## Cosmic-Ray Nucleon-Nucleon Collisions in Photographic Emulsions

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WE have so far found four events in Ilford G5 emulsions exposed at about 85,000 feet[1] which show only relativistic or near relativistic singly charged particles with a typical forward shower cone, and none of the usual low energy nuclear disintegration products. It seems plausible to regard these events as being due to multiple production of mesons by primary protons in single nucleon-nucleon collisions.

All four events show an incoming singly charged particle, and Table I gives the number of shower particles ($N$) and their angular distribution with respect to the direction of the primary. Event $B$ is illustrated in Fig. 1. From multiple scattering measurements the particle shot backwards appears to be a meson with energy $\sim$400 Mev in the laboratory system, corresponding to a fairly high energy emission in the CM system for a nucleon-nucleon collision. Although only a few particle energies can be measured, we are attempting to compare these, the angular distributions and multiplicities, with the theories of multiple meson production.[2] A similar event with 7 emitted particles was shown by Camerini *et al.*,[3] and Lord, Fainberg, and Schein[4] have discussed a very high energy event with 17 particles emitted, including 15 in narrow cones.

TABLE I. Angular distribution of shower particles.

| Event | $N$ | $\theta$ (deg)—Polar angle with primary direction 0–5 | 5–10 | 10–20 | 20–30 | 30–50 | 50–90 | 90–180 |
|---|---|---|---|---|---|---|---|---|
| $A$ | 6 | 1 | 2 | | 1 | 1 | 1 | |
| $B$ | 7 | 3 | 1 | 1 | | 1 | | 1 |
| $C$ | 12 | 6 | 4 | | | 2 | | |
| $D$ | 13 | 3 | 1 | 5 | 2 | | 1 | 1 |

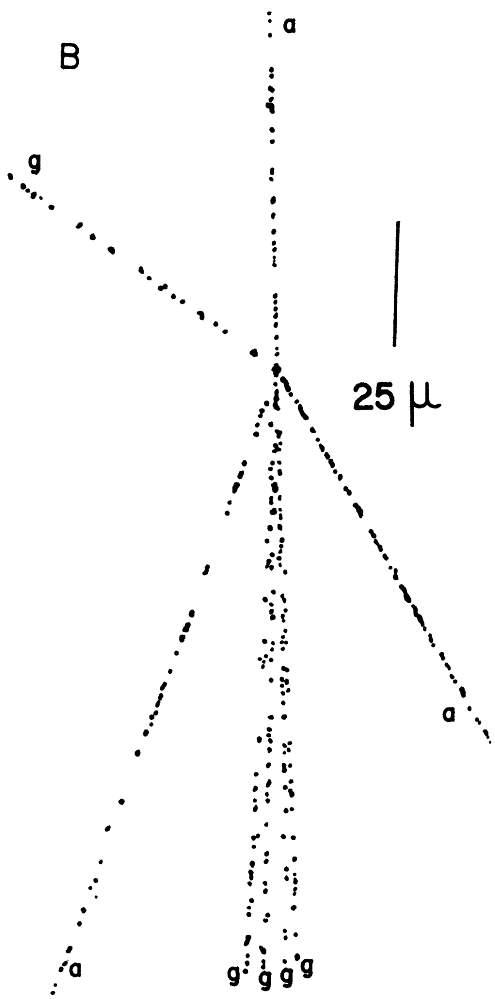


FIG. 1. Projection tracing of event $B$. The tracks marked $a$ go to the air and those marked $g$ go to the glass backing of the emulsion.

We might expect single nucleon-nucleon interactions in a collision between an incoming proton and a hydrogen nucleus or a nucleon in a heavier nucleus in the emulsion. Some observations can be made on the basis of conservation of charge. In a purely $p$-$p$ (or anti $p$-$p$) collision this requires that there be an even number of emitted charged particles, whereas for a $p$-$n$ collision the number would be odd. Thus, it would appear that our events $B$ and $D$, and the events of Camerini *et al.* and of Lord, Fainberg, and Schein cannot represent collisions of a proton with a hydrogen nucleus, but could be $p$-$n$ or possibly $p$-$p$ collisions with the target nucleon in a heavy nucleus. Furthermore, event $A$ can only represent a collision with a hydrogen nucleus or with part of a heavier nucleus in the emulsion. A complete breakup of a carbon nucleus (next lightest to hydrogen in the emulsion) would require at least 7 emitted charged particles in the event, even with the very improbable assumption of no meson production. It seems likely, therefore, that most of the events observed so far represent partial collisions with the heavier nuclei in the emulsion, although $A$ and $C$ could be $p$-hydrogen collisions.

In addition to $A$, $B$, $C$, and $D$, we have observed several events with up to 20 shower particles and with only one or two low energy disintegration products. These may represent events of a similar nature to those described above rather than the more frequent high energy disintegrations involving pluro-multiple meson production, and large numbers of low energy products.

[1] The emulsions were exposed through a collaborative program of cosmic-ray investigations by the Bartol Research Foundation and the National Research Council of Canada with the cooperation of the ONR project, "Skyhook."
[2] E. Fermi, Prog. Theor. Phys. 5, 570 (1950); W. Heisenberg, Nature 164, 65 (1949); Lewis, Oppenheimer, and Wouthuysen, Phys. Rev. 73, 127 (1948).
[3] Camerini, Fowler, Lock, and Muirhead, Phil. Mag. 41, 413 (1950).
[4] Lord, Fainberg, and Schein, Phys. Rev. 80, 970 (1950).

## Meson Production Accompanying Uranium Fission*

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THE 160 to 200 Mev released in the fission of uranium is sufficient to make the production of a pi-meson energetically possible. The process seems unlikely, however, and was not considered seriously until the event shown in Fig. 1 was discovered[1] in a uranium loaded plate exposed by Al-Salam to cyclotron mesons.[2] Here is definitely a 5-Mev meson (a) coming from a fissioning nucleus and leaving the emulsion just before coming to rest. It is not possible to determine the charge of the meson, since it does not end in the emulsion. Track (b), which stays in the emulsion for 2.4 mm, is a proton of energy 115$\pm$20 Mev as determined by grain count and scattering measurements. A nonuniform development of the plate makes it impossible to say with certainty whether this proton was entering or leaving the fission.

If the proton was entering the uranium nucleus, then the meson must have been produced as a result of the fission, since the threshold energy for direct production is greater than 150 Mev. If the proton was leaving the uranium nucleus, the event was