is small. The extrapolated He flux comes out $160\pm27/m^2$ sec steradian. Both systematic and statistical errors in the flux that entered the cloud chamber are included in the estimate.

The absorption mean free path in local matter for $Z>2$ nuclei should not be greater than about 50 g/cm², since heavy secondary from local interactions should nearly always enter the chamber accompanied by other secondaries. (Two such events were photographed, and they are not included in the 13.) The $Z>2$ flux that entered the cloud chamber, corrected about 30 percent for local absorption, implies a vertical flux $23\pm6/m^2$ sec steradian of nuclei with $Z>2$ and energy >500-Mev nucleon at atmospheric depth 17 g/cm².

If one accepts the flux measurements of Bradt and Peters[3] for primaries with $Z\geqslant 6$, such primaries can account for only half the events observed, even if six tenths of their collisions in the atmosphere give secondaries with $Z>2$. The probability of a statistical fluctuation great enough to account for the other half is 0.01. The excess events can be attributed to such a fluctuation or to primary nuclei with $3\leqslant Z\leqslant 5$ in abundance comparable to that of heavier nuclei.

* Research supported in part by the joint program of the U. S. Atomic Energy Commission and the U. S. Office of Naval Research.
[1] Balloon flight by Project Skyhook.
[2] Collision cross sections have been calculated from Peters' empirical formula. B. Peters in *Progress in Cosmic Ray Physics* (Interscience Publishers, Inc., New York, 1952), Vol. 1.
[3] H. L. Bradt and B. Peters, Phys. Rev. **77**, 54 (1950).

Photoproduction of π^+ Mesons from Hydrogen and Carbon*

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We have measured π^+-meson photoproduction cross sections for hydrogen and carbon at a laboratory angle of 90°. Mesons having energies down to 10 Mev were detected.

Our experimental arrangement is shown schematically in Fig. 1. γ rays from the M.I.T. Synchrotron strike the polyethylene or carbon target. The π^+ mesons are detected and identified upon coming to rest in a single scintillation counter. The meson detection solid angle was determined by the counter itself and not by a meson collimator. A collimator would scatter some mesons into the counter, and this effect would distort the meson energy spectrum because the scattered mesons would have undergone energy losses. Pulses from the photomultiplier are amplified and fed into a delayed coincidence arrangement. The characteristic π-μ decay serves to trigger an oscilloscope upon which the triggering pulses are displayed.

A pulse corresponding to a π^+ meson had a height directly indicative of the energy of the incident π^+ meson. The largest π^+

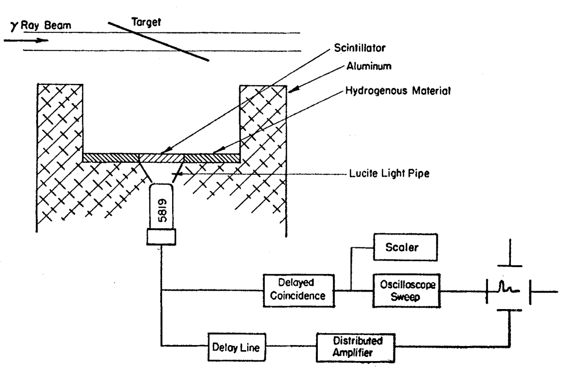

Fig. 1. Schematic experimental arrangement.

pulse heights observed corresponded to π^+ mesons with a range just equal to the thickness of the scintillation counter. The energy corresponding to this range was 21.2 Mev. This provided an energy pulse-height calibration.

All the pulses corresponding to μ mesons had very nearly the same height. Since the energy of a μ^+ meson from the decay of a π^+ meson at rest is known to be 4.15 Mev, the average μ pulse height was used to establish a second independent energy pulse-height calibration.

The detection of π^+ mesons by π-μ decay has three important advantages over detection by μ-e decay: (1) the mean life of the π meson is about 1/80 of that of the μ meson so that accidental delayed coincidences can be kept smaller; (2) because of the uniform μ pulse heights, it is not necessary to extrapolate a decay-particle pulse-height distribution to zero pulse height for evaluation of the detection efficiency; and (3) the sensitive volume of the detector is well defined because the range of the decay μ meson (0.153 g cm⁻²) is small compared to practical counter dimensions. The principal source of uncertainty (±3 percent) entering the evaluation of our detection efficiency was the standard error in the measurements of the π^+-meson mean life.

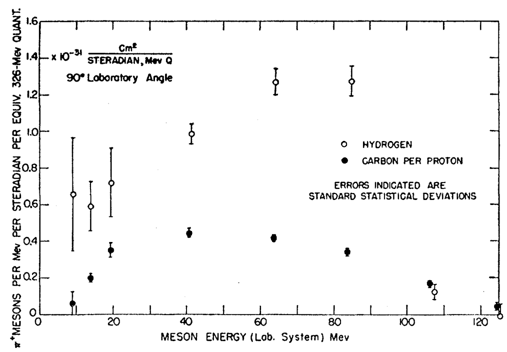

Fig. 2. Meson-energy distribution from hydrogen and carbon, observed at 90° in the laboratory system.

Uncertainties in the absolute beam calibration (in our case ~40 percent) do not enter the comparison of our results with other measurements made in this laboratory. Recent intercalibrations with Cornell and Illinois indicate that our cross sections should be decreased by a factor of approximately 1.7.

In one series of measurements, very thin carbon and polyethylene targets were used (0.153 g cm⁻² and 0.121 g cm⁻², respectively), and no absorber was placed in front of the counter. The measured π^+ pulse-height distributions were thus direct measures of the produced meson-energy distributions subject only to small corrections for target absorption. For the higher meson energies, absorbers were placed in front of the counter, and the initial meson-energy intervals were determined by the thickness of the counter.

The energy distribution of the mesons observed at 90° in the laboratory system is plotted in Fig. 2. All errors shown are standard statistical deviations. The hydrogen π^+ cross sections in the center-of-mass system are plotted against laboratory photon energy and against center-of-mass meson momentum in Fig. 3. For photon energies above 200 Mev, our results are in agreement with those obtained by Steinberger and Bishop.[1] The π^+ cross section appears to be linear with meson momentum (see Fig. 3) from threshold up to about 185 Mev/c (285-Mev γ-ray energy). This is consistent with a pure S-state hypothesis for photon energies up to about 200 Mev. The continued linearity above 200 Mev cannot be taken as evidence of continued pure S-wave predominance in view of the angular distributions.

The meson-energy distribution for carbon is seen to be in agreement with earlier measurements[1,2] made at meson energies

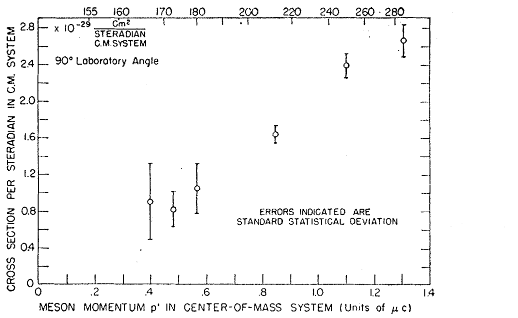

FIG. 3. π^+ photoproduction cross sections in the center-of-mass system of coordinates *versus* initial photon energy in the laboratory system and meson momentum in the center-of-mass system.

above 25 Mev, but our results seem to indicate a sharp drop near 15 Mev.

Dr. Guiseppe Fidecaro participated in the early phases of this experiment. The assistance of the M.I.T. Synchrotron crew is greatly appreciated.

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A Double Star Connected by a Heavy Meson

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IN the course of measurements of the mass distribution of fast particles produced in high-energy nuclear explosions, a case of a double star connected by a heavy meson of mass $1310m_e$ was found.

The double star was observed in a G5 Ilford plate, exposed to cosmic radiation at 30 km. The first star is a $4+4\alpha$ star induced by an alpha particle of 5 Bev (the energy of the primary was estimated by multiple scattering). The heavy meson travels 34 mm before it produces a $5+0K$ secondary star. Multiple scattering and grain density measurements were made along the connecting track. Using the method described by Gottstein *et al.*,[1] we found a value of $p\beta=427\pm41$ Mev/c for the first 16 mm of the track, and a value of $p\beta=417\pm42$ Mev/c for its last 18 mm. The grain density of the track along the first 5 mm is 16.55 ± 0.41 grains per 50μ.

Together with the heavy meson a proton is produced in the same nuclear collision. The proton travels in the emulsion in the direction of the heavy meson and leaves the emulsion after 6.4 mm. Measurements of multiple scattering and grain density (G.D.), for the proton, yield $p\beta=550\pm90$ Mev/c and G.D. $=17.45\pm0.42$ grains/50μ.

The plateau value of the grain density on this plate is 11.5; and the normalized value of ionization, for the heavy meson and proton are 1.44 ± 0.036 and 1.52 ± 0.037, respectively. With the help of the $p\beta$ *vs* grain density curves of Gottstein *et al.*[1] and Daniel *et al.*[2] we have found that the masses of the proton and the heavy meson are 1830 ± 295 and $1300\pm125m_e$, respectively. If we take the correct mass of the proton $m_p=1838m_e$, the corresponding mass of the heavy meson is $m_K=1310\pm245m_e$.

In deriving the last mass value we have used the formula:

$$\frac{m_K}{m_p}=\frac{K_K}{K_p}\frac{\bar{\alpha}_p}{\bar{\alpha}_K}\frac{(\gamma\beta^2)_p}{(\gamma\beta^2)_K},$$

where K_K and K_p are the scattering constants of the heavy meson and the proton, respectively. The value of $\gamma\beta^2$ has been found according to the curve: grain density *vs* γ of Shapiro and Stiller.[3] The mass of the heavy meson derived in this way is almost independent of the plateau value of the grain density.

In the same set of measurements we have found six other heavy mesons with mass between 1000 and $1300m_e$. The total length in the emulsion of the tracks of all the seven heavy mesons is 7.62 cm. According to Daniel and Perkins,[4] 10 cm of track of identified K particles with mass $1200\pm40m_e$ were examined, without finding any nuclear interaction. Assuming that all the observed heavy mesons are K particles and combining the results obtained in Bristol and in this laboratory, we have found one nuclear interaction produced by a K particle along 17.6 cm of emulsion. The interaction mean free path of pions, in the same range of energy, is 25.6 ± 7.56 cm,[5] and it seems likely that both K particles and pions have the same interaction mean free path. This is in agreement with the observation of Daniel *et al.*[2] on the interaction mean free path of shower particles ejected from jets and supports the suggestion[6] that pions and K particles interact with nuclear matter in a similar way.

We are greatly indebted to Dr. M. M. Shapiro of Nucleonics Division, Naval Research Laboratory, Washington, D. C., for the plates in which the double star was observed. We also wish to thank Mrs. M. Weinberg for careful scanning of the plates.

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Nonconservation of Rest Mass and the Dirac Equation

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IN recent years a number of attempts have been made to introduce a fundamental length into the quantum theory of a particle without destroying the covariance of the equations. The most notable of these attempts are the nonlocalizable field theory of Yukawa[1] and the reciprocity theories of Born and Green.[2] These theories are closely related to the notion that the coordinates and time describing the motion of a particle are not parameters but observables that must be represented by operators.

It is possible to arrive at a somewhat similar point of view by considering a system in which the rest mass m_0 is not conserved. This would be true in systems in which nonmechanical energy of some sort is produced. Let us suppose that Q is the amount of nonmechanical energy developed per unit time in the rest system of a particle. Then the rest mass will no longer be conserved, and we have[3]

$$dm_0/d\tau=Q/c^2, \tag{1}$$

where τ is the proper time and is related to the velocity u of the particle and the time t by the equation

$$d\tau=(1-u^2/c^2)^{\frac{1}{2}}dt. \tag{2}$$

We must therefore have

$$dm_0/dt=[1-(u^2/c^2)]^{\frac{1}{2}}(Q/c^2). \tag{3}$$

From this equation it is obvious that m_0 cannot be a constant of the motion and therefore cannot commute with the Dirac Hamiltonian of the particle. Since in a relativistic quantum theory of a particle $[1-(u^2/c^2)]^{\frac{1}{2}}$ is represented by the Dirac matrix β, we shall write

$$[m_0,H]=i\hbar(Q/c)\beta \tag{4}$$

as the quantum-mechanical equivalent of (3). This means that