existence of an attractive $\pi$-$\pi$ force in the $T=0$ state[5] or a repulsive force in the $T=2$ state, or both, would lead to deviations from a symmetrical $\pi^-$ energy distribution of the type observed by us.

The $\tau$-decay data presented at the Pisa Conference[4] do not show the pronounced energy asymmetry which we observe in 54 cases. Our method of scanning could not have introduced an asymmetry in the energy of the type observed. The question also arises as to whether our observations represent a statistical accident or a sample which is less subject to bias than one obtained by an accumulation of data from many laboratories. We plan to continue this work and improve our statistics in the hope of resolving this question.

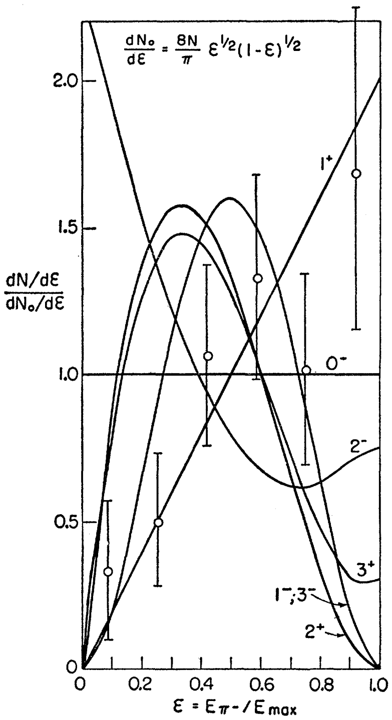

FIG. 3. Energy distribution of the odd pion in $\tau$ decay, corrected for the phase-space factor, Eq. (1). Theoretical energy distributions[1] are computed on the assumptions outlined in the caption to Fig. 1.

*Note added in proof.*—G. Harris and J. Orear (Columbia University, private communication) find in a similar sample a large number of low energy $\pi^-$'s associated with their $\tau$ decays. These additional data, even in combination with ours, rule out $1^+$, and make $0^-$ the preferred solution, although some deviation from isotropy in the direction indicated by our results is not ruled out.

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† Now with the Department of Physics, University of Illinois, Urbana, Illinois.

[1] R. H. Dalitz, Phys. Rev. **94**, 1046 (1954).

[2] Ritson, Pevsner, Fung, Widgoff, Zorn, Goldhaber, and Goldhaber, Phys. Rev. (to be published).

[3] We wish to express our gratitude to E. Lofgren and G. Goldhaber for their kind assistance in arranging this exposure.

[4] Proceedings of the International Conference on Elementary Particles, Pisa, 1955 (to be published).

[5] F. Dyson, Phys. Rev. **99**, 1037 (1955).

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## Angular Distribution of $\Lambda^0$ and $\theta^0$ Decays*

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QUALITATIVELY, it is clear that the angular distribution of the decay products of the $\Lambda^0$ and $\theta^0$ must be related to the spins of these particles. In particular, it is well known[1,2] that the complexity of the angular distribution of decay particles is limited by the magnitude of the spin of the parent state. If the angular distribution about an arbitrary direction is written as a polynomial in $\cos\vartheta$, only even powers of $\cos\vartheta$ will appear in the terms and the highest power will be equal to $2a$, where $a$ is equal to the spin of the particle for bosons and to the spin minus one-half for fermions. The use of this rather loose restriction can only establish a lower limit to the spin of a state.

It is the purpose of this note to point out that an examination of the angular correlations of the $\Lambda^0$ and $\theta^0$ decay products is particularly informative when restricted to $\Lambda^0$ and $\theta^0$ particles produced in the backward or forward direction by the $\pi^-+p\rightarrow\theta^0+\Lambda^0$ reaction, at energies near threshold. In particular, the determination of the angular distributions of those $\Lambda^0$ decays which are in coincidence with $\theta^0$ mesons which decay in the forward or backward direction, uniquely determines the spin of the $\Lambda^0$. Likewise, a measurement of the decay distribution of those $\theta^0$ mesons in coincidence with $\Lambda^0$ particles which decay in the forward or backward direction will determine a number which will generally be equal to the spin of the $\theta^0$, and will always be as great as the spin minus one.

A general expression for the reaction amplitude for the $\pi^-+p\rightarrow\Lambda^0+\theta^0$ is:

$$\begin{aligned}A= & \sum_{\pi j m_j L S m_L m_A m_l} a_{\pi j L S}(j+\tfrac{1}{2})^{\frac{1}{2}}(LSjm_j|LSm_L,\, m_j-m_L) \\ & \times\Theta_L^{m_L}(ABS,\, m_j-m_L|ABm_A,\, m_j-m_L-m_A)\Theta_A^{m_A} \\ & \times(l\tfrac{1}{2}\Lambda,\, m_j-m_L-m_A|l\tfrac{1}{2}m_l,\, m_j-m_L-m_A-m_l) \\ & \times\Theta_l^{m_l}\chi^{m_j-m_L-m_A-m_l}\,\delta(\pi,\,(-1)^{L+l+A+1})\alpha(m_j), \qquad (1)\end{aligned}$$

where the complex constants, $a$, are determined by the dynamics of the reaction and the magnetic quantum numbers represent values in the direction of the beam. In this equation $\pi$ represents the parity of the state formed with total angular momentum, $j$; $L$ and $S$ represent the relative orbital angular momentum and the total spin of the $\Lambda^0-\theta^0$ system, respectively; while the $A$, $B$, $l$, and $\chi$ stand for the spin of the $\theta^0$, the spin of the $\Lambda^0$, the $\pi^--p$ relative orbital angular momentum in the decay of the $\Lambda^0$, and the proton spin function in that order. The $\alpha(m_j)$, which are unit vectors such that $\alpha(m)\alpha(m')=\delta(m,m')$, establish that the bombarded protons are unpolarized. The value of $m_j$ must be equal to the spin component of the bombarded proton since

TABLE I. Angular distributions of $\Lambda^0$ decays for $\Lambda^0$ particles produced by the $\pi^- + p \rightarrow \Lambda^0 + \theta^0$ reaction in the beam direction, in coincidence with $\theta^0$ mesons which decay in the beam direction.

| $\Lambda^0$ spin | Angular distribution |
|---|---|
| 1/2 | 1 |
| 3/2 | $\frac{1}{2}+\frac{3}{2}\cos^2\vartheta$ |
| 3/2 | $\frac{3}{4}-\frac{3}{2}\cos^2\vartheta+(15/4)\cos^4\vartheta$ |
| 7/2 | $(9/16)+(45/16)\cos^2\vartheta-(165/16)\cos^4\vartheta$ $+(175/16)\cos^6\vartheta$ |

the orbital angular momentum can have no component in the beam direction. It can be seen that the spherical harmonics $\Theta_L$, $\Theta_A$, and $\Theta_l$ determine the angular distributions, of the production of $\Lambda^0$ and $\theta^0$ particles, the decay of the $\theta^0$, and the decay of the $\Lambda^0$, respectively. The selection of events in which the $\Lambda^0$ and $\theta^0$ particles are produced in the direction of the beam reduces the sum over magnetic quantum numbers $m_L$ to one term, $m_L=0$. Further selection of $\Lambda^0$ decays in conjunction with $\theta^0$ mesons decaying in the beam direction reduces the sum over $m_A$ to one term, $m_A=0$. From Eq. (1), we see that for each value of $m_j$, $+\frac{1}{2}$, or $-\frac{1}{2}$, the decay amplitude for $\Lambda^0$ decays will reduce to

$$\sum_{m_l} (l\tfrac{1}{2}\Lambda m_j | l\tfrac{1}{2}m_l, m_j-m_l)\Theta_l^{m_l}\chi^{m_j-m_l}. \qquad (2)$$

which results in angular distributions which depend only on $B$, the spin of the $\Lambda^0$. Angular distributions for various values of $B$ are presented in Table I. If, again restricting ourselves to production in the beam direction, we observe $\theta^0$ decays in coincidence with those $\Lambda^0$ mesons which decay at 0° or 180°, somewhat weaker restrictions hold. From Eq. (1), we see that for each value of $m_j$ two states $\Theta_A{}^{m_j+\frac{1}{2}}\chi^{-\frac{1}{2}}$ and $\Theta_A{}^{m_j-\frac{1}{2}}\chi^{\frac{1}{2}}$ will occur. The $\theta^0$ decay distributions then take the form:

$$\beta(\Theta_A{}^{m_j-\frac{1}{2}})^2+(\Theta_A{}^{m_j+\frac{1}{2}})^2, \qquad (3)$$

where $\beta$ is a real number largely undetermined by geometric considerations. In general this angular distribution will be of the form:

$$d\sigma/d\Omega = a\cos^{2A}\vartheta + a'\cos^{2A-2}\vartheta. \qquad (4)$$

Fortuitous values of $\beta$ can result in either $a$ or $a'$ vanishing, but they will not vanish simultaneously. Therefore an analysis of the angular distribution will establish a number which will likely be the spin of the $\theta^0$, and will certainly be as large as the spin minus one.

Practical considerations demand an estimate of the deviation from 0° or 180° allowable in order that the relations discussed here will hold. The acceptable angle of production must be of the order of $L'^{-1}$ radian, where $L'$ is the maximum important angular momentum $L$. If we estimate $L'=p/mc$, where $p$ is the momentum in the center-of-mass system of the $\Lambda^0$ or $\theta^0$ and $m$ is the $\pi$ meson Compton wavelength, we find we can allow an acceptance angle of $\pm 30°$ at a $\pi$ bombardment energy of 950 Mev. Similarly decays of $\theta^0$ particles at angles less than $A^{-1}$ radian and $\Lambda^0$ decays at angles less then $(B-\frac{1}{2})^{-1}$ radian can be considered forward or backward in the sense of this note.

Similar considerations can, of course, be applied to the associated production of other particles.

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# Alpha-Decay Properties of $Am^{239}$

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OF considerable interest concerning the nuclear spectroscopic states in the heavy-element region is the appearance of a number of $E1$ transitions of low energy signifying the existence of close-lying states of opposite parity. The data on this subject have been collected by Stephens[1] and discussed in terms of the shell model. One of the first of these to be studied in some detail is the 59.6-kev gamma transition in $Np^{237}$ observed through the alpha decay of $Am^{241}$. Beling, Newton, and Rose[2] showed its $E1$ character and observed the curious fact that its lifetime is measurable. The measurement of the alpha spectrum of $Am^{241}$ showed the presence of at least five $\alpha$ groups but almost all populated the 59.6-kev state either directly or through a still higher-lying level.[3]

More recently it has been shown that $Am^{243}$, with two neutrons more, has virtually the identical alpha spectrum.[4,5] Five alpha groups were observed with close to the same intensities of corresponding groups of $Am^{241}$, and the energy-level spacings of the $Np^{239}$ states are the same as those of $Np^{237}$ except that the 59.6-kev state has moved up to 74 kev. The 74-kev gamma ray is by far the most intense and, like the 59.6-kev transition of $Np^{237}$, it is electric dipole.

The present report is concerned with the $Am^{239}$ which was examined in order to see if here too the favored alpha transition led to a state of $Np^{235}$ which was de-excited by an $E1$ transition. This isotope of americium decays predominantly by electron capture with a 12-hour half-life.[6] The alpha branching is only $3\times10^{-3}\%$.[7]

The sample prepared for the present study was made by irradiating $Pu^{239}$ with 18-Mev deuterons and consisted of about 200 alpha disintegrations per minute of $Am^{239}$ and a small quantity of $Am^{243}$. The preponderant radiation from the electron-capture branching was eliminated by detecting only the gamma spectrum in coincidence with alpha particles. Even so, it was necessary to use only about 10% of the sample in order to lower the chance coincidence rate. The alpha particles were detected with a zinc sulfide screen and the coinci-