Faraday cup.[2] Results obtained with carbon and sulfur targets at 40° in the laboratory system are shown in Figs. 1 and 2. The data are plotted in the c.m. system. The dotted and crossed points represent two sets of data taken one after the other and the full line is drawn through them. The broken line represents the results after a correction for nuclear absorption in the telescope has been applied.

For both carbon and sulfur targets, the highest-energy peak corresponds to elastically scattered protons: the half-width of 3 Mev represents the estimated energy resolution of our experiment at the high-energy end. The lower-energy peaks are due to inelastically scattered protons which leave the residual nucleus in well defined energy states. We have also plotted the known energy levels of C^{12} and S^{32} that are listed in recent compilations,[3,4] and the threshold energies for the simpler reactions. The low-energy peaks (around

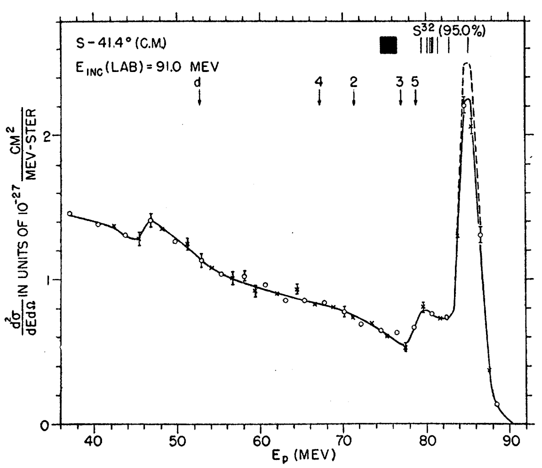

FIG. 2. Energy distribution of protons scattered from a sulfur target.

45 Mev) are believed to represent pickup deuterons whose range corresponds to protons of this energy.

The proton spectrum from carbon suggests that among the first three excited states, only the 4.43-Mev and the 9.61-Mev levels are strongly excited by high-energy protons. Due to our limited energy resolution, it is difficult to estimate any possible small contribution from protons exciting the residual nucleus to the 7.5-Mev level. The 61-Mev peak corresponds to a nuclear excitation of 20.0 ± 1 Mev[5] which could correspond to one or more known levels of C^{12}. The continuum of protons corresponds either to unresolved energy levels of C^{12}, or to breakup of the carbon nucleus, or to both.

The rather broad high-energy inelastic peak obtained with the sulfur target probably corresponds to the unresolved excitation of some if not all of the low-energy levels known in this nucleus. No single peak stands out over the continuum in this case.

The results reported here are typical of the spectra of the light elements that we are investigating. It is quite apparent that many nuclear energy states can be excited by high-energy protons that interact with the target nucleus for a "short" time only; "short," that is, compared to the average time between collisions of the nucleons inside the nucleus. This type of excitation is different from that prevalent at low energies where compound nucleus formation occurs. Experimentally this means that the separation of truly elastic events from inelastic events is often difficult. This fact must be borne in mind in high-energy scattering investigations such as recent diffraction and polarization experiments. However at smaller scattering angles than those reported here, the elastic peak becomes much more prominent compared to inelastic events. Between 40° and 30° (laboratory system) the elastic and first inelastic peaks of C increase by factors of 4.80 and 2.66, respectively. This makes the elastic—inelastic separation easier at small angles.

We are very much indebted to the staff of the Harvard Cyclotron Laboratory for assistance in this investigation.

* Supported by the joint program of the U. S. Office of Naval Research and the U. S. Atomic Energy Commission.

[1] J. A. Hofmann and K. Strauch, Phys. Rev. **90**, 449 (1953).
[2] We are much indebted to Mr. U. Kruse for this calibration.
[3] F. Ajzenberg and T. Lauritsen, Revs. Modern Phys. **24**, 321 (1952).
[4] P. M. Endt and J. C. Kluyver, Revs. Modern Phys. **26**, 95 (1954).
[5] R. Britten [Phys. Rev. **88**, 283 (1952)] studied the scattering of 31.5-Mev protons from carbon. He interpreted as deuterons, particles lying under a peak corresponding to an excitation energy of 18 Mev. In our experiment only protons can produce the 61-Mev peak.

Narrow Shower of Pure Photons at 100 000 Feet*

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(Received June 15, 1954)

A VERY unusual new event consisting of a large number of individual electron pairs has been found in a stack consisting of 18 Ilford G-5 600 μ pellicles flown in a Skyhook balloon from Goodfellow Air Force Base, Texas (41°N geomagnetic latitude). The pellicles were exposed in an aluminum exposure box with walls 0.7 g/cm^2 and free of other matter. The emulsions were flown for six hours over 100 000 feet. The event entered the side of the stack at a zenith angle of 66° and passed through 14 of the 18 pellicles with a total length of more than 50 000 μ at an angle of 7.5° to the emulsion surface. This makes it possible to carry out accurate measurements on individual tracks. Preliminary results of this analysis will be reported here.

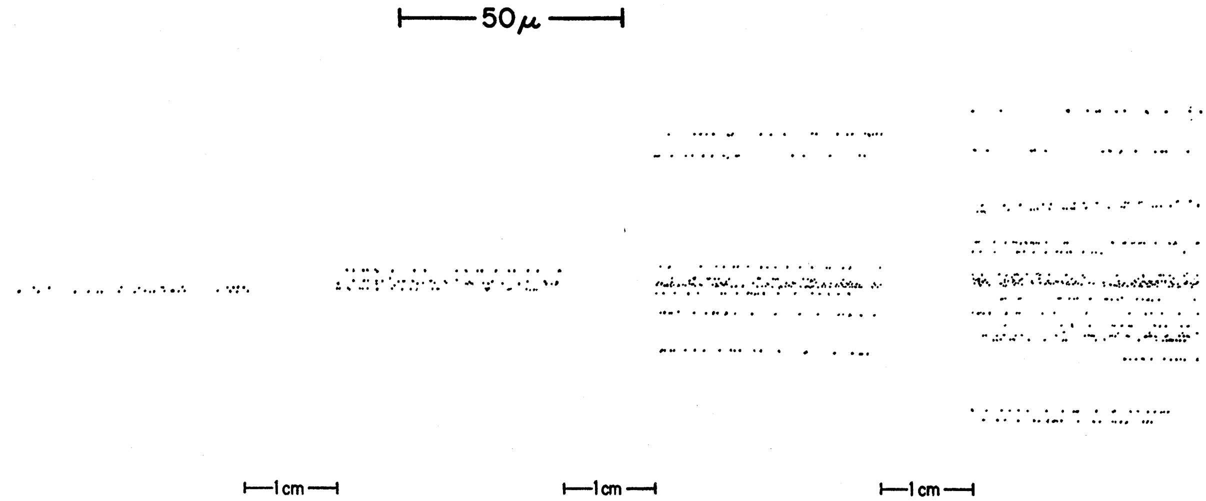

FIG. 1. Narrow shower of pure photons. Sections at arbitrary intervals to show development of shower. Note pair starting in last section.

No incident charged particle can be seen within a radius of 250 μ of the axis of the event with a direction such that it can be considered associated, except for the first of the electron pairs, which had already materialized before entering the sensitive area of the emulsion. Sixteen pairs have been found in the first 33 000 μ, which is just a little less than the mean pair conversion length for high-energy photons in this emulsion. Table I shows the distance of the origin of the first 16 pairs from the start of the event itself. Also shown are the results of multiple scattering measurements on the first five pairs. As already indicated, Pair 1 has already materialized before entering the emulsion. Pairs 6, 7, 8, and 9 are very narrow pairs which go through more than 3500 μ of emulsion before separating into resolvable tracks. From the separation we can get a minimum estimate of the energy of the pair. The energy can be much higher than this if the separation is caused by the multiple scattering of the lower energy electron of the pair and if the pair happens to divide the photon energy unequally. The number of pairs already materialized at a given distance increases approximately linearly and permits an estimate of the number of incident photons to be made from the rate of pair production and the mean pair conversion length λ. We have calculated the value of λ to be 3.6 cm. This gives an estimate of 21±3 incident photons. The tracks of the electrons are such that the photons producing them must have been very nearly parallel. This can be seen clearly in Fig. 1, which represents small sections at arbitrary intervals along the event and shows the very remarkable character of the development of the photon shower in the first radiation unit.

TABLE I. First 16 pairs in narrow photon shower. The radial distance is the distance from the pair origin to the median of the electrons at the pair's point of origin. E_1, E_2 are the measured energies of individual electrons. E is the total energy of the photon. The estimate of E for pairs 6, 7, 8, 9 is made from the distance the pair goes before becoming resolvable into individual tracks.

Pair	Distance to point of conversion (μ)	Radial distance (μ)	E_1 (Mev)	E_2 (Mev)	E (Mev)
1			400±160	100±40	500±165
2	2020	1	350±140	300±120	650±330
3	4440	12	350±140	550±220	900±260
4	13 100	3	100±40	800±320	900±325
5	13 350	23	500±200	150±60	650±210
6	15 750	10			>5000
7	15 770	3			>5000
8	19 900	1			>20 000
9	21 600	2			>20 000
10	27 000	6			
11	27 200	8			
12	29 800	2			
13	30 800	4			
14	31 100	2			
15	31 400	26			
16	33 300	16			

It is quite important to get some idea of the radial spread of the origins of the pairs which corresponds to the radial spread of the photons. For this purpose the distance of each pair origin from the median of the other shower tracks at the point of origin has been computed and is shown in Table I. These values are almost all less than 15 μ while the largest is 23 μ. The total width of the photon burst thus does not exceed 25 μ. Since the shower is observed in the emulsion over a distance of more than 30 000 μ it is evident that for the half-angle θ of the cone enclosing all particles we have

$$\theta \leqq 0.001 \text{ radian},$$

which proves that the shower must be of extremely high energy in accordance with the direct measurements carried out on individual pairs.

From Table I it is evident that several of the pairs have an unusually low energy in comparison with the very high energy necessary to account for such a narrow collimation.

A more detailed account of this event will be published later when a more careful discussion of possible causes can be undertaken. It should be noted, however, that this event has very remarkable features in that it consists of about 20 photons with no electrons present. Such a phenomenon would appear to be incompatible with the production of these photons by any conventional electromagnetic process. Nuclear collisions can also be ruled out, since even if one had the extreme improbability of no charged particles created in the event, but only neutral pions, the high collimation of the tracks would be totally incompatible with energies of the order of 1 Bev as observed for several of the pairs. No process known to the authors at the present time seems to explain all the features of the event. One possibility, however, which has been considered in an effort to account for it, is that it may be produced by an annihilation process in flight at very high energy. In such a case the event occurs in a center-of-mass system moving with such a high velocity that any very low-energy photons which might be emitted could receive rather high energies in the laboratory system. If the particles which receive practically all of the energy in the center-of-mass system are also neutral, for instance photons, then they might be missed and an event of the kind described here would be produced. It is of special interest to note that the event occurred under only 12 g/cm^2 of air, which means that at the zenith angle of the event only $\frac{1}{3}$ of a nuclear mean free path was traversed. It is thus improbable that the event could be the result of two successive collisions, so that if the event is due to an antiparticle it is probably not produced in the atmosphere, but enters from outside as an extremely high-energy particle ($E>10^{13}$ ev). Production of antiparticles at these energies by cosmic-ray particles outside the atmosphere would be predicted by Fermi's theory.[1]

The authors wish to thank the U. S. Office of Naval Research for arranging the launching of the balloon and Mrs. E. Goodman, who located the event.

* Supported in part by the joint program of the U. S. Office of Naval Research and the U. S. Atomic Energy Commission.

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Photopion S Wave Near Threshold and the Pion Nucleon Coupling Constant

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IN a previous letter,[1] the authors presented results of investigations of π^+ photoproduction from hydrogen near threshold. New data have been added for a center-of-mass angle of about 90° and all the data for this angle, together with the experimental curve, are presented in Fig. 1. The pellicle data have been corrected for nuclear absorption and scanning efficiency. The maximum correction is 15 percent (for the high-energy point) and the corrections themselves are believed to be accurate to within 30 percent. Errors in the abscissas have been propagated into the indicated errors. Possible errors in the photon flux calibration are not included. They are believed to be less than 3 percent.[2]

In terms of the S-matrix formulation, the 90° cross section for photoproduction of positive and negative pions may be expressed, quite generally, as follows:

$$\left(\frac{d\sigma}{d\Omega}\right)^{\pm}_{\text{c.m.}}=\frac{k}{\nu E_i E_f \omega}|\mathcal{H}^{\pm}|^2\left(1+\frac{\nu}{E_i}\right)^{-1}\left(\frac{1}{\omega}+\frac{1}{E_f}\right)^{-1}. \quad (1)$$

Here $k, \omega=$ final meson momentum, energy; $\nu=$ photon momentum (or energy); E_i, $E_f=$ initial and final nucleon energies; and $\mathcal{H}^{\pm}$ are the matrix elements for the production of positive and negative pions. All quantities are in the center-of-mass system and in units $\hbar=c=1$.

The two factors in parentheses represent dynamical corrections to the incident photon flux and final available phase space, respectively, arising from the motion of a nucleon of finite mass. Near threshold $E_i\simeq E_f\simeq M$, the nucleon rest energy (or inverse Compton wavelength of nucleon), and (1) may be written

$$\left(\frac{d\sigma}{d\Omega}\right)^{\pm}_{\text{c.m.}}=\left(\frac{1}{M}\right)^2|\mathcal{H}^{\pm}|^2\chi;$$
$$\chi=\frac{k}{\nu}\left(1+\frac{\omega}{M}\right)^{-1}\left(1+\frac{\nu}{M}\right)^{-1}. \quad (2)$$

The matrix element $|\mathcal{H}^{\pm}|$ is not known, but its square can almost certainly be expressed as follows:

$$\left(\frac{1}{M}\right)^2|\mathcal{H}^{\pm}|^2=\{A_0{}^{\pm}+A_2{}^{\pm}\eta^2+\cdots \text{ higher-order terms}\}, \quad (3)$$

where $\eta=(k/\mu c)$, μ is the meson rest mass, and the A coefficients depend upon the sign of the pion. The absence of the first power term can be shown to follow from the disappearance of interference effects at 90°. Exploring the possibility that the higher-order terms in k may be negligible within the scope and accuracy of this work, the experimental values of $(d\sigma/d\Omega)/\chi$ have been plotted *versus* η^2 (Fig. 2). Within the indicated errors a straight line seems to be a very good fit to the experimental points up to $\eta\simeq1$ ($E_\gamma\simeq2.30$ Mev). Three points, which represent the averages of several counter experiments,[3] have been also added to show more clearly the trend of the curve at energies over 200 Mev and the point of deviation from a straight line.