and

$$\Lambda^0 \rightarrow p+\pi^-. \qquad (14)$$

All the previous formulas for $I(\theta)$, $p(\theta)$, $W(\theta,\xi)$, and $\alpha$ [i.e., Eqs. (2), (4), (6), (7), and (8)] remain unchanged. The only difference is that in Eq. (8) the amplitudes $A$ and $B$ of $s$- and $p$-wave final states in the decay process of $\Lambda^0$ are now each a mixture of two isotopic spin states. These amplitudes can be written as

$$\begin{aligned} A&=(\tfrac{2}{3})^{\frac{1}{2}}A_{\frac{1}{2}}+(\tfrac{1}{3})^{\frac{1}{2}}A_{\frac{3}{2}},\\ B&=(\tfrac{2}{3})^{\frac{1}{2}}B_{\frac{1}{2}}+(\tfrac{1}{3})^{\frac{1}{2}}B_{\frac{3}{2}}, \end{aligned} \qquad (15)$$

where $A_{\frac{1}{2}}$, $B_{\frac{1}{2}}$ are, respectively, the $s$- and $p$-wave amplitudes for final states with the total isotopic spin value $I=\frac{1}{2}$, and $A_{\frac{3}{2}}$, $B_{\frac{3}{2}}$ the corresponding amplitudes for states with $I=\frac{3}{2}$. In place of Eqs. (9) and (10) we have now the following conditions for invariance under time reversal and charge conjugation:

If the decay process is invariant under time reversal, then we can choose[8]

$$\begin{aligned} A_{\frac{1}{2}}&=|A_{\frac{1}{2}}|e^{i\delta_1},\\ A_{\frac{3}{2}}&=\pm|A_{\frac{3}{2}}|e^{i\delta_3},\\ B_{\frac{1}{2}}&=\pm|B_{\frac{1}{2}}|e^{i\delta_{11}},\\ B_{\frac{3}{2}}&=\pm|B_{\frac{3}{2}}|e^{i\delta_{31}}. \end{aligned} \qquad (16)$$

On the other hand, if the decay process is invariant under charge conjugation operation, then these amplitudes are[8]

$$\begin{aligned} A_{\frac{1}{2}}&=|A_{\frac{1}{2}}|e^{i\delta_1},\\ A_{\frac{3}{2}}&=\pm|A_{\frac{3}{2}}|e^{i\delta_3},\\ B_{\frac{1}{2}}&=\pm i|B_{\frac{1}{2}}|e^{i\delta_{1,1}},\\ B_{\frac{3}{2}}&=\pm i|B_{\frac{3}{2}}|e^{i\delta_{3,1}}. \end{aligned} \qquad (17)$$

The phase shifts $\delta$ are the usual pion-nucleon scattering phase shifts at 37-Mev total kinetic energy:

$\delta_1$ = phase shift for $s$ waves, $I=\frac{1}{2}$, $J=\frac{1}{2}$,

$\delta_3$ = phase shift for $s$ waves, $I=\frac{3}{2}$, $J=\frac{1}{2}$,

$\delta_{\lambda\mu}$ = phase shift for $p$ waves, $I=\lambda/2$, $J=\mu/2$.

All these phase shifts are small at 37-Mev total kinetic energy. Therefore any appreciable asymmetry in $W(\theta,\xi)$ with respect to the sign of $\xi$ is an indication that conservation of parity and invariance under charge conjugation do not hold in the decay of $\Lambda^0$.

A measurement of the branching ratio in the decay processes

$$\Lambda^0 \rightarrow p+\pi^-, \qquad (18)$$

$$\Lambda^0 \rightarrow n+\pi^0, \qquad (19)$$

and a measurement of the distribution function $W(\theta,\xi)$ for process (19) would lead to additional information concerning the amplitudes $A_{\frac{1}{2}}$, $B_{\frac{1}{2}}$, $A_{\frac{3}{2}}$, and $B_{\frac{3}{2}}$.

* Work supported in part by the U. S. Atomic Energy Commission.

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[4] Budde, Chretien, Leitner, Samios, Schwartz, and Steinberger, Phys. Rev. **103**, 1827 (1956); D. A. Glaser (private communication); R. Adair (private communication).

[5] T. D. Lee and C. N. Yang, Phys. Rev. **104**, 254 (1956).

[6] T. D. Lee and C. N. Yang, Phys. Rev. **104**, 822 (1956).

[7] In view of the recent experimental developments (references 1, 2, and 3) there appears to be at present no *theoretical* necessity to introduce the complication of parity doublets. (See footnote 8 in reference 5.)

[8] Lee, Oehme, and Yang, Phys. Rev. **106**, 340 (1957). See the proof of Theorem 2.

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## Excited States in the Proton $f_{7/2}$ Shell*

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GOLDSTEIN and Talmi[1] have pointed out that it is sometimes possible to determine the excitation energies of the states of a $j^n$ configuration by making use of the experimentally measured splittings of the $j^2$ configuration together with the tabulated coefficients of fractional parentage.[2] We have used this technique to make spin assignments for the excited states of nuclei with $(f_{7/2})^n$ protons and 28 (closed shell) neutrons. The purpose of this note is to stimulate interest in obtaining experimental verification of these predictions.

As our starting point we take the excitation energies for the configuration $(f_{7/2})^{-2}$ as given by $(p,p')$ measurements[3] on Fe$^{54}$. Making use of these, one finds it a simple matter to compute the energy splittings for $(f_{7/2})^{-3}$—which, of course, should be the same as $(f_{7/2})^3$. We also predict that the lowest states of $(f_{7/2})^4$ should be the same as those of $(f_{7/2})^{\pm 2}$. This conclusion follows from the supposition that the lowest states should be those of lowest seniority. Consequently, the $(f_{7/2})^4$ states of seniority two, $J=2$, 4, 6, correspond to the recoupling of only two of the protons, the identical physical situation occurring in $(f_{7/2})^2$. A summary of our predictions together with the known experimental information is contained in the table.

It should be noted that the predictions for $(f_{7/2})^{\pm 3}$ are extremely sensitive to the values assumed for the two-particle energies. If, for example, one averages the $(f_{7/2})^{-2}$ excitation energies from Buechner and the $(f_{7/2})^4$ values obtained by Huiskamp *et al.*,[4] one obtains for $(f_{7/2})^{\pm 3}$ the energies 0.32 (5/2) Mev (above ground), 0.89 (3/2), 1.73 (9/2), 1.75 (11/2), and 3.12 (15/2).

TABLE I. Excitation energies of protons in the $f_{7/2}$ shell. The calculated energies are based upon the levels from Buechner and Sperduto,[a] assuming spin assignments $4^+$ and $6^+$ for the second and *fourth* excited states in $\text{Fe}^{54}$. Spin assignments, where known, are given in parentheses.

| Configuration | Predicted spin | Theoretical energy (Mev) | Known levels | | |
|---|---|---|---|---|---|
| | | | $_{22}\text{Ti}^{50}$ [b] | $_{24}\text{Cr}^{52}$ [c] | $_{26}\text{Fe}^{54}$ [a,d] |
| $(f_{7/2})^{\pm 2,4}$ | $0^+$ | 0 | 0 $(0^+)$ | 0 $(0^+)$ | 0 $(0^+)$ |
| | $2^+$ | 1.41 | 1.58 | 1.46 $(2^+)$ | 1.41 $(2^+)$ |
| | $4^+$ | 2.54 | | 2.40 $(4^+)$ | 2.54 |
| | | | | | 2.57 |
| | $6^+$ | 3.16 | 3 | 3.13 $(6^+)$ | 3.16 |
| | | | $_{23}\text{V}^{51}$ [d] | | $_{25}\text{Mn}^{51}$ [d] |
| $(f_{7/2})^{\pm 3}$ | $7/2^-$ | 0 | 0 $(7/2^-)$ | | 0 $(7/2^-)$[e] |
| | $5/2^-$ | 0.24 | 0.32 $(5/2^-)$ | | 0.38 $(5/2^-)$ |
| | $3/2^-$ | 0.98 | 0.93 $(3/2^-)$ | | 1.27 |
| | $11/2^-$ | 1.74 | 1.61 | | |
| | $9/2^-$ | 1.82 | 1.84 | | |
| | | | 2.22 | | |
| | | | 2.43 | | |
| | | | 2.65 | | |
| | $15/2^-$ | 3.14 | 3.11 | | |

[a] See reference 3.
[b] See reference 5.
[c] See reference 4.
[d] From *Nuclear Level Schemes*, $A=40-A=92$, compiled by Way, King, McGinnis, and van Lieshout, Atomic Energy Commission Report TID-5300, June, 1955 (U. S. Government Printing Office, Washington, D. C., 1955).
[e] Dobrowolski, Jones, and Jeffries, Phys. Rev. **104**, 1378 (1956).

Here the positions of the 5/2 and 3/2 states are in excellent agreement with experiment, and the relative positions of the 9/2 and 11/2 levels are reversed from the predictions made by using only Buechner's values.

In Table I we have given, under $\text{Ti}^{50}$, only the levels that have been found by Pieper.[5] If we take the $\text{Ti}^{50}$ level at 1.58 Mev to be a $2^+$ level, we can make use of the known excitation energies of $\text{V}^{51}$ to find that the $4^+$ and $6^+$ levels should lie, respectively, 2.76 and 3.56 Mev above ground. Morinaga[6] has observed coincidence gamma rays from $\text{Ti}^{50}$ with energies of 1.59 and 1.17 Mev, which would tend to verify this prediction.

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