(γ, np) reaction in C^{12}. This indicates a small cross section for the (γ, p) reaction in carbon at the given energy. When C^{12} is irradiated with bremsstrahlung of $E_{\gamma_{max}} = 64$ Mev the maximum proton energy corresponds to the energy threshold of the (γ, p) reaction; thus indicating that the latter reaction makes a considerable contribution to the total photoproton yield at the given excitation energy. Similar conclusions cannot be drawn for Be^9 because in this instance the thresholds of the (γ, p) and (γ, np) reactions practically coincide.

We converted the angular distributions to the center-of-mass system on the assumption that the principal contribution is made by the reactions C^{12} (γ, p) B^{11} and Be^9 (γ, p) Li^8 when ejection of a proton transfers recoil energy to the residual nucleus. These results can be approximated by curves of the form

$$a + b\sin^2\theta(1 + \gamma\cos\theta)^2.$$

In this analysis the relative amount of quadrupole absorption was found to be unsually large, amounting to 60 – 80% of the dipole contribution. This fact produces doubt as to the correctness of the scheme chosen to describe the interaction between quanta and the nuclei under consideration. A recalculation must be based on the above hypothesis that in the given energy range gamma rays interact with nuclei mainly through structures formed within the nucleus.

The extensive experimental results which are now available for light nuclei can be interpreted on the basis of theoretical concepts regarding the existence of structural units within the nuclei, *i.e.*, that a nucleon in a nucleus interacts not with all the other nucleons of the nucleus but only with those which are in definite states of motion with respect to the given nucleon (see Ref. 4, for example).

Our experimental data on photoprotons from Be^9 and C^{12} are in agreement with this hypothesis.

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Correlations in $\pi \to \mu \to e$-Decay

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120 positrons from $\pi \to \mu \to e$ decays in emulsion were analysed by energy and by the angle between μ-meson and positron tracks. The observed distributions are in qualitative agreement with the two-component neutrino theory. If λ is the theoretical asymmetry parameter and α the fraction of the μ-mesons not depolarized by the emulsion, the measurements give the result $\alpha\lambda = 0.5 \pm 0.25$.

THIS PAPER DESCRIBES measurements of the positron energy and of the angle between μ-meson and positron tracks in $\pi^+ \to \mu^+ \to e^+$ decays in photographic emulsion. The problem arose from the observation by Lee and Yang[1] that a departure from parity conservation could lead to a correlation between the directions of μ-meson and electron. Landau[2] suggested that the interactions such as $\pi \to \mu \to e$ decay in which parity is not conserved are still invariant under "combined inversion," the combination of space-reflection with charge conjugation. He also showed that if the neutrino is polarized along its direction of motion and the antineutrino in the opposite direction (or vice versa), then the distribution in energy and angle of electrons emitted in $\pi \to \mu \to e$ decay has the form

$$dN = 2N\varepsilon^2 \{(3 - 2\varepsilon) + \lambda \cos\vartheta\,(2\varepsilon - 1)\}\, d\varepsilon\, d(\cos\vartheta). \quad (1)$$

Here ε is the ratio of the electron energy to the maximum possible energy, ϑ is the angle between the directions of μ-meson and electron, and λ is a constant of the theory, lying in the interval -1 to $+1$, and characterizing the degree of longitudinal polarization of the electron in $\mu \to e + \nu + \bar{\nu}$ decay. The formula shows that the correlation is small for $\varepsilon = \frac{1}{2}$, changes sign at $\varepsilon = \frac{1}{2}$, and increases strongly at the top of the spectrum. If $\lambda = 1$ (or -1), the electrons with maximum energy are all emitted forward (or all backward).

Garwin, Lederman and Weinrich[3] discovered the existence of an angular correlation of the form $(1 - \alpha \cos \vartheta)$ in $\pi^+ \to \mu^+ \to e^+$ decay in graphite and polyethylene, and they measured the magnetic moment of the μ-meson by observing the precession of the correlation axis in a magnetic field. But they did not observe the sharp increase in asymmetry from the middle to the top of the spectrum, which is characteristic of the two-component neutrino theory.

We here report only the preliminary results of observations which we have begun on the positron spectra and angular correlations in $\pi^+ \to \mu^+ \to e^+$ decay. Up to now we have observed 2334 $\pi - \mu$ decays in a systematic scan of a part of an emulsion block which we obtained from Prof. C. Powell. The block consists of 600 μ layers of Ilford G-5 emulsion, and was exposed in the stratosphere at a height of 28 km. From these decays we selected 120 cases in which the positron track-length is greater than 1 mm, so than an energy-measurement by the method of multiple scattering is possible. The selected events were also required to have the $\mu - e$ decay distant at least 100 μ from the emulsion surface and at least 1 cm from the edges. The scattering measurements were made twice (by two independent observers) for each track, by the coordinate method with cells of length 100 μ and 200 μ, and the usual checks on the correctness of the measurements were made. The results were not corrected for the effects of bremsstrahlung. The relation between second differences and electron energy was taken to be

$$E \approx 44/D_2^{(100)},$$

where E is the energy in Mev, and $D_2^{(100)}$ is the second difference measured in 100 μ cells. The distribution of visible track lengths was as follows:

Track length, mm	1—2	2—3	3—4	4—5	5—6	6
Number of tracks	62	31	15	6	5	1

The statistical error of the energy-measurements varies from 25% to 10% as the track-length varies from 1 mm to 6 mm.

The tracks of positrons and μ-mesons make small angles with the plane of the emulsion. The half-width of the distribution of these angles is less than 10° for positron and 15° for meson tracks. Hence we may assume without serious error that we observe the correlation for particles whose tracks lie in the emulsion plane.

The observed positron spectrum is shown in Fig. 1. It closely reproduces the positron spectrum observed in μ-e decay by previous observers.[4] The numbers in the histogram represent the angles ϑ measured in the emulsion plane. The inner (shaded) region of the histogram contains angles $\vartheta < 90°$, *i.e.*, those positrons which are emitted into the same half-plane as their parent μ-mesons. We separated from the spectrum the particles with energy exceeding 40 Mev, and selected those among them which made small angles with the μ-meson direction, obtaining the results shown in the table. The table shows a forward-backward asymmetry which is very large at small angles, not so large at wider angles, and agrees in magnitude with the asymmetry to be expected from Eq. (1).

When we look at the forward-backward asymmetry including all angles (0 – 90° and 90 – 180°), the effects are less marked but still noticeable. In particular, we may extract from the spectrum of Fig. 1 the following conclusions.

1. The total numbers of positrons are 54 forward and 66 backward.

2. The fraction of backward positrons increases significantly from 25 to 40 Mev. Counting positrons of energy greater than 25 Mev, the numbers are 49 forward and 59 backward. For energy greater than 40 Mev, the numbers are 20 forward and 31 backward.

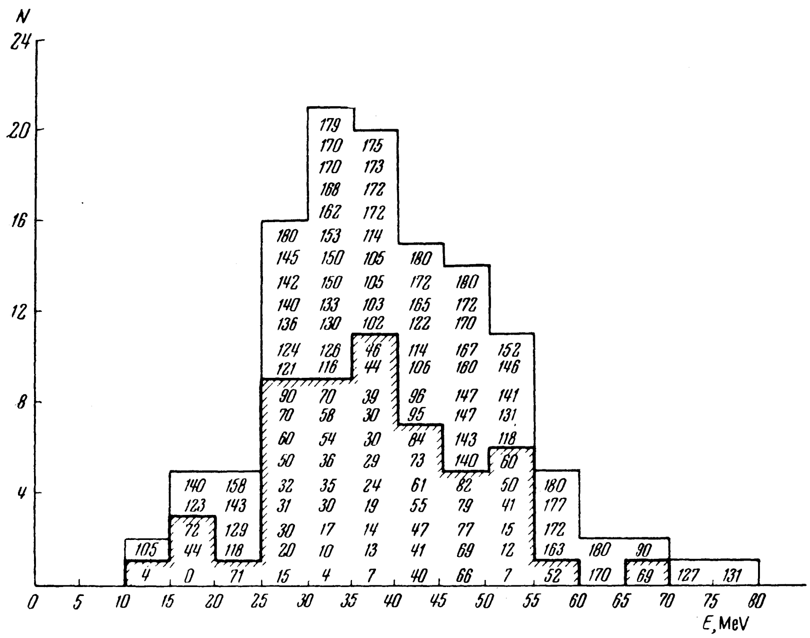

FIG. 1. Positron spectrum from $\pi \to \mu \to e$ decay.

Angles (degrees)	Direction	Number of positrons	Forward-backward ratio according to Eq. (1) with $\lambda = 1$.
0—10 170—180	Forward Backward	1 9	1 : 4
0—20 160—180	Forward Backward	3 14	~1 : 4
0—45 135—180	Forward Backward	6 21	1 : 3.5
45—90 90—135	Forward Backward	14 10	1 : 1.6

3. Of particles with energy greater than 55 Mev, 9 are backward and only 2 forward. The spectrum extends to these high energies because of the error in the energy measurements. From Eq. (1), the differential spectrum of backward-emitted positrons increases with energy like ε^2, while the spectrum of forward-emitted positrons decreases like $\varepsilon^2(1-\varepsilon)$. Thus we should expect to find a high-energy tail to the backward positron spectrum only, and this is what is observed.

Fig. 2 shows a comparison of our data with Eq. (1). The continuous curves are integral energy spectra for forward and backward positrons, calculated for the plane angular ranges $0-20°$ and $160-180°$ (Fig. 2a), $0-45°$ and $135-180°$ (Fig. 2b), and $0-90°$ and $90-180°$ (Fig. 2c). The theoretical curves are calculated with $\lambda = -1$. In Figs. 2b and 2c, the backward experimental points are lower and the forward experimental points are higher than the theoretical curves. This is presumably a result of depolarization. If depolarization occurs, then the coefficient λ in Eq. (1) should be changed to $\alpha\lambda$, where α is the fraction of μ-mesons which is not depolarized. Our data give a determination of the quantity $\alpha\lambda$. A least squares fit to all our data, including all angles and energies, gives $\alpha\lambda = 0.50 \pm 0.25$. It should be mentioned that a least squares fit to the part of the data represented in Figs. 2a and 2b gives a rather higher value of $\alpha\lambda$. This is because the experimental points lie closer to the theoretical curves in Figs. 2a and 2b than they do in Fig. 2c. We defer any analysis of this phenomenon until we have collected a significantly larger number of measured decays.

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Note Added in Proof (May 7, 1957). We have subsequently measured energies and angles for 440 positrons from π-μ-e decay in a NIKFI-R emulsion exposed to the π^+ beam of the Dubna synchrocyclotron. Analysis of the total sample of 560 energies and

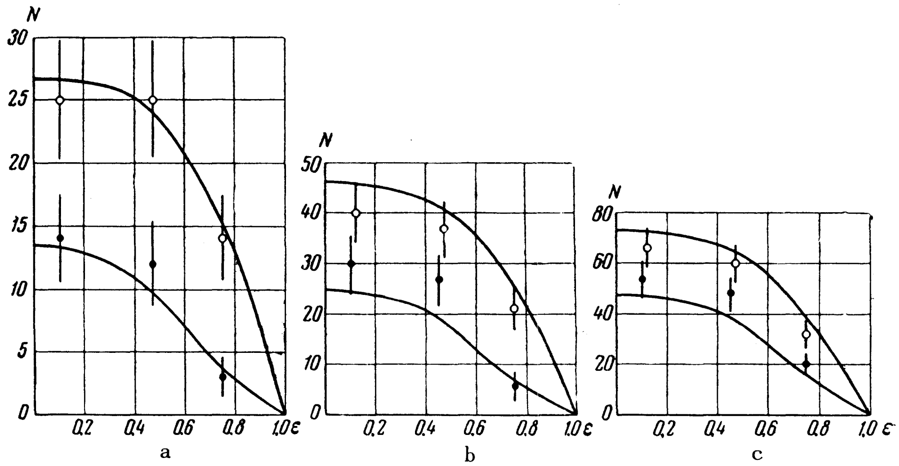

FIG. 2. Integral spectra of positrons from $\pi \to \mu \to e$ decay. a: solid circles, $\vartheta = 0-20^\circ$, open circles, $\vartheta = 160-180^\circ$; b: solid, $\vartheta = 0-45^\circ$, open, $\vartheta = 135-180^\circ$; c: solid, $\vartheta = 0-90^\circ$, open, $\vartheta = 90-180^\circ$. The curves show the theoretical distributions given by Eq. (1) with $\lambda = -1$.

angles shows that the asymmetry effect decreases from the top to the middle of the energy-spectrum and goes through zero in the range 20 – 30 Mev. This result is in complete agreement with Eq. (1) which is predicted by the two-component neutrino theory. A detailed analysis of the new data will be published later.

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