chamber instruments equipped with an arrangement for removing the requirement $I>3.2I_{\min}$ at predetermined pressure intervals. By taking into account local nuclear interactions initiated by protons, knock-on electrons accompanying protons, and slow protons (albedo)[1] which actuate the apparatus, the alpha-particle flux is determined from the extrapolated values of N_{total} and $N(I>3.2I_{\min})$ at the "top of the atmosphere." The results are:

$$49\pm13 \text{ particles m}^{-2}\text{ sec}^{-1}\text{ sterad}^{-1} \text{ at } \lambda=3°,$$
$$81\pm22 \text{ particles m}^{-2}\text{ sec}^{-1}\text{ sterad}^{-1} \text{ at } \lambda=18°.$$

It is assumed in the analysis that every nuclear interaction initiated in the apparatus by a fast proton produces an ion-chamber pulse exceeding that characteristic of a relativistic particle with $Z=1$. The results of an experiment by McClure[2] at $\lambda=10°$ with a modified arrangement incorporating a multicounter shower detector and pulse-height recorder appear to be compatible with this hypothesis. Any alternative assumption would *increase* the value of the alpha-particle flux. The qualitative effect of the other presumably small systematic uncertainties is generally also in the direction of making the above values low.

Figure 1 shows previous measurements of the alpha-particle intensity at higher latitudes together with the present flux values plotted as a function of kinetic energy per nucleon. With one exception, the abscissa corresponds to the threshold energy, determined from geomagnetic theory, for entry in the vertical direction at the latitude at which the measurements were obtained. The indicated limits, along the energy axis, of the points at low latitudes are defined by the main cone and the Störmer cone plus earth's shadow cone, respectively, in view of the uncertainty regarding the contribution from the penumbral region. In the case of Linsley's measurement, the cutoff is determined by the Čerenkov detector rather than by the earth's magnetic field.

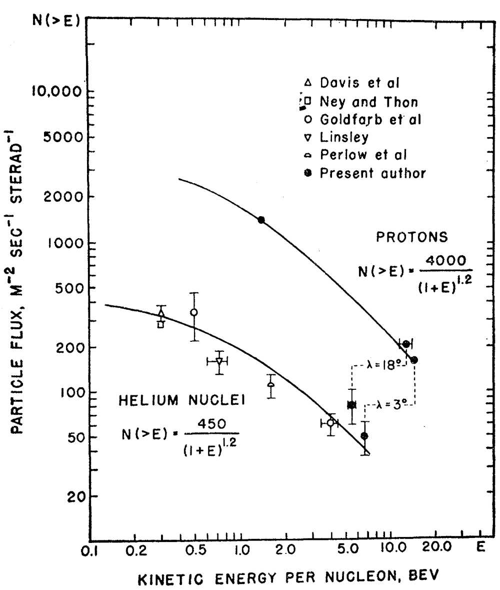

FIG. 1. Dependence upon threshold energy of the flux of primary protons and helium nuclei, respectively. References are as follows: Davis, Caulk, and Johnson, Phys. Rev. **91**, 431 (1953); E. P. Ney and D. M. Thon, Phys. Rev. **81**, 1069 (1951); Goldfarb, Bradt, and Peters, Phys. Rev. **77**, 751 (1950); J. Linsley, Phys. Rev. **93**, 899 (1954); Perlow, Davis, Kissinger, and Shipman, Phys. Rev. **88**, 321 (1952).

The proton points are the author's determinations of the total primary flux at geomagnetic latitudes 52°, 18°, and 3°, respectively, less the contribution from splash albedo[1] and nuclei with $Z>1$.

Both the protons with $1.5<E<15$ Bev and alpha particles with $0.3<E<7$ Bev/nucleon can be represented by an integral energy distribution of the form

$$N(>E)=k(1+E)^{-1.2},$$

where E is kinetic energy per nucleon, and $k=4000$ for protons and 450 for alpha particles. The available data relating to the heavier primaries in this energy interval likewise appear to be consistent with the same power-law relationship.

The anomaly in the total intensity at $\lambda=18°$ in India has been reported previously.[3] Within the experimental uncertainties, the ratio $N(I>3.2I_{\min})/N_{\text{total}}$ at a given altitude is constant between 3°N and 18°N, revealing that the composition of the primary cosmic radiation is not drastically different at these two stations. Thus, the enhanced intensity at $\lambda=18°$ does not appear to be attributable predominantly to a single component.

A complete account of these experiments will be published later, elsewhere.

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† Fulbright Professor, Muslim University, Aligarh, U.P., India, during the year 1952–1953.

[1] K. Anderson (private communication). The author wishes to thank Dr. Anderson for making his results available prior to publication.

[2] G. W. McClure (private communication).

[3] M. A. Pomerantz, Phys. Rev. **95**, 531 (1954).

Elastic Photoproduction of π^0 Mesons from Helium

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THE "elastic" photoproduction of π^0 mesons in helium near threshold has been observed. The term "elastic" denotes that process which may be written: $h\nu+\text{He}^4\rightarrow\pi^0+\text{He}^4$.

In general, when photomesons are created in the vicinity of a nucleon, the nucleon spin direction may or may not change. Since the helium nucleus has no bound excited states, a spin flip of one of its nucleons must

TABLE I. Threshold energies for the elastic process and several "inelastic" processes.

Process	Threshold energy (Mev)
$h\nu + He^4 \rightarrow \pi^0 + He^4$	137
$h\nu + He^4 \rightarrow \pi^0 + H^3 + p$	158
$h\nu + He^4 \rightarrow \pi^0 + He^3 + n$	159
$h\nu + He^4 \rightarrow \pi^0 + H^2 + H^2$	162

result in disintegration, with an accompanying increase of about 20 Mev in the aggregate mass. Thresholds for the elastic process and for several "inelastic" processes are listed in Table I. The π^0 mass value used here is $\mu_0 c^2 = 135$ Mev.[1]

Elastic photoproduction of S-wave mesons from helium would violate the $H=0 \nrightarrow J=0$ selection rule. P-wave emission may then be expected to dominate at low energies. The only multipole absorption which can lead to this process ($\Delta l=1$, $\Delta s=0$, no parity change) is magnetic dipole.

The yield of π^0 photomesons from a 4-in. diameter cylinder of liquid helium was measured as the maximum energy of the betatron x-rays was varied between 150 and 190 Mev. The energies were known with an accuracy of the order of 1 percent. Detection of π^0 mesons was accomplished by observing the π^0 decay γ-ray pairs in two γ-ray telescopes.[2] All runs were made with the plane of the two telescopes making an angle $\theta = 80°$ with the incident x-ray beam. The correlation angle, ϕ, between telescope axes was varied from 180° to 90° in 30° steps. Each telescope subtended an angle of 20° at the target. Counting rates from helium are presented in Figs. 1 and 2.

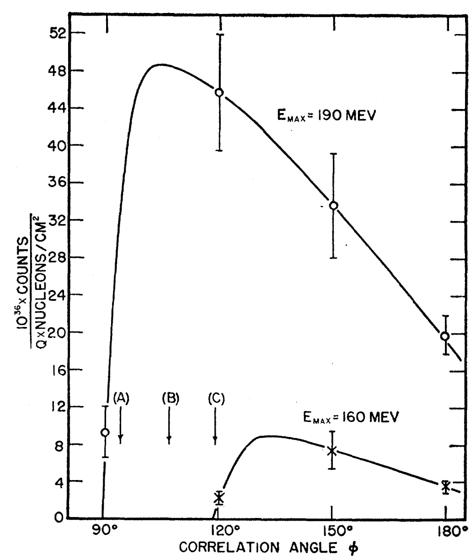

FIG. 1. Counting rates of γ-ray pairs from helium as a function of the angle ϕ between telescope axes. Arrows indicate minimum angles possible for (A) elastic production at 190 Mev; (B) inelastic production at 190 Mev; (C) elastic production at 160 Mev. Inelastic production is negligible at 160 Mev. Curves are arbitrarily drawn through experimental points.

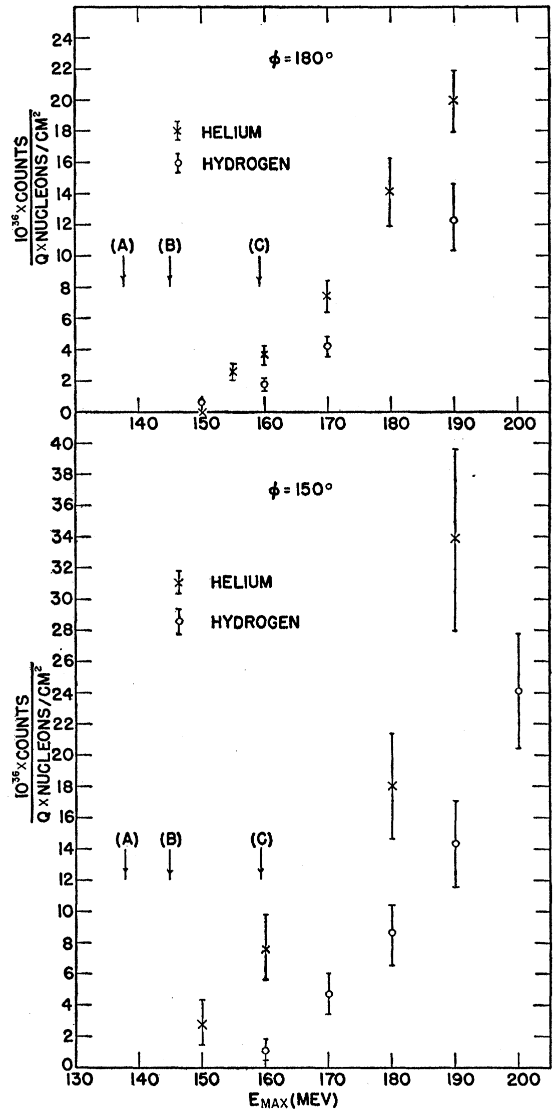

FIG. 2. Counting rates of γ-ray pairs from helium and hydrogen plotted against betatron energies for angles $\phi = 180°$ and $\phi = 150°$ between telescope axes. Arrows indicate: (A) elastic helium threshold, (B) hydrogen threshold, (C) inelastic helium threshold; all for zero-energy mesons.

The finite counting rates observed at betatron energies of 150, 155, and 160 Mev prove conclusively that elastic π^0 production occurs in helium. Of interest also are the relative contributions from the elastic and inelastic processes at energies above the inelastic production threshold. The angle ϕ between the two γ rays serves as a nonunique measure of the meson energy.[3] In particular, the smallest angle dynamically possible is given by the relation $\sin(\phi_c/2) = 1/\gamma$, where the total energy of the meson is $E = \gamma\mu_0 c^2$. The counting rates as functions of ϕ at 160 and at 190 Mev are plotted in Fig. 1, and the critical angles are indicated by arrows.

At 160 Mev, the π^0 production is confined almost entirely to the elastic process (Table I), so the lower

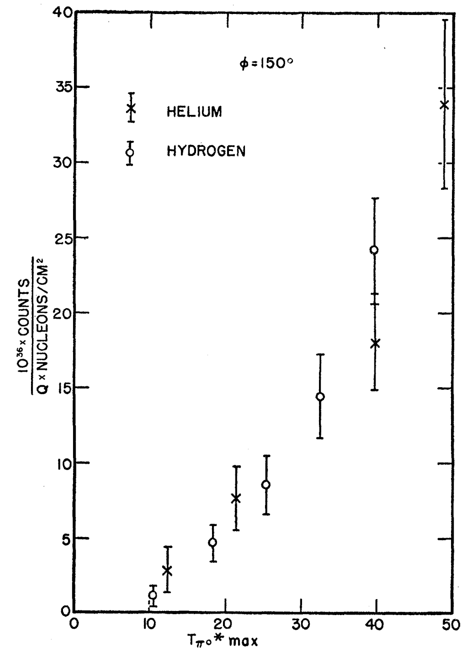

FIG. 3. Counting rates of γ-ray pairs from helium and hydrogen plotted against maximum π^0 kinetic energy in the center-of-mass system corresponding to $E_{\max}$ of betatron radiation. For helium, the dynamics for the elastic process have been used.

curve (Fig. 1) serves as an indication of the proper relation between observed counting rates and ϕ_c. At 190 Mev, both elastic and disintegration processes are allowed, but clearly the value of ϕ_c corresponding to elastic production fits better than the value corresponding to inelastic production. Apparently, therefore, the elastic process is still important at 190 Mev.

The counting rates shown in the graphs are normalized per equivalent quantum (Q) and per nucleon/cm² to permit some comparison with hydrogen production. Activation curves for helium and hydrogen at $\phi=180°$ and $\phi=150°$ are plotted in Fig. 2. The hydrogen points were observed with the same apparatus.[2] A valid comparison must take into account the difference between center-of-mass momenta in the hydrogen and helium cases. Figure 3 is obtained from Fig. 2 by changing the scale of abscissas from betatron energies to the corresponding π^0 kinetic energies in the center-of-mass system. All helium events are assumed to be elastic. If the hydrogen and helium cross sections depend on π^0 momentum in the same way, as they appear to do, then this is a meaningful comparison which indicates equal efficiencies per nucleon in hydrogen and helium at identical center-of-mass meson energies. This ratio of unity is in sharp contrast with the helium/hydrogen efficiency ratio of one-half obtained for charged mesons at higher energies.[4] Also, theoretical lower limits placed on the amount of S-wave production in hydrogen[5] suggest that the helium production efficiency should be relatively lower because of the absence of S-wave production. Cross-section calculations now in progress are necessary for a more accurate comparison.

[1] Smith, Birnbaum, and Barkas, Phys. Rev. **91**, 765 (1953); Chinowsky, Sachs, and Steinberger, Phys. Rev. **93**, 586 (1954).
[2] F. E. Mills and L. J. Koester (to be published).
[3] Panofsky, Steinberger, and Steller, Phys. Rev. **86**, 180 (1952).
[4] Jakobson, Schulz, and White, Phys. Rev. **91**, 695 (1953).
[5] K. M. Watson, Phys. Rev. **95**, 228 (1954).

Polarization in p-p Scattering at 415 Mev*†

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A POLARIZED proton beam has been obtained from the Carnegie synchrocyclotron by scattering the internal beam from a carbon target. Protons which were thereby scattered outward through an angle of about 13° passed through a 2 in. × 2 in. collimator in the shield wall. The intensity in the experimental area was measured with an ionization chamber to be about 10^5 protons cm^{-2} sec^{-1}. The beam energy as determined from a differential range curve was 415 Mev with a full width of 10 Mev.

We have measured the asymmetries produced when this beam underwent second scatterings coplanar with the first. The asymmetry, $\epsilon(\theta)$, is defined as $[I(\theta)-I(-\theta)]/[I(\theta)+I(-\theta)]$, where $I(\theta)$ is the intensity of protons scattered through an angle θ, and where positive values of θ are in the same sense as the first scattering.

Measurements of ϵ have been made by using carbon as the second scatterer in order to determine the degree of polarization of the beam. If the first and second scatterings were identical, the polarization, P, would be given by $P=\epsilon^{\frac{1}{2}}$, with ϵ the asymmetry observed in the second scattering. From the results of such an experiment we estimate that our beam polarization is between 40 and 50 percent.

The reality of the observed asymmetries was tested by scattering our normal unpolarized external beam[1]

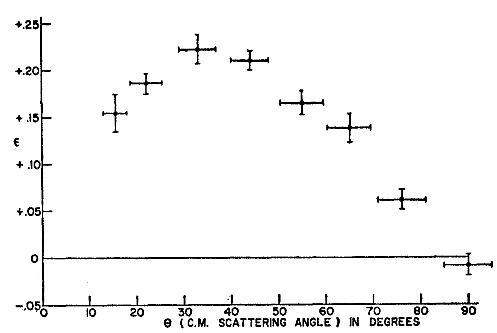

FIG. 1. Polarization in p-p scattering. The observed values for ϵ (defined in test) are shown *versus* the center-of-mass scattering angle. The vertical errors are the standard deviations from counting statistics. The horizontal bars indicate the angular resolution.