ON RELATIVISTIC PARTICLES IN HIGH ENERGY SHOWERS

By RAMA
(*Tata Institute of Fundamental Research, Bombay* 1)

Received February 22, 1954
(Communicated by Prof. B. Peters, F.A.SC.)

SEVENTY-NINE high energy showers have been investigated for determining:

(1) the interaction cross-section for shower particles in emulsion.

(2) the ratio[1] of neutral π-mesons to charged shower particles.

For these investigations, a nuclear emulsion block detector[2] consisting of 24 Ilford G-5 stripped emulsions 600 μ thick, and $4'' \times 6''$ lateral dimensions, was used. After processing the emulsions were so aligned that the tracks of all charged particles which entered or originated in the stack during a balloon flight could be followed from emulsion to emulsion.

The showers used by us were produced by primaries with energies lying between 50 and 1,000 Bev. per nucleon and the number of charged shower particles in each shower varied between 5 and 40 per incident nucleon. Six such showers produced by heavy primaries were located by following the tracks of heavy primaries from the outside plates into the stack. The remaining showers were found by normal scanning. The energy of the primary was in each case estimated from the opening angle of the shower, using the relation $E/MC^2 = 2/\theta_{\frac{1}{2}}^2$, where $\theta_{\frac{1}{2}}$ is the half angle of the cone containing half the number of shower particles around the shower axis.

In all, 1,635 shower particles were examined for a total track length of 439 cm. in emulsion and 15 secondary interactions were observed corresponding to an interaction mean free path of $29 \cdot 3 \pm 7 \cdot 6$ cm. The term 'secondary interaction' as used here denotes not only stars but charge exchange scattering (no case was observed) as well as ordinary scattering provided the scattering angle exceeds 10° (one case was observed).

The data on secondary interactions in similar investigations reported previously from this laboratory and Bristol is given in Table I.

Combining all the results, we get an interaction mean free path of $28 \cdot 4 \pm 4 \cdot 8$ cm. for shower particles in emulsion, while the value of interaction mean free-path corresponding to geometrical interaction cross-section in G-5 emulsion is 27 cm. (This value is based on a nuclear radius of

TABLE I

Primary energy region	Track length (cm.)	No. of interactions	Authors
8,000 Bev.	301	8	Lal *et al.* [3]
50–3,000 Bev.	129	5	Daniel *et al.* [4]
20,000 Bev.	140	4	Mulvey[5]
50–1,000 Bev.	439	15	Present work
Total ..	909	32	

$1\cdot 38 \times 10^{-13} A^{\frac{1}{3}}$ cms. for each constitutent nucleus of atomic weight A.) The result indicates that probably all shower particles interact with nearly geometric cross-section. However, witin statistical accuracy the result allows still a small admixture (less than 19%) of non-interacting shower particles.

It has been observed that in the secondary stars produced by shower particles the number of heavy prongs, n_h, is generally very small. The distribution of secondary stars with respect to n_h is given in Table II.

TABLE II

n_h ..	0	1	2	3	4	5	6	7	8	9	10	11	12	13
No. of secondary stars	1	8	..	1	..	..	2	..	..	1	1	..	1	..

The number of charged shower particles, n_s, in these interactions varies from 0 to 4. In the secondary interactions with n_s varying from 1 to 4, we find the average n_h to be < 4. In stars having similar number of charged shower particles but produced by all cosmic ray components (presumably mostly nucleons), Camerini *et al.*,[6] find the average n_h to be about 10. In both cases the energies of the particles responsible for the interaction lie in about the same energy interval. There is then some indication that meson production by particles emerging from energetic showers causes less excitation in the target nucleus than meson production by nucleon. A similar indication was obtained earlier.[3]

The ratio[1] of neutral pions to charged shower particles has been determined by counting electron pairs associated with showers upto a maximum distance of 6 mm. ($\cdot 16$ conversion units) from the shower origin. From the results it appears that cascade multiplication should be less than 20%

upto ·16 conversion units, and negligible at ·12 conversion units. We obtain the ratio of neutral pions to charged shower particles as $\cdot 40 \pm \cdot 08$. Combining this result with other similar investigations,[1] the ratio becomes $\cdot 40 \pm \cdot 04$.

If one assumes:

(1) that all pairs observed derive from neutral π°-meson;

(2) that the ratio of neutral to charged π-meson production is $\frac{1}{2}$; and

(3) that the charged shower particles contain not more than 10% protons,

one concludes that the number of shower particles which are neither π-mesons nor protons should be less than 18%.

We observed only two deflections of $\sim 5^{\circ}$ each in all the 1,635 shower tracks. These two particular tracks before the deflection could be identified as due to π-mesons. One case could be interpreted as due to π-μ decay or due to scattering; the second case as that of scattering only.

We observed no event which could be interpreted as the decay of K-meson into L-meson.

Two events were observed in which the shower particle gives rise to only one grey proton track. If they are assumed to be the decays of charged hyperons into proton and a neutral pion, the Q-values turn out very large (·4 and 1·4 Bev. respectively). It seems very unlikely that either of these events is caused by hyperon decay.

I am extremely indebted to Professor B. Peters for his guidance and keen interest throughout this work. I am also thankful to Dr. R. R. Daniel, Mr. G. B. Friedmann, Miss P. A. Irani, Mr. D. Lal and Mr. Y. Pal for their co-operation.

REFERENCES

1. Lal, D., Pal, Y. and Rama .. *Proc. Ind. Acad. Sci.*, 1954, **39**, 127.
2. ——, —— and Peters, B. .. *Ibid.*, 1953, 38, 277.
3. ——, ——, —— and Swamy, M. S. .. *Ibid.*, 1952, 36, 75.
4. Daniel, R. R., Davies, J. H., Mulvey, J. H. and Perkins, H. D. *Phil. Mag.*, 1952, **43**, 753.
5. Mulvey, J. H. .. *Proc. Roy. Soc.*, 1954, **221**, **367**.
6. Camerini, U., Davies, J. H., Fowler, P. H., Franzinetti, C., Muirhead, H., Lock, W. O., Perkins, D. H. and Yekuteili, G. *Phil. Mag.*, **1951**, **42**, 1241.