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High Energy Cosmic-Ray Showers in Nuclear Emulsions*

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A detailed and statistical study of high energy events in nuclear emulsions exposed at high altitudes has given some information on a model to describe the showers found in cosmic rays. There is evidence shown that shower multiplicity increases with primary energy. Differences in the behavior of events from heavy and light nucleus collisions are described. From multiplicity and angular spread of the tracks in individual events, arguments are presented to support a pluromultiple model for meson production in high energy collisions with a nucleus.

I. INTRODUCTION

THE study of cosmic rays by various methods has revealed the occurrence of nuclear interactions wherein many secondary particles of very high energies are ejected, apparently from the collision of an incoming particle with some nucleus. These secondary particles are emitted more or less collimated in a direction opposite to the incoming particle (if such is visible). In some instances the secondary particles have been identified as mesons.[1–4] With the evidence for meson production from nuclear collisions obtained with the cyclotron at Berkeley,[5] it seems reasonable that these high energy showers involve the production of mesons. The development of very sensitive nuclear photographic emulsions has made possible the recording of these high energy showers and the detection of all charged particles, incoming and emitted.[6]

The purpose of this experiment is to study such events from a statistical basis and in detail to provide information for a satisfactory model to explain these events.

II. EXPERIMENTAL PROCEDURE

Eastman NTB3 photographic plates were used in the experiment. The plates were exposed on balloon flights carried out by the Cosmic Ray group of Brookhaven National Laboratory. The data were acquired from four flights at three different geomagnetic latitudes, 31°, 48°, and 57°. In all these flights the balloons ascended to an altitude of about 90,000 feet (15 g/cm^2 of air) and remained there between four and six hours. The rise time was about 2 hours, the descent 1 hour. The plates were mounted so that the vertical was included in the plane of the emulsion. There was no appreciable material placed over them.

The plates were scanned and all nuclear events recorded. The tracks in a star were further classified by their specific ionization (grain count) into the following sets corresponding to energy ranges of a singly charged particle:

"Minimum"—energy>0.5 mc^2.
"Near minimum"—energy>0.1 mc^2, <0.5 mc^2.
"Medium"—energy<0.1 mc^2.
"Heavy"—specific ionization greater than that of a singly charged particle of any energy.

Additional measurements were made on stars which showed high minimum track multiplicity. A microscope provided with a tilting stage was used to measure the direction angles of the tracks with respect to the vertical and the plane of the emulsion; the tilting stage allowed easy location and measurements on each minimum ionizing track. The angle with respect to the emulsion plane was corrected for the emulsion shrinkage during development. When a long near-minimum track was found, a scattering measurement was made to determine the mass of the particle. The heavy tracks were examined to determine their charge. If these tracks ended in the emulsion, it was possible to use the methods suggested by Bradt and Peters.[7] When the track left the emulsion, it was possible to establish the minimum charge it could have by comparison with tracks of known Z.

III. STATISTICAL ANALYSIS OF ALL STARS

By adding the total recognizable charge, Z min, carried away by low energy particles (heavy and medium tracks) one obtains an estimate of nuclear charge "boiled off" from the residual excited nucleus. If one examines the stars with 4 or more emitted minimum tracks, it appears that the values obtained for Z min fall into two groups, large and small Z min, as shown in the histogram, Fig. 1. The emulsion of the plates is composed of elements of high and low A as shown[8] in Table I. It is reasonable to suppose that the large or small "boiled-off" charge is an indication of a collision with a high A or low A nucleus; this conclusion assumes that we must have charge production in the light nucleus events. This agrees with similar

* Supported by the joint program of the ONR and AEC.
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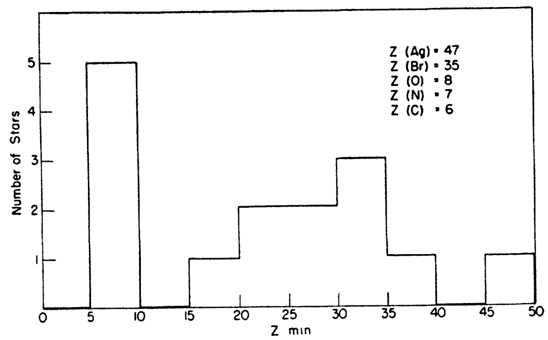

FIG. 1. Histogram of the total charge carried by nonrelativistic particles in stars which show a cone of minimum ionizing particles.

results obtained by Harding[9] and by the Brookhaven group.[10] We obtain a ratio for the number of heavy to light nucleus events with 4 or more emitted minimum tracks of 2.8 (36 to 13). This compares with a total geometrical cross-section ratio of 2.5 expected from the composition of the emulsion. This agreement could be only approximately good, since events of 4 or more minimum tracks could be initiated by incoming particles of different energy ranges in heavy and light nuclei. If we examine events with less than 4 minimum tracks, it is not always possible to judge an event as the product of a light or heavy nucleus collision.

In stars showing collimation of secondary particles, it is possible to determine the existence of an initiating relativistic charged particle. For the stars with no collimation, we have adopted the convention of classifying them as initiated by a relativistic charged particle if a track of minimum ionization is seen in the upper hemisphere.

In Table II we have classified all the stars found in our plates at three latitudes. A comparison of the plates exposed at Cuba with those of the other flights shows a relative depletion in the classes of stars with 4 or less minimum tracks. We can explain this observation if we assume that stars of multiplicities less than about 5 are initiated by protons of energy less than that of the magnetic cutoff at Cuba (8 Bev). This same effect is possibly shown by comparison of the Pennsylvania and Minnesota plates; in this case a multiplicity of about unity corresponds to the cutoff in Pennsylvania. This evidence indicates that the higher energy primaries produce in general a high multiplicity of outgoing minimum tracks. If we take the primary energy cutoff in the vertical direction at 30° geomagnetic latitude as computed by Lemaître and Vallarta[11] at 8 Bev, we conclude that showers with greater than 5 relativistic particles are initiated by primaries of greater than 8 Bev. These data show qualitative agreement with the results of other observers.[10,12]

[9] J. B. Harding, Nature **163**, 440 (1949).
[10] Salant, Hornbostel, Fisk, and Smith, Phys. Rev. **79**, 184 (1950).
[11] G. Lemaître and M. S. Vallarta, Phys. Rev. **50**, 493 (1936).
[12] Camerini, Coor, Davies, Fowler, Lock, Muirhead, and Tobin, Phil. Mag. **40**, 1073 (1949).

IV. ANALYSIS OF VERY HIGH ENERGY SHOWERS

This section presents the details and final results of an experiment previously reported.[13] We have selected 16 of the highest multiplicity showers, 6 from the light nucleus collisions and 10 from heavy nucleus collisions, for analysis.

The tracks are plotted on an angular coordinate system representing the surface of a sphere whose center is the star. Each track is represented on the plot by its point of emergence from the sphere. By using the celluloid plot made in the same way, one can measure directly the angle between any two tracks. Two such plots are shown in Fig. 2, for both a heavy and light nucleus collision. For each of these events we have found the mean latitude and longitude angle for the emitted minimum tracks; this point is the "center of gravity" of the points representing the minimum tracks on the plots. We define the "shower axis" as that direction from the star represented by this point. This direction will not necessarily be the extrapolated direction of the incoming particle; however, the convention allows consistent treatment of events with and without visible incoming tracks.

We have measured the angle, ψ, which each track in the star makes with the shower axis. From these data we have also computed the average angle, $\bar{\psi}$, for the minimum and near-minimum tracks for each event. The values of $\bar{\psi}$ obtained if we had defined the shower axis as the direction of the incoming particle, wherever possible, agree with those computed, within 10 percent (except for $H1$ where there is doubt that the backward-directed minimum track is indeed an incoming particle). This result is to be expected, since these two axes are separated by an angle sufficiently less than $\bar{\psi}$, and a small change in the position of the axis has only a second-order effect on the value of $\bar{\psi}$. A general idea of the angular divergences of these tracks is given by Fig. 3, where we have plotted in a histogram the superimposed angular distributions from all heavy and light nucleus showers. The plot for the heavy and medium tracks illustrates their spherical symmetry, thus leading to the explanation that they are "boiled-off" particles from a residual excited nucleus. In 4 of the light nucleus events there is a pronounced cylindrical asymmetry in the distribution of minimum tracks about the shower axis. The degree of this asymmetry is measured by

TABLE I. Composition of the nuclear emulsions.

Element	Z	A	Percent by weight	Percentage of total nuclear geometric cross section
Ag	47	107	47	38
Br	35	80	34	30.5
C	6	12	8.5	14.5
N	7	14	3.1	5
O	8	16	4.8	7.5
H	1	1	1.2	4.5

[13] Feld, Lebow, and Osborne, Phys. Rev. **77**, 731 (1950).

finding the average component of $\bar{\psi}$, $\bar{\psi}_{max}$, along the major axis of the distribution and $\bar{\psi}_{min}$ along the minor axis. The ratio, $\bar{\psi}_{max}/\bar{\psi}_{min}$, has been computed for these 4 events. The data on each event are presented in Table III.

Eight "near-minimum" tracks were long enough to allow scattering measurements. These measurements were accurate enough to detect the scattering of a non-relativistic particle of 80 Mev or below. Thus, if a near minimum track ($0.1<E/mc^2<0.5$) shows definite scattering, its mass must be less than 800 Mev/C^2. Of the 8 tracks measured, 7 showed no scattering, and one gave a mass measurement of 150 Mev$\pm$50 Mev/C^2.

Calculation on a Nucleon-Nucleon Meson-Producing Collision Model

To interpret these data we have computed the expected angular distribution if we assume the simple picture of a nucleon-nucleon collision producing mesons which come off in the center-of-mass system of the two nucleons with a total energy, ϵ, and with an angular distribution given by some even power of $\sin\theta$ or $\cos\theta$. We assume also that all the energy available in the center-of-mass system is used to produce mesons which enables us to compute the maximum multiplicity, M, for a given collision.

TABLE II. Statistical survey of all events found in the nuclear emulsions for various geomagnetic latitudes.

Table IIa
Cuba (lat. 31°) 6.0 c.c. hours of exposed emulsion

Incoming particle	Struck nucleus	Number of outgoing minimum tracks ≥10	5–9	4	3	2	1	0
	heavy	3	2	0				
Minimum	light	0	2	0				
	total	3	4	0	1	4	3	9
	heavy	0	0	0				
Other	light	2	0	1				
	total	2	0	1	4	2	9	50
Total		5	4	1	5	6	12	59

4 π-meson events

Table IIb
Pennsylvania (lat. 48°) 3.6 c.c. hours of exposed emulsion

Incoming particle	Struck nucleus	Number of outgoing minimum tracks ≥10	5–9	4	3	2	1	0
	heavy	1	2	3				
Minimum	light	0	1	1				
	total	1	3	4	4	11	10	14
	heavy	1	1	1				
Other	light	0	0	0				
	total	1	1	1	2	4	10	63
Total		2	4	5	6	15	20	77

3 π-meson events

Table IIc
Minnesota (lat. 57°) 10.8 c.c. hours of exposed emulsion

Incoming particle	Struck nucleus	Number of outgoing minimum tracks ≥10	5–9	4	3	2	1	0
	heavy	3	3	6				
Minimum	light	1	0	2				
	total	4	3	8	12	21	54	65
	heavy	1	4	5				
Other	light	0	2	1				
	total	1	6	6	19	23	54	158
Total		5	9	14	31	44	108	223

16 π-meson events

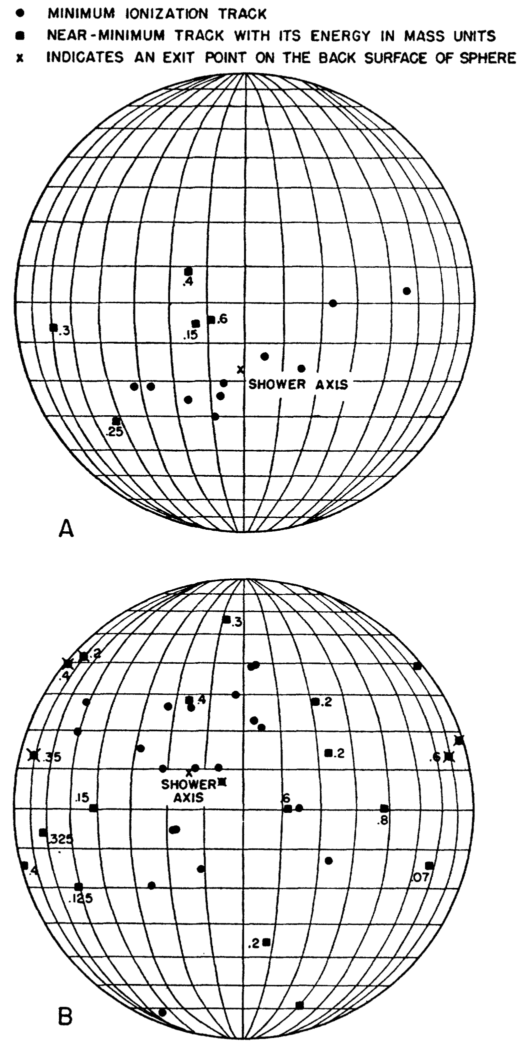

FIG. 2. Shown here for comparison are two typical spherical plots of a light (Fig. A) and heavy (Fig. B) nucleus shower. Figure 2A shows the typical conical asymmetry exhibited by the cone of minimum ionizing particles in 4 of the 6 light nucleus showers.

From these assumptions we calculate $\bar{\psi}$ for the emitted mesons in the laboratory system. The details of the computation are given in the Appendix. In addition, a computation assuming a spectrum, $d\epsilon/\epsilon$, with spherical symmetry was made. The results are plotted in Fig. 4 for various values of meson energy in the center-of-mass system and spherical symmetry as a plot of $\bar{\psi}$ *versus* M. It was found that $\bar{\psi}$ is relatively insensitive to an assumed asymmetry of the type $\cos^{2n}\theta$ or $\sin^{2n}\theta$ ($\sim$5 percent for $n=1$). It is also evident from the plotted curves that the results are changed little by the assumption on meson energy.

V. INTERPRETATION OF HIGH ENERGY SHOWERS

The evidence that we are indeed observing meson production comes from an analysis of the light nucleus collisions. The total charge (from all tracks) emitted in the 6 stars is

$$Z = 11,\ 13,\ 17,\ 15,\ 20,\ 22,$$

compared with the charges of the light nuclei in the emulsion C, N, and O ($Z=6$, 7, 8). This charge creation would be most naturally attributed to meson production, though one cannot logically exclude the explanation that some other charged particle is created (say, electron pairs). Further evidence for charge creation is seen in the two heavy nucleus events $H9$ and $H11$; the charge observed is greater than the Z of the highest Z material, namely, Ag($Z=47$).

We can state further that the near-minimum tracks in these showers are protons for the most part. This is indicated by the scattering measurement giving 7 protons to 1 meson. In addition we find that there are 156 events in our plates which produce 2 or more minimum ionization tracks (i.e., which represent a high energy collision), yet there are only 23 π-mesons (+ and −) ending in the emulsion. The geometry of the stack of plates represents roughly the range of a 50-Mev meson. Statistically, then, one finds less than one meson of energy less than 50 Mev for every 7 high energy events. Looking again at the light nucleus events the charge carried away by the nonminimum tracks is

$$Z = 9,\ 6,\ 8,\ 5,\ 5,\ 10.$$

This corresponds roughly to the Z of the light nuclei. Therefore, we conclude that the minimum tracks are mostly mesons. These results have been ascertained by other experimenters.[3, 4]

To compare the observed events with calculations for the nucleon-collision model, we take the multiplicity and $\bar{\psi}$ of the minimum tracks as referring to the emitted mesons and compare these with our calculations (Fig. 4). We assume in this comparison that the mesons, if produced by one encounter, are not scattered by additional collisions in the nucleus. The plot points out:

(1) The angular dispersion of relativistic tracks decreases in general with multiplicity.

(2) The events in light nuclei are not inconsistent with a single collision model.

(3) The heavy nucleus events cannot be described by this model. $\bar{\psi}$ is larger by a factor of about 2 from the computed value. This disagreement is difficult to reconcile by other assumptions about the energy and angular distribution of mesons in the center-of-mass system. A less inelastic collision aggravates the disagreement. It has been computed that if all the mesons came off so as to give the maximum angle in the laboratory system, the results would be just satisfied; but this is at the expense of eliminating front to back symmetry in the center-of-mass system. Of the two heavy nucleus collisions giving the lowest $\bar{\psi}$, one is initiated by an α-particle, the other is too close to the emulsion surface to identify the initiating particle. It is not unreasonable to expect that an α-particle initiated shower of the same multiplicity would give a narrower cone of emitted particles.

We conclude that these events cannot be described with a single collision model, particularly if we take into account further indirect evidence:

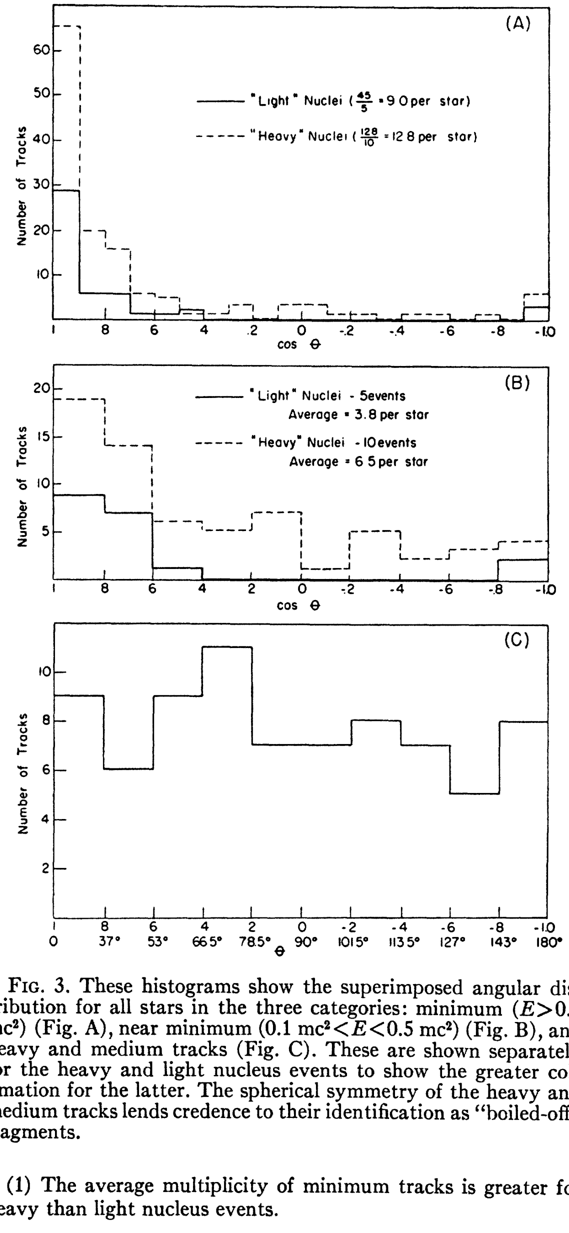

FIG. 3. These histograms show the superimposed angular distribution for all stars in the three categories: minimum ($E>0.5$ mc²) (Fig. A), near minimum (0.1 mc² $<E<0.5$ mc²) (Fig. B), and heavy and medium tracks (Fig. C). These are shown separately for the heavy and light nucleus events to show the greater collimation for the latter. The spherical symmetry of the heavy and medium tracks lends credence to their identification as "boiled-off" fragments.

(1) The average multiplicity of minimum tracks is greater for heavy than light nucleus events.

Heavy nuclei (9 showers):	12.6
Light nuclei (6 showers):	9.1.

This indicates that the extra nuclear material of the heavy nuclei is involved in the process though not in the ratio of nuclear diameters, which is about 2 to 1.

(2) The large number of near-minimum tracks (mostly protons) with forward collimation indicates multiple nucleon interactions.

The other extreme model of successive collisions through the nucleus each producing one meson seems unsatisfactory. A measure of the maximum number of collisions is given by the number of particles which do *not* appear as "boiled-off" particles. We assume a like number of neutrons as protons in this category and take the average A for the light nuclei to be 14. This number, 14 minus $2Z$ min, corresponding to the maxi-

TABLE III. Summary of data on each shower.

Star	Minimum tracks number	Minimum tracks $\bar{\psi}$	Near-minimum tracks Number	Near-minimum tracks $\bar{\psi}$	Heavy tracks Number	Heavy tracks Z_{min}	Z_{min} including near-min tracks	Total observable charge	Incoming minimum track?	$\pi-\psi$ for incoming track	$\bar{\psi}_{max}/\bar{\psi}_{min}$
*L*1	6	34°	2	30°	4	4	6	12	Yes	10°	4.2
*L*2	7	35	3	85	4	4	7	14	Yes	10°	
*L*3	9	17.5	5	43	2	4	9	18	Maybe[a]		
*L*4	10	16.5	4	68	3	3	7	17	No		2.5
*L*5	10	20	5	31	5	5	9	19	No		4.5
*L*6	13	17	5	7	4	4	9	22	No		1.7
*H*1	5	45	9	65	14	27	36	41	Yes?	65°	
*H*2	5	40	10	54	18	26	36	41	Yes	15°	
*H*3	9	44	6	72	20	28	34	43	Yes	20°	
*H*4	10	43	8	74	17	24	32	42	No		
*H*5	11	35.5	1	(137)	11	15	16	27	Yes	20°	
*H*6	12	32	6	38	15	18	24	36	Yes	18°	
*H*7	12	22	6	59	11	17	23	35	α-particle	9°	
*H*8	13	37	8	87	17	19	27	40	No		
*H*9	14	9	5	50	22	43	48	62	Maybe		
*H*10	15	32	4	55	11	22	26	41	Yes	19°	
*H*11	20	25.5	19	65	15	19	38	58	Yes	10°	

[a] The doubt occurs because of the star being near an emulsion surface.

mum number of nucleons ejected in some collision, is for the 6 light nucleus cases: 6, 6, 6, 8, 4, and 6. On the other hand, the amount of excess charge produced is 3, 5, 10, 10, 13, and 15. The last four cases indicate that more than one meson is produced per nucleon involved in the collision. In all this we have not considered the additional possibility that neutral mesons are produced as well.

As mentioned above, we have found a definite asymmetry in the cones of minimum tracks associated with light nucleus collision. To interpret this asymmetry we should inquire whether it is statistically significant. We may imagine the points of emergence of the minimum tracks on the sphere plots as points on a plane with a center at the shower axis. We define the "major axis" of the distribution as the line passing through the shower axis and the point farthest from the center. If cylindrical symmetry were expected, of the remaining points, there should be an equal population in the two quadrants bisected by the major axis, as in the two bisected by the minor axis. We have used this analysis on the six events, including the points from the two stars showing no asymmetry, and find 34 points in the major axis quadrants to 15 for the minor axis. By the laws of probability the chance that this or greater asymmetry is a statistical misfortune of a symmetric distribution is 2.5 percent. These observations could be explained by assuming the cone to be produced by subsidiary cones of a primary plus secondary collision; however, our data cannot confirm such a speculation.

To compare these results with those of other observers, cloud-chamber pictures by Freier and Ney[14] give the result that showers from heavy nuclei show a higher multiplicity of penetrating particles than those from light nuclei, though the average angular dispersions are the same. This is in essential agreement with our data as shown in Fig. 4. Evidence for pluromultiple meson production has also been found in large showers occurring in nuclear emulsions as seen by Kaplon *et al.*[15] and LePrince-Ringuet *et al.*[16]

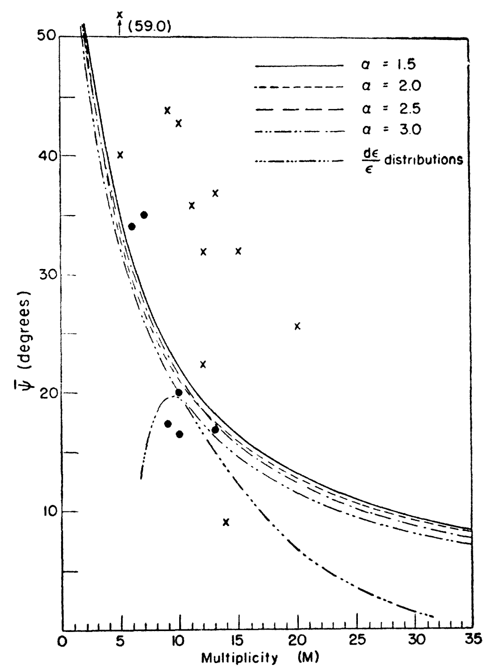

FIG. 4. This plot shows the average dispersion angle, $\bar{\psi}$, for the "minimum" tracks in each event *vs* the corresponding multiplicity. The heavy nucleus events are marked by a (×) and the light nucleus events by a (●). The lines give the predicted multiplicity *vs* $\bar{\psi}$ for a single completely inelastic nucleon-nucleon collision for various center-of-mass meson spectra: (1) monoenergetic mesons of total energy, α, in meson rest mass units: (2) a $d\epsilon/\epsilon$ spectrum.

[14] Phyllis Freier and E. P. Ney, Phys. Rev. **77**, 337 (1950).

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[16] LePrince-Ringuet, Bousser, Hoang-Tchang-Fong, Jauneou, and Morellet, Phys. Rev. **76**, 1273 (1949).

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APPENDIX

We have calculated the average angle of dispersion for mesons emitted in the collision of two nucleons if the mesons are produced in the center-of-mass system of the two nucleons with a single energy and an angular distribution corresponding to the $2n$th power of the sin or cos.

β = velocity of meson in c-of-m system.
β_0 = velocity of c-of-m system.
θ = angle of meson emission in c-of-m system.
ψ = angle of meson emission in laboratory system.

We assume a distribution in the center-of-mass system

$$\text{if}\quad N(\theta)\sim\cos^{2n}\theta\,\sin\theta d\theta,$$

then,

$$\bar{\psi}=\int_0^\pi\cos^{2n}\theta\psi(\theta)\,\sin\theta d\theta\Big/\int_0^\pi\cos^{2n}\theta\,\sin\theta d\theta,$$

$$\psi(\theta)=\tan^{-1}[(1-\beta_0^2)^{1/2}\sin\theta/(\beta_0/\beta)+\cos\theta].$$

This expression can be integrated exactly

$$\bar{\psi}=(\pi/2)+(\pi/2)(1/\beta_0)(1/\alpha_1-\alpha_2)[G(\alpha_1)=G(\alpha_2)]\quad\beta_0<\beta,$$
$$\bar{\psi}=(\pi/2)(1/\beta_0)(1/\alpha_2-\alpha_1)[G(\alpha_1)-G(\alpha_2)]\quad\beta_0>\beta,$$
$$\alpha_{1,2}=(1/\beta_0\beta)\{1\pm[(1-\beta_0^2)(1-\beta^2)]^{1/2}\},$$
$$G(\alpha)=\left(-\frac{\beta_0}{\beta}\alpha+1\right)\left[\alpha^{2n}+\tfrac{1}{2}\alpha^{2n-2}+\cdots+\frac{1\cdot3\cdots(2n-1)}{2\cdot4\cdots2n}-\frac{\alpha^{2n-1}}{(\alpha^2-1)^{1/2}}\right].$$

We can find $\bar{\psi}$ for a distribution, $\sin^{2n}\theta$, from the corresponding $\cos\theta$ moments. For instance,

$$\bar{\psi}(\sin^2\theta)=\tfrac{1}{2}[3\bar{\psi}(n=0)-\bar{\psi}(\cos^2\theta)].$$

For the case $n=0$ (spherical symmetry)

$$\bar{\psi}=[1-(1-\beta^2)^{1/2}](1-\beta_0^2)^{1/2}/\beta\beta_0\quad\beta_0>\beta,$$
$$\bar{\psi}=1-\{[1-(1-\beta_0^2)^{1/2}]/\beta\beta_0\}\quad\beta_0<\beta.$$

To obtain the curves of Fig. 4, we have assumed various total energies, ϵ, for the mesons in the center-of-mass system. Assuming then a given nucleon total energy, U_0, (laboratory system), we find the velocity of the center-of-mass, β_0,

$$1-\beta_0^2=2Mc^2/(U_0+Mc^2),\quad M\text{ is the nucleon mass.}$$

We find the total energy available in the center-of-mass system and divide by the meson energy to obtain the multiplicity, M_0

$$M_0=[2Mc^2(U_0+Mc^2)^{1/2}-2Mc^2]/\epsilon,$$
$$\epsilon=mc^2/(1-\beta^2)^{1/2}=\alpha mc^2,$$
$$m=\text{meson mass.}$$

The values of $\bar{\psi}$ for the $d\epsilon/\epsilon$ spectrum are obtained by an integration of the above expressions for $\bar{\psi}$ over the center-of-mass meson energy. The resulting curves of M_0 *vs* $\bar{\psi}$ are shown in Fig. 4.

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A Search for Cosmic-Ray Diurnal Effects at Balloon Altitudes

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In two balloon flights in Minnesota a search was made for diurnal effects in the cosmic radiation at altitudes above 50,000 feet. Measurements were made simultaneously of the total ionizing radiation, γ-radiation in the energy range of approximately 0.75 to 5 Mev, and fast neutrons. The ionizing radiation and γ-radiation component was measured by means of a central horizontal counter tube surrounded by a closely packed ring of horizontal counters. Coincidences between the central counter and the outer ring determined the ionizing radiation, while anticoincidences gave the intensity of the γ-radiation. The neutron flux was measured by two BF_3 counters, one filled with enriched BF_3, mounted side by side in a vertical paraffin cylinder eight inches in diameter surrounded by Cd. One flight was launched at 12:30 A.M. LCT and remained aloft until 8:30 A.M. The other flight was launched at 6:00 P.M. and landed at 10:00 P.M. No diurnal effects were observed. The statistical accuracy of this measurement is on the order of 1 percent for the total ionizing radiation, 3 percent for the γ-radiation, and 2 percent for the neutron measurement.

I. INTRODUCTION

THE possible existence of a diurnal variation in the cosmic-ray intensity is of considerable interest, since it bears both on the matter of a permanent solar magnetic moment[1] and on the energy spectrum of the primary cosmic radiation. A solar magnetic moment of adequate magnitude to account for the apparent "knee" in the cosmic-ray latitude curve[2] should also give rise to an appreciable diurnal effect.[3,4] Measurements of this effect may provide evidence to aid in the resolution of the present doubtful status of the solar moment. If the absence of a diurnal effect can be established, some other mechanism will be required to explain an energy cut-off at high latitudes.

The relatively low energy particles of 3 Bev or less which would be affected by the solar field contribute very little to the intensity at ground level. These

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