Finally we have applied this method also to the gamma decay of $\pi^0$ to see what results from this model.[7] This process is forbidden if $K$ interactions are switched off. Taking the mass difference into account, the lifetime turns out in this model to be $0.5\times10^{-15}$ sec, which is much longer than the usual one, $0.5\times10^{-16}$ sec. In the latter case the contributions from $\Xi$ are neglected. This result is again not inconsistent with the experimental result $\tau\lesssim0.5\times10^{-15}$ sec given recently by Harris, Orear, and Taylor.[8]

* Assisted by the Air Force Office of Scientific Research and U. S. Atomic Energy Commission.

† Permanent address: Department of Physics, Purdue University, Lafayette, Indiana.

‡ On leave of absence from Osaka City University, Osaka, Japan.

[1] S. Lokanathan and J. Steinberger, Phys. Rev. **98**, 240(A) (1955).

[2] For the pure axial vector coupling for both $NNe\nu$ and $NN\mu\nu$ interactions, the branching ratio $(\pi\rightarrow e+\nu)/(\pi\rightarrow\mu+\nu)$ turns out to be reasonable, say $10^{-4}$. But this interaction does not correspond to reality. M. Ruderman and R. Finkelstein, Phys. Rev. **76**, 1458 (1949).

[3] S. B. Treiman and H. W. Wyld, Phys. Rev. **101**, 1552 (1956).

[4] C. N. Yang and T. D. Lee, Nuovo cimento **3**, 749 (1956).

[5] M. Gell-Mann, Phys. Rev. **106**, 1296 (1957); J. Tiomno, Nuovo cimento **6**, 67 (1957).

[6] We consider here only beta decays that satisfy $\Delta S=0$. The assumption here is, precisely speaking, that all beta-decay interactions are of the $STV$ combination and that they are transformed in charge space as vector components.

[7] T. Kinoshita, Phys. Rev. **94**, 1384 (1954); J. Tiomno, Nuovo cimento **6**, 255 (1957).

[8] Harris, Orear, and Taylor, Phys. Rev. **106**, 327 (1957).

---

## Vanishing of the Neutrino Rest Mass*

K. Nishijima†

*Brookhaven National Laboratory, Upton, New York*

(Received September 12, 1957)

THE vanishing rest mass of the neutrino is guaranteed by the invariance of the theory under the transformation

$$\psi_\nu\rightarrow-\gamma_5\psi_\nu,\quad \psi_\mu\rightarrow\psi_\mu,\quad \psi_e\rightarrow\psi_e, \tag{1}$$

which constitutes the basis of the two-component theory.[1–3] However, this is not the only invariance that guarantees the vanishing rest mass of the neutrino. Among many other possibilities we shall consider the simultaneous transformation[4]

$$\psi_\nu\rightarrow-\gamma_5\psi_\nu,\quad \psi_\mu\rightarrow-\psi_\mu,\quad \psi_e\rightarrow\psi_e, \tag{2}$$

and require the invariance of the theory under the above transformation. This new invariance leads to a theory completely different from the two-component theory.

(a) From the invariance requirement under the transformation (2) there follows at once the selection rule: Neutrinoless transitions involving an odd number of $\mu$ mesons and an odd number of electrons are strictly forbidden. Examples of forbidden transitions are given by

$$\mu\rightarrow e+e+e,\quad \mu\rightarrow e+\gamma,$$
$$\mu+p\rightarrow p+e,$$
$$K\rightarrow\mu+e+\pi,\quad K\rightarrow\mu+e,\ \text{etc.}$$

These processes have not yet been observed experimentally.

(b) There is no difference in beta decay between the two-component theory and the present one, since no $\mu$ meson takes part in beta decay. Hence the theories cannot be distinguished in beta decay.

(c) The decay modes $\mu^+\rightarrow e^++\nu+\nu$ and $\mu^+\rightarrow e^++\nu+\bar{\nu}$ in the present theory lead respectively to exactly the same energy dependence, as well as the same asymmetry in the angular distribution of the decay electrons, as do the modes $\mu^+\rightarrow e^++\nu+\bar{\nu}$ and $\mu^+\rightarrow e^++\nu+\nu$ in the two-component theory.[5] Since in the two-component theory the $\nu\bar{\nu}$ mode is experimentally favored over the $2\nu$ mode, the $2\nu$ mode is experimentally favored in the present theory. The polarizations of the neutrinos in both theories are given, respectively, by

$$\mu^+\rightarrow e^++\nu_R+\bar{\nu}_L\quad \text{(two-component theory)}, \tag{3a}$$

$$\mu^+\rightarrow e^++\nu_R+\nu_L\quad \text{(present theory)}. \tag{3b}$$

In this case, the left-handed antineutrino in the two-component theory is replaced in the present theory by the left-handed neutrino which does not occur in the former theory.[6] Therefore it is not possible to differentiate the present theory from the two-component theory through the experimental investigation of the $\mu-e$ decay process, unless one can distinguish between left-handed (right-handed) neutrino and left-handed (right-handed) antineutrino.

(d) It is in principle possible to distinguish between the two theories through the observation of successive transitions. For instance, in the two-component theory the following successive transitions are expected to occur:

$$\mu^-+p\rightarrow n+\nu,\quad \nu+n\rightarrow p+e^-. \tag{4}$$

Namely, the neutrino resulting from the $\mu$-meson capture hits a neutron to produce an electron. In the present theory the latter transition cannot occur because of the selection rule (a). This difference bears a strong resemblance to that between the Dirac theory and Majorana theory of the neutrino, and the process (4) corresponds to the double beta decay.

(e) If the conservation of leptons holds, it is clear from (c) that we must assign $e^-$, $\nu$, and $\mu^+$ as particles but not $e^-$, $\nu$, and $\mu^-$ as is the case in the two-component theory. Such a particle-antiparticle assignment was proposed some years ago by Konopinski and Mahmoud.[7]

If leptons are conserved in the above sense, one can require the invariance of the theory under a wider group of transformations, i.e.,

$$\psi_\nu \rightarrow e^{ia(\gamma_5+1)/2}\psi_\nu, \quad \psi_\mu \rightarrow e^{-ia}\psi_\mu, \quad \psi_e \rightarrow \psi_e. \qquad (5)$$

The invariance requirement under the foregoing continuous transformations leads to the following conservation law:

$$N(\nu_L) - N(\bar{\nu}_R) + N(\mu^+) - N(\mu^-) = \text{const}, \qquad (6)$$

where $N(\nu_L)$ denotes the number of left-handed neutrinos and so on. Combining (6) with the lepton conservation law, one gets another conservation law:

$$N(\nu_R) - N(\bar{\nu}_L) + N(e^-) - N(e^+) = \text{const}. \qquad (7)$$

To conclude, the author would like to emphasize that although there is no feasible experimental means at present to differentiate the present theory from the two-component theory, the present one has an advantage over the latter in the sense that it leads to the selection rule (a) which forbids many unwanted processes and which does not follow from the two-component theory.

* Assisted by the U. S. Atomic Energy Commission.
† On leave of absence from Osaka City University, Osaka, Japan.

[1] A. Salam, Nuovo cimento, **5**, 299 (1957).
[2] T. D. Lee and C. N. Yang, Phys. Rev. **105**, 1671 (1957).
[3] L. Landau, Nuclear Phys. **3**, 127 (1957).

[4] We may equally well consider the transformation $\psi_\nu \rightarrow \gamma_5\psi_\nu$, $\psi_\mu \rightarrow \psi_\mu$, $\psi_e \rightarrow -\psi_e$, which leads to a theory equivalent to the one given in the text. In this sense the present theory deals with the electron and $\mu$ meson in a symmetrical manner.

[5] The interaction Hamiltonians for (3a) and (3b) are given respectively by

$$H_a = \sum_{A,V} g_i \bar{\psi}_\mu O_i \psi_e \cdot \bar{\psi}_\nu O_i (1-\gamma_5)\psi_\nu + \text{Herm. conj.},$$

$$H_b = \sum_{A,V} g_i \bar{\psi}_\mu O_i \psi_e \cdot \bar{\psi}_\nu O_i (1-\gamma_5) C \bar{\psi}_\nu + \text{Herm. conj.},$$

where $C$ is the charge conjugation matrix satisfying $C\gamma_\mu{}^T C^{-1} = -\gamma_\mu$. Notice in the latter case the relations $\bar{\psi}_\nu O_i (1-\gamma_5) C\bar{\psi}_\nu = \bar{\psi}_\nu O_i (1+\gamma_5) C\bar{\psi}_\nu$. It is clear that both interactions lead to the same results concerning decay electrons.

[6] In this sense the present theory is essentially a four-component theory and equivalent to introducing two kinds of two-component neutrinos.

[7] E. J. Konopinski and H. M. Mahmoud, Phys. Rev. **92**, 1045 (1953).

## Rare High-Energy Photon Jet in Cosmic Rays*†

O. B. Young and T. S. Yoon
*Southern Illinois University, Carbondale, Illinois*
(Received July 8, 1957)

THIS report concerns a high-energy photon shower similar to an event previously reported,[1] but with interesting points of difference, including lower energy, axis zenith angle larger than 90 degrees, and a smaller number of electron pairs. The event consists of seven electron pairs in a stack of three Ilford G-5, 600 micron pellicles, exposed in a flight over Texas (Aero Medical Flight 59, June 3, 1955) at 114 000 foot altitude and at geomagnetic latitude of N 41 degrees. Observations were restricted to the three plates. The energies of the seven pairs of electron tracks range from 126 to 3630 Mev and total nearly 11 Bev. The 98 degree zenith angle of the axis indicates the source to be a nuclear interaction at lower altitude than the balloon.

Inasmuch as this event did not terminate in the three plates, measurements are restricted. The first electron pair materialized 95 microns from the air side of plate No. 4002 and traveled 10 050 microns, making an angle of 98 degrees with the zenith before entering the next plate, No. 4001. Two new electron pairs were observed

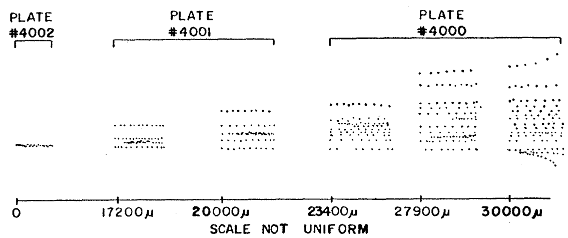


FIG. 1. Drawing of a high-energy photon event in cosmic rays.

in plate No. 4001 and 4 more electron pairs were seen in plate No. 4000. A drawing of this event appears in Fig. 1. Measurements and energy determinations are listed in Table I. No other tracks nearby could be associated with this event.

While this event is similar to one previously reported,[1] it is far from being identical and has interesting points of difference. The complete explanation of this type of event has not been made. A chief characteristic is that the electron pairs are formed at different distances, i.e., the photons did not materialize at the same distance from some common origin. Nor is there evidence that

TABLE I. Seven pairs in the photon shower. $E_1$ and $E_2$ are the energies of individual electrons obtained by multiple scattering measurements. $E$ is the total energy of a pair. $E'$ is the energy of a photon obtained from measurements of the angle of divergence of the pair. The radial distance is the maximum departure of a track from the axis of the jet.

| Pair No. | Distance to point of conversion in microns | Radial distance in microns from axis | $E_1$ (Mev) | $E_2$ (Mev) | Total energy $E$ (Mev) | Total energy $E'$ (Mev) |
|---|---|---|---|---|---|---|
| 1 | | | 1770±480 | 1860±570 | 3630±740 | 16 300 |
| 2 | 17 600 | 4.2 | 200±55 | 400±100 | 620±114 | 240 |
| 3 | 20 000 | 4.1 | 950±200 | 1200±250 | 2150±320 | 2900 |
| 4 | 23 400 | 10.0 | 130±50 | 38±3 | 168±51 | 130 |
| 5 | 27 900 | 2.3 | 2000±600 | 1530±400 | 3530±720 | 1570 |
| 6 | 28 400 | 17.0 | 410±100 | 120±20 | 530±102 | 136 |
| 7 | 29 900 | 23.0 | 126±40 | 0.24 | 126±40 | ... |

materialization depends dominantly upon a definite energy. The great range of photon energies indicates a heterogeneous formation process.