unlikely from these results that there exists any $S$ or $V$ contribution as great as 10%: this result is of course to be expected from the fact that change in total isotopic spin is forbidden in Fermi interactions. Examination of Fig. 2 shows that the spin and parity of $\mathrm{Li}^8$ cannot be $1^+$ or $3^+$, except in the unlikely contingency that $A$ and $T$ interactions contribute equally. We conclude that $\mathrm{Li}^8$ has spin and parity $2^+$, and that the beta-decay interaction is at least 90% Gamow-Teller. These conclusions are essential to the elucidation of the nature of the $\mathrm{Li}^8$ beta-decay interaction as indicated by Barnes et al.[4]

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

[1] Christy, Cohen, Fowler, Lauritsen, and Lauritsen, Phys. Rev. 72, 698 (1947).

[2] Lauterjung, Schimmer, and Maier-Leibnitz, Z. Physik 150, 657 (1958).

[3] R. P. Feynman and B. Stech (private communication)· M. Morita, Phys. Rev. Lett. 1, 112 (1958).

[4] Barnes, Fowler, Greenstein, Lauritsen, and Nordberg, following Letter [Phys. Rev. Lett. 1, 328(1958)] .

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# NATURE OF THE $\mathrm{Li}^8$ BETA-DECAY INTERACTION *

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It has been established in the preceding Letter[1] that the spin and parity of $\mathrm{Li}^8$ are $2^+$, and that the beta decay to the $2^+$ excited state of $\mathrm{Be}^8$ proceeds at least 90% of the time by a Gamow-Teller transition. With the spin sequence $2^+$-$2^+$-$0^+$, a measurement of the recoil momentum from the electron and antineutrino, perpendicular to the direction of the alpha break up, distinguishes vector ($V$) and scalar ($S$) interactions from each other and from axial vector ($A$) and tensor ($T$) interactions, but does not allow a distinction between $A$ and $T$.

The distinction between $A$ and $T$ can be made, however, by a determination of the distribution of recoil momenta along the alpha break-up direction.[2] This component will generally be larger when the electron and antineutrino are emitted preferentially in the same direction ($V$ and $T$), and smaller in the opposite case ($S$ and $A$). Theoretically, $V$ and $T$ give identical predictions for the spin sequence $2^+$-$2^+$-$0^+$, and $S$ and $A$ are likewise indistinguishable.

In the present experiment, the $\mathrm{Li}^8$ is produced by bombarding a thin layer of $\mathrm{Li}^7$ on a 0.005-inch aluminum backing, with a deuteron beam pulsed at 60 pulses per second. During the periods when the beam is cut off, alpha particles following the $\mathrm{Li}^8$ beta decay are magnetically analyzed and detected in a 0.002-inch thick CsI(Tl) crystal in coincidence with electrons travelling perpendicular to the alpha direction, or alternatively antiparallel to the alpha direction. The electrons are detected in collimated plastic scintillators so that pulse-height analysis can be carried out to select various ranges of electron energy. The measured alpha-particle momentum spectra for the two counter configurations, and for two different ranges of electron energy, are shown in Figs. 1 and 2. Corrections to the experimental data have been made for the $\mathrm{He}^+/\mathrm{He}^{++}$ ratio and for the momentum loss of the alpha particles in escaping from the target.

To first order in $p_\beta/p_\alpha$, the alpha-particle spectrum observed for the perpendicular counter configuration is just the spectrum in the rest system of the $\mathrm{Be}^{8*}$ slightly broadened symmetrically, for all interactions, by the antineutrino momentum. Also to first order, the momentum of an alpha particle in the antiparallel configur-

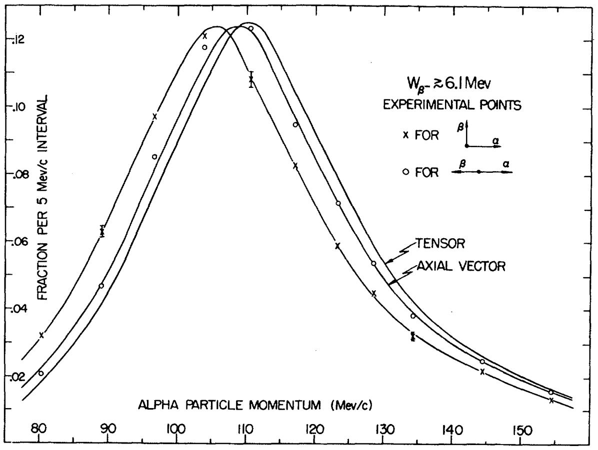

FIG. 1. Alpha-particle momentum spectra obtained in $\beta\alpha$-coincidence measurements on the decay of $\mathrm{Li}^8$. The crosses are experimental points for electrons with $W_\beta \gtrsim 6.1$ Mev perpendicular to the observed alpha particle; the open circles are for electrons with $W \gtrsim 6.1$ Mev antiparallel to this alpha particle. Theoretical curves corrected for finite experimental resolution are shown for axial vector (or scalar) and tensor (or vector) interaction.

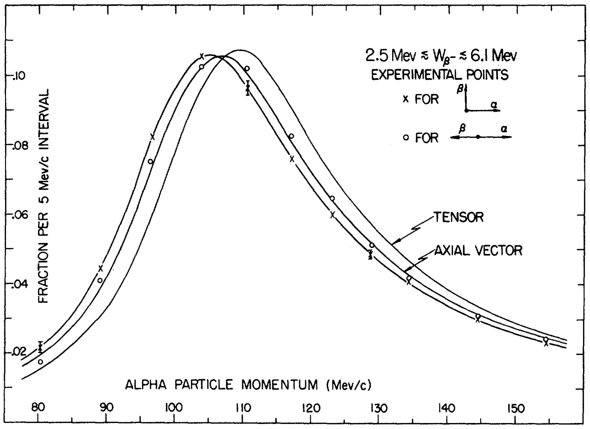

FIG. 2. Theoretical and experimental spectra as in Fig. 1 except for electrons with 2.5 Mev $\lesssim W_\beta \lesssim$ 6.1 Mev.

ation is increased by an amount

$$\Delta p_\alpha = \tfrac{1}{2}\,(p_\beta - p_{\bar\nu}\cos\theta_{\bar\nu\alpha}), \qquad (1)$$

where $p_\beta$ and $p_{\bar\nu}$ are the absolute magnitudes of the electron and antineutrino momenta. The theoretically predicted angular correlation for antineutrino and alpha particle is, for $\cos\theta_{\beta\alpha}=-1$,

$$W(\theta_{\bar\nu\alpha}) = 1 \pm \frac{v}{c}\cos\theta_{\bar\nu\alpha}, \qquad (2)$$

where the plus sign holds for $A$ or $S$ and the minus sign for $T$ or $V$.[2,3] When the antineutrino momenta are averaged over all angles, with the angular correlation given by Eq. (2), and average magnitudes inserted for the electron and antineutrino momenta, the spectrum of the observed alpha particles in the antiparallel configuration will be shifted upwards on the average by

$$\langle \Delta p_\alpha \rangle = \tfrac{1}{2}\langle p_\beta \rangle \pm \tfrac{1}{6}\langle p_{\bar\nu} \rangle \;, \qquad (3)$$

where the plus sign holds for $T$ or $V$ and the minus sign for $A$ or $S$. Since the measurements described in the preceding Letter[1] set upper limits for $S$ and $V$, we are here interested in distinguishing $A$ from $T$. To calculate $\langle p_\beta \rangle$ and $\langle p_{\bar\nu} \rangle$ we have assumed that the spectra of electron and antineutrino momenta in coincidence with alpha particles of energy $E_\alpha$ are given by the usual Fermi expression with an end-point energy $W_0=(16.6-2E_\alpha)$ Mev.

The crosses in Fig. 1 give the experimental alpha-particle momentum spectrum for the perpendicular configuration, with a smooth curve drawn through the points. The other two curves in Fig. 1 are constructed from this smooth curve with the aid of Eq. (3), for electrons of total energy $W_\beta \gtrsim$ 6.1 Mev. A small correction has been made for the beta counter pulse height resolution which was ~15% at 6.1 Mev. It is evident that the open circles, which give the measured spectrum for the antiparallel configuration, agree well with the axial vector prediction.

The curves in Fig. 2 are derived similarly for 2.5 Mev $\lesssim W_\beta \lesssim$ 6.1 Mev. In addition to the resolution correction already mentioned, corrections have been made for high-energy electrons scattered from the collimator, as determined experimentally, and for the "tail" of small pulses always present in the pulse-height spectrum of high-energy electrons. Again, it is evident that the observed shifted spectrum agrees well with the axial vector prediction. A qualitative comparison of the results in Fig. 2 with those in Fig. 1 is instructive. A relatively large shift is expected for either $A$ or $T$ in the antiparallel curve of Fig. 1 since the antiparallel electron has the greater share of the decay energy and the shift is thus not very sensitive to the orientation of the low-energy antineutrino. The measurements show that the experimental arrangement was capable of measuring such a relatively large shift. On the other hand, the small shift in Fig. 2 shows the partial cancellation to be expected for the axial vector interaction between the antiparallel momentum of the low-energy electron and the average parallel component of momentum of the high-energy antineutrino.

A more quantitative comparison of the experimental shifts with the theoretically expected shifts may be made by correcting all shifts for their dependence on $p_\alpha$ and then averaging. Table I displays the average shifts, corrected to

Table I. Experimental and theoretical momentum shifts ($\Delta p_\alpha$ in Mev/$c$) (Corrected to $p_\alpha$ = 100 Mev/$c$ and averaged).

| | Axial vector | | Tensor | |
|---|---|---|---|---|
| $W_\beta$ | Exp. | Theory | Exp. | Theory |
| $W_\beta \gtrsim$ 6.1 Mev | 3.55 ± 0.16 | 3.41 | 3.63 ± 0.17 | 5.18 |
| 2.5 Mev $\lesssim W_\beta \lesssim$ 6.1 Mev | 1.50 ± 0.08 | 1.51 | 1.60 ± 0.10 | 4.23 |
| $W_\beta \gtrsim$ 2.5 Mev | 2.61 ± 0.17 | 2.40 | 2.71 ± 0.17 | 4.67 |

$p_\alpha = 100$ Mev/c ($E_\alpha = 1.33$ Mev). The quoted errors are standard deviations of the mean values. It will be noted that the corrected experimental shifts differ only slightly for the two theoretical predictions.

The results show that the $Li^8$ beta decay proceeds by the axial vector interaction with an upper limit on the tensor interaction of approximately 10%. These results incidentally set a similar upper limit on the vector interaction but cannot exclude a large contribution from the scalar interaction. However, the preceding Letter sets an upper limit of 10% on this latter interaction. The two combined results establish the $Li^8$ decay as at least 90% Gamow-Teller and the Gamow-Teller portion as at least 90% axial vector.

Morita[3] has shown that the coefficient of the second term on the right-hand side of Eq. (2) is $-\frac{1}{3}$ for $J^\pi(Li^8) = 1^+$ and $+\frac{4}{7}$ for $J^\pi(Li^8) = 3^+$, so that the magnitude of the observed shifts exclude these possibilities as do the results of the preceding Letter. The conclusions of this and the preceding Letter are in accord with results reported on $Li^8$ by Lauterjung et al.[4] and on the nature of the Gamow-Teller interaction in $He^6$ as recently revised by Herrmannsfeldt et al.[5]

It is a pleasure to acknowledge our indebtedness to R. F. Christy, R. P. Feynman, M. Gell-Mann, and B. Stech for many helpful discussions.

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[1] Lauritsen, Barnes, Fowler, and Lauritsen, Phys. Rev. Lett. 1, 326 (1958).

[2] R. P. Feynman and B. Stech (private communication).

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# CIRCULAR POLARIZATION OF EXTERNAL BREMSSTRAHLUNG PRODUCED BY BETA RAYS

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Beta particles longitudinally polarized on account of parity violation give rise to a circularly polarized external bremsstrahlung. This was shown by Goldhaber et al.[1] observing the transmission of the photons through magnetized iron. However, this method works only for photon energies above 600 kev. For smaller energies the polarization was measured by Galster and Schopper[2] using the forward scattering from magnetized iron. These results are in qualitative agreement with calculations[3, 4] but a quantitative comparison has not yet been performed. The computations were done for monoenergetic electrons falling on a thin absorber whereas in all experiments the whole beta spectrum and thick absorbers were used. It will be shown here that even in this case a comparison with theory is possible as the diffusion of the electrons in the absorber has practically no influence on the polarization.

Cohen et al.[5] reported in one case a strong dependence of the circular polarization on the atomic number $Z$ of the absorber. As this effect is rather unexpected we investigated it more carefully. The experimental setup was the same as that used in a former experiment.[2] The bremsstrahlung was produced by beta particles of $Sr^{90}+Y^{90}$ in absorbers of different $Z$ and the photons were scattered from magnetized iron. The relative change in counting rate $\epsilon$ on reversing the magnetization was measured for different photon energies. The results are represented in Fig. 1. There is no indication of $Z$ dependence

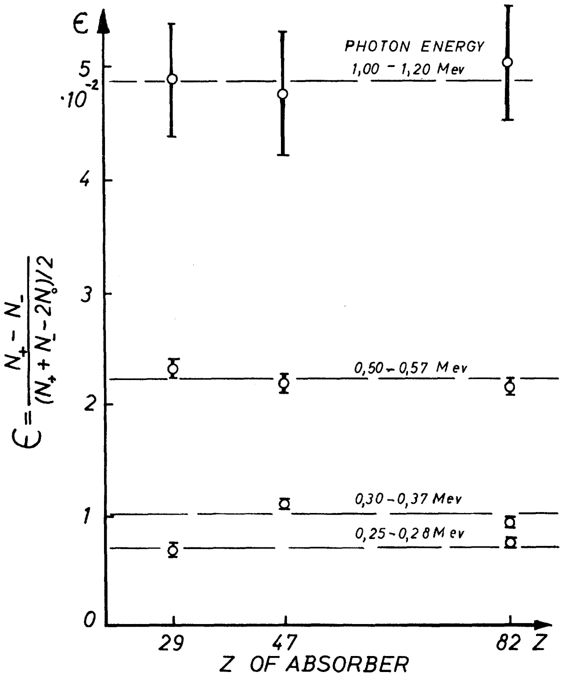

FIG. 1. The relative change in counting rate $\epsilon$ on reversal of magnetization as a function of the atomic number $Z$ of absorber. Source: $Sr^{90} + Y^{90}$.