Production of Mesons by the 184-Inch Berkeley Cyclotron

We have observed tracks which we believe to be due to mesons in photographic plates placed near a target bombarded by 380-Mev alpha particles. The identification of the particles responsible for these tracks was first made on the basis of the appearance of the tracks.

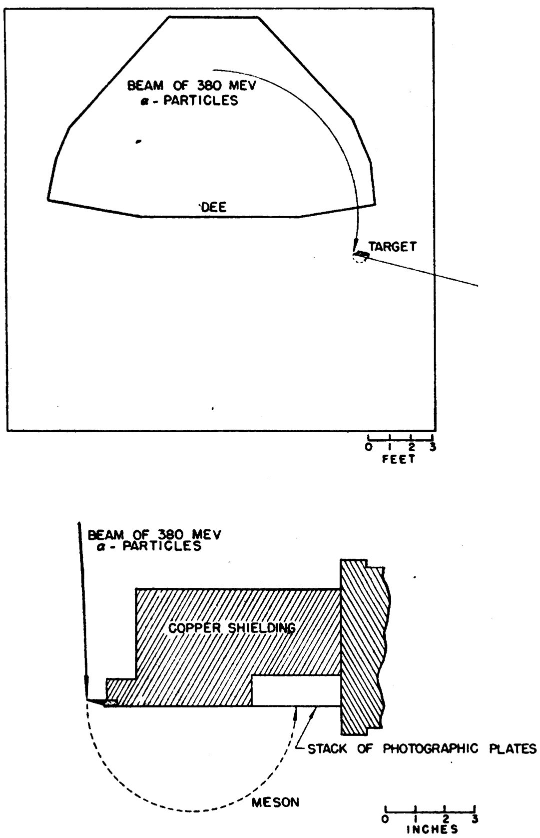

FIG. 1. Arrangement of apparatus in the cyclotron. *Top*: Plan view of cyclotron showing position of target. *Bottom*: Detail view of target showing meson trajectory and position of stack of photographic plates.

These show the same type of scattering and variation of grain density with residual range found in cosmic-ray meson tracks by Lattes, Occhialini, and Powell (*Nature, Lond.*, 1947, **160**, 453, 486), and roughly two-thirds of them produce observable stars at the end of their range. Their appearance is sufficiently characteristic that a practiced observer can recognize them on sight. Later, the identification was confirmed by a direct determination of the mass from $H\rho$ and range measurements (to be described below) which gave the value 313 ± 16 electron masses, showing that they are almost certainly the heavy mesons described by Lattes, Occhialini, and Powell.

The experimental arrangement is shown in Fig. 1. The circulating beam of 380-Mev alpha particles inside the cyclotron passes through a thin target, producing mesons and other particles; the negative mesons are sorted out by the magnetic field and roughly focused on the edge of a stack of photographic plates placed as shown. All the measurements reported here refer to negative mesons produced in a carbon target by full-energy alpha particles, although a few observations have been made with other targets and energies. Beryllium, copper, and uranium targets were bombarded with full-energy alpha particles and gave mesons in numbers comparable to those from carbon; a carbon target bombarded with 300-Mev alpha particles gave a greatly reduced yield.

The photographic plates used are Ilford Nuclear Research plates, type C.2, with an emulsion thickness of $50\,\mu$; the exposure times were about 10 min, and the alpha-particle current about $\frac{1}{10}$ microampere. Each plate shows about 50 meson tracks along its edge, with about 10 times as many heavy-particle tracks in the same area. The latter are attributed to stars and recoils produced by neutrons and are found all over the plates. Fig. 2 shows a typical meson track which produces a star; Fig. 3, one which does not.

The opportunity for making a mass determination is furnished by the magnetic deflection of the mesons. By measuring the point and angle of incidence of each track on the edge of the plate, the radius of curvature in the field is determined. The range in the emulsion is measured with an eyepiece micrometer, and to this is added the path through a one-mil aluminum foil covering the plates. (The earlier observations were made with black paper covering the plates, but these are not suitable for range measurements because of the uncertain thickness of the paper.) A total of 49 tracks have so far been measured in this way, with the following results. There is no significant difference between the masses of the star and no-star particles, and the mean mass of all the particles is 313 ± 16 electron masses; the spread in individual values is probably within the errors of the measurements. The most important source of error is the scattering of the particles in the aluminum foil and in the first $80\,\mu$ of the emulsion. The angle measurements could not be made closer to the edge than this because of the distortion of the emulsion on processing.

The mass value found would indicate that at least 160 Mev should be available in the collision to produce these particles, and furthermore it seems likely that this energy should be concentrated in a single nucleon-nucleon collision. The means for this concentration is provided by the internal motions of the nucleons in the colliding nuclei, as first suggested by McMillan and Teller (*Phys. Rev.*, 1947, **72**, 1) and further developed by Horning and Weinstein (*Phys. Rev.*, 1947, **72**, 251). According to this idea, there are three velocities to consider: the relative velocity of the two nuclei (corresponding to an energy per nucleon of 95 Mev), the velocity of a nucleon inside the alpha particle (corresponding to a maximum energy of about the Fermi limit, 25 Mev), and a similar internal velocity in the carbon nucleus. In the most favorable collision these can add together, giving an effective available energy of $1/2(\sqrt{95} + \sqrt{25} + \sqrt{25})^2 = 195$ Mev in the center of mass system of the two nucleons concerned. Thus, the observations are not inconsistent with a simple picture of meson formation by nucleon-nucleon collisions.

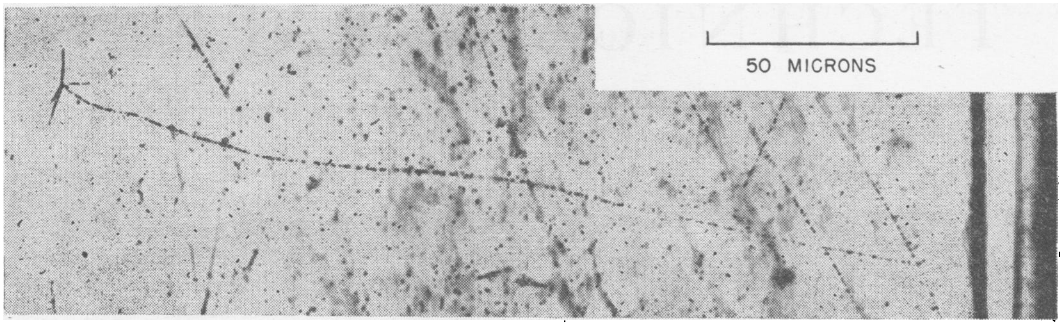

FIG. 2. Track of meson which initiates a star. Meson enters the edge of the photographic plate on the right, moves toward the left, and forms star in upper left hand corner. Note the scattering in the track and the increase in grain density toward the star. (The heavy parallel lines on the right show the edge of the photographic plate.)

The measurements reported here are admittedly preliminary, and much more work is to be done, but it seems certain that this marks the beginning of meson study under controllable laboratory conditions. The large intensities, approximately 10^8 times those available in cosmic rays, mean that the rate of progress in this field can be greatly accelerated.

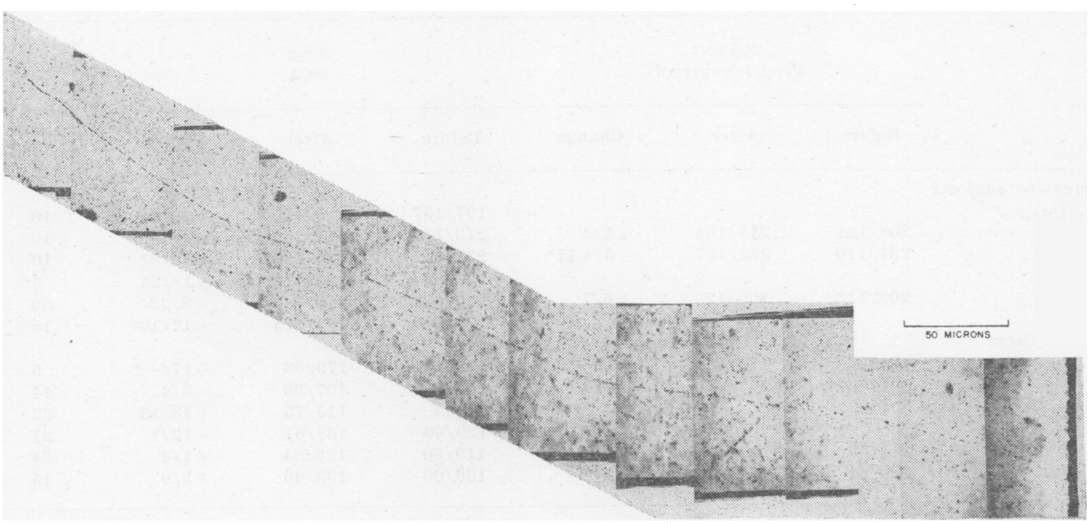

FIG. 3. Track of a meson which does not initiate a star. Meson enters the edge of the photographic plate on the right and moves toward the left. Note the scattering in the track and the increase in grain density toward the left.

In conclusion, we wish to express our deepest appreciation to Prof. E. O. Lawrence, whose interest and encouragement have made this work possible. The program has been greatly aided by help from Profs. R. L. Thornton, E. M. McMillan, R. Serber, and L. W. Alvarez. The authors are indebted to John Burfening, Lt. Col., U. S. Army, for his work on methods of exposing plates in the cyclotron. We also wish to thank Mr. D. J. O'Connell and Mr. A. J. Oliver for microscope work and photography, and Mr. Duane Sewell and the cyclotron crew for making the bombardments. The construction of the 184-inch cyclotron was made possible by a grant from the Rockefeller Foundation. This paper is based on work performed under Contract No. W-7405-eng-48 with the Atomic Energy Commission, in connection with the Radiation Laboratory, University of California, Berkeley, California.

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