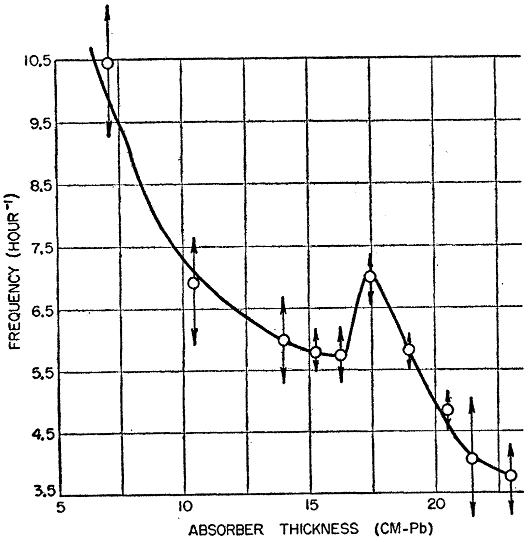

FIG. 2. Rossi transition curve for Pb (total events—pairs and showers).

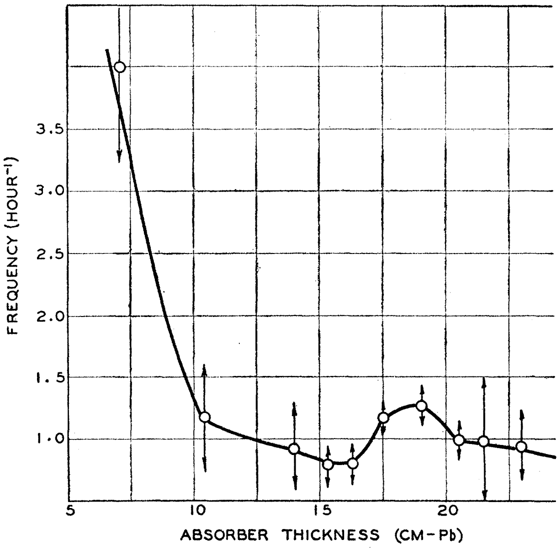

FIG. 3. Cosmic-ray shower transition curve for Pb (all showers—i.e., events with more than two particles).

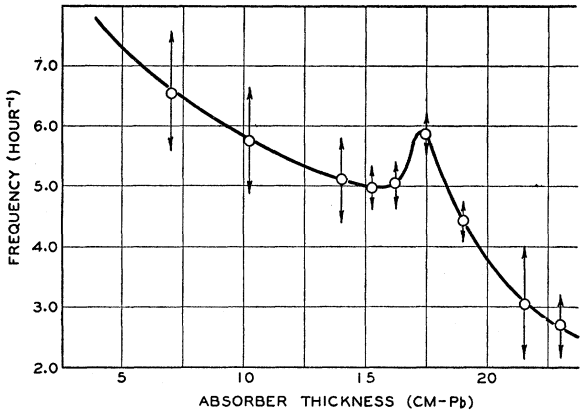

FIG. 4. Cosmic-ray transition curve for pair production in Pb (total pair production).

pictures taken, the total time elapsed, and the averaged resetting time of the chamber were recorded. The total active time of the chamber was thus the difference between the total elapsed time and the product of the number of pictures and the dead time of the chamber. The pictures were scanned and those with pairs or showers marked. The total number of pictures in each series with three or more particles (showers) were counted and recorded. The frames with pairs (two particles) were projected and the angular divergence of the tracks measured.

The selection criteria for defining and using a track were (1) it must be a minimum ionization particle as indicated by the track in the photograph, (2) it must not scatter but be energetic enough to give a straight track through the chamber, (3) pairs or showers must appear to have originated in the lead above the chamber, i.e., the reprojection of the tracks must intersect within the lead block. Under this criterion parallel tracks were counted as single particles and not as a very narrow angle pair.

The thicknesses of lead used were 7.0, 10.4, 14.0, 15.2, 16.3, 17.5, 19.0, 20.5, 21.5, and 23.0 centimeters. Data were taken continuously over a period of time covering about 2½ months. One thickness was used for one particular day, for instance 14.0 centimeters, and the next day a 20.5 cm thickness might be used, the thickness being selected at random to minimize barometric effects or other systematic errors. The pairs were separated into groups having angular divergences ranging between 0–5°, 5–10°, 10–15°, 15–20°, and greater than 20° for the particular thickness of lead being studied.

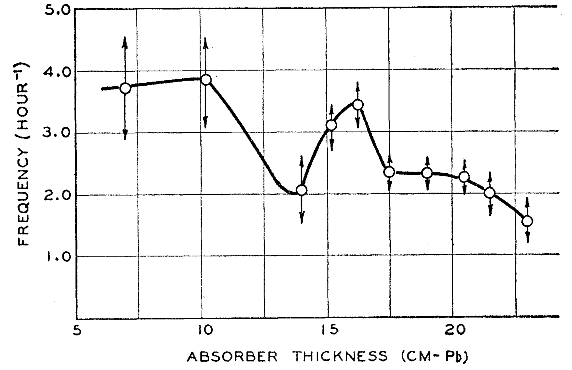

FIG. 5. Cosmic-ray transition curve for pair production in Pb (pair production with angular divergence greater than 20° between the particles).

Only a very few pictures, less than 1%, showed no tracks, and few pictures showed tracks which were not representative of penetrating particles as defined by the foregoing criteria. This indicated that the equipment as a whole was functioning reliably and that the geometry and performance of the G-M telescope was satisfactory. Most of the pictures showed single tracks. About 15% of the pictures contained pairs or showers according to criterion (3).

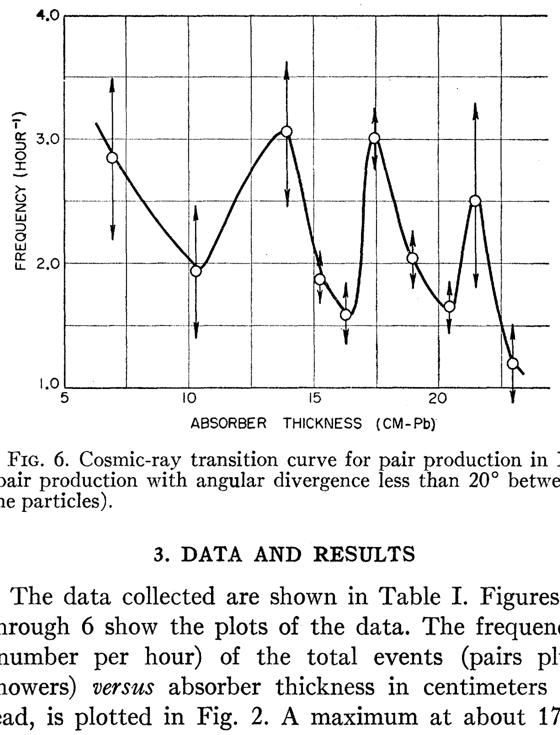

FIG. 6. Cosmic-ray transition curve for pair production in Pb (pair production with angular divergence less than 20° between the particles).

3. DATA AND RESULTS

The data collected are shown in Table I. Figures 2 through 6 show the plots of the data. The frequency (number per hour) of the total events (pairs plus showers) *versus* absorber thickness in centimeters of lead, is plotted in Fig. 2. A maximum at about 17.5 centimeters is indicated. The standard error is shown for each data point. The plot of showers (events with more than two particles originating from a common source in the lead) is shown in Fig. 3. Again a maximum is suggested at about 18.0 centimeters of lead. Figure 4 is a plot of the total pair production. Again a maximum is exhibited but now the maximum is at about 17.0 centimeters of lead. The right side of the curve shows an increasing downward trend as absorber thickness is increased. Figure 5 represents the pairs with angular divergence larger than 20°. Again a maximum occurs, in this case at about 16 centimeters. Figure 6 represents the pairs with angular divergence less than 20°. A maximum is definitely marked at 17.5 cm where the rate is at least four standard errors above the nearest two points on either side.

The results displayed in the last column of Table I agree with what others in the field have reported: the maximum is not indicated by the total intensity of the particles. The upward trend suggested by the last two points may be discounted because of an inadequate number of counts.

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Influence of Geomagnetic Quadrupole Fields upon Cosmic-Ray Intensity*†

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The effect upon cosmic-ray particles of the quadrupole part of the earth's magnetic field has been calculated, using the results of the magnetic survey of 1945. The effect predicted from the zonal quadrupole term is a northern shift of the cosmic-ray latitude curve. The 1945 magnetic center was calculated, using Schmidt's method, and it is 0.0629 earth radii from the center of the earth, as compared to 0.0536 earth radii in 1922. The shift in magnetic center results in an increase in the predicted longitude effect. The residual or sectorial quadrupole effect upon cosmic-ray intensity is predicted to be a two-period sine curve in the longitude effect.

I. INTRODUCTION

THE latitude effect in cosmic-ray intensity has been explained by Fermi and Rossi.[1] They used the angular integral of motion for a charged particle moving in a dipole magnetic field, i.e., Stoermer's theorem,[2] and assumed an isotropic cosmic-ray flux at infinity. The longitude effect has been shown to be consistent with an off-center position for the earth's magnetic dipole.[3] The present investigation is concerned with the influence upon cosmic-ray intensity of all the quadrupole terms of the earth's magnetic field. The calculations made are based on the 1945 magnetic survey by Vestine and Lange.[4]

During a magnetic survey, measurements of the earth's magnetic field are made at a large number of stations all over the world. For the analysis of the measurements, a magnetic potential function is introduced and expanded in spherical harmonics, the coefficients of the expansion being called Gauss coefficients. The coefficients are adjusted so that the gradient of the magnetic potential renders a best fit to the experimentally measured field.[5]

In the study of geomagnetic effects upon cosmic-ray intensity, two different dipole approximations to the earth's magnetic field have been used. The first approximation is a dipole located at the geographic center of the earth, which can be represented mathematically by the first three Gauss coefficients. The second and higher approximation is an off-center dipole located at the magnetic center. The equations for the magnetic center involve the first eight Gauss coefficients and are given by Schmidt.[6] A line along the centered dipole determines the magnetic axis of the earth. A quadrupole which is symmetric about this axis, i.e., a zonal quadrupole, can be added to the centered dipole and the motion of charged particles in the combined dipole and zonal quadrupole fields can be studied, following a suggestion by S. B. Treiman. The cylindrical symmetry leads to an angular integral of motion which is similar to Stoermer's theorem, and critical magnetic rigidities or cutoff rigidities are defined analogous to the ordinary Stoermer case.

The location of the off-center dipole has been computed by Schmidt[6] from the magnetic survey of 1922. To find the effect of the off-center dipole upon cosmic-ray intensity, ordinary Stoermer theory can be applied

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