phase angle $\theta$, we shall assume that $C_A = x\, C_V e^{i\theta}$, and $C_A' = C_A$, $C_V' = C_V$, with $x$ and $C_V$ real. The relations between primed and unprimed constants correspond to right-handed antineutrinos; the absence of phase differences between primed and unprimed members of either pair is strongly suggested by the high polarization of beta particles. Taking $x = +1.19 \pm 0.04$,[7] which is consistent with our most recent value ($\mathcal{A} = -0.11 \pm 0.02$) for the correlation between electron momentum and neutron spin, we conclude that $\theta$ does not differ from $\pi$ by more than $\pm 8°$. It is to be noted that the combination of our values of $\mathcal{A}$ and $\mathcal{B}$ already implies this difference is not more than 45°.

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†Now at Atomics International, Los Angeles, California.

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## ANGULAR CORRELATION OF ALPHA PARTICLES FROM DECAY OF $Li^{8}$*

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The determination of the electron-antineutrino correlation in an allowed transition has for many years constituted a basic experimental approach to the solution of the problem of the nature of the beta-decay interaction. In the case where only the directions of the electron and antineutrino are observed, the correlation is given by

$$W(\theta_{\beta\bar{\nu}}) = 1 + \alpha (v/c) \cos\theta_{\beta\bar{\nu}} ,$$

where $\alpha$ has the values 1, 1/3, -1/3, -1 for vector, tensor, axial vector, and scalar interactions, respectively. As a practical matter, the direction of the antineutrino emission is ordinarily deduced from coincident measurements of the vector momenta of the electron and the recoil nucleus. Even so, the experiment involves great difficulties because of the extremely low energy of the heavy recoil particle. Some years ago[1] it was pointed out that the decay of $Li^8$ provides a particularly attractive object of study in this regard, both because the decay energy is relatively high and because the kinematics of the alpha-particle decay of the daughter nucleus, $Be^{8*}$, permits extraction of the necessary information from observations on the relatively high-energy, easily detectable alpha particles.

Radioactive $Li^8$, which has a half-life of 0.84 sec, decays to the 2.9-Mev, $J^\pi = 2^+$, excited state of $Be^8$, which immediately breaks up into two alpha particles. The half-width of the $Be^{8*}$ is about 1 Mev. In the $Be^{8*}$ frame of reference the two alpha particles emerge with equal energies, and in opposite directions. In the laboratory frame, the effect of the recoil is seen as a deviation in angle between the alpha particle paths or as a difference in their energies, depending upon the direction of recoil. With a total beta transition energy of 13.6 Mev, the maximum deviation in angle is about 7 degrees and the maximum energy difference is about 20%. It is clear that determination of the vector momenta of the electron and the two alpha particles uniquely determines the vector momentum of the antineutrino, and with a sufficient number of cases, permits the desired distinction between the $V$, $T$, $A$, or $S$ interactions.[1,2] On the other hand, the much simpler experiment in which only the distribution in angle between the alpha particles is observed also permits certain distinctions, though of a more restricted character. In effect, such a distribution is a direct measure of the distribution of recoil momenta perpendicular to the line of emission of the alpha particles. Qualitatively, it may be seen that if the electron and the antineutrino are emitted mainly parallel to one another (vector interaction), the mean square perpendicular recoil momentum will be large, while if they are most often antiparallel (scalar case), the recoil momentum will be small. The $T$ and $A$ interactions would be expected to

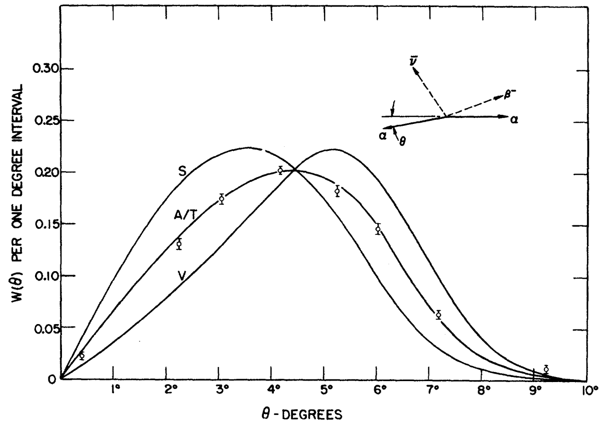


FIG. 1. The experimental points are the results of measurements on the distribution in $\theta$, the angular deviation from 180°, in the laboratory frame of reference, between the directions of emission of the two alpha particles from the reactions $Li^8$ $(\beta^-, \bar{\nu})$ $Be^{8*}$ $(\alpha)He^4$. The theoretical curves, corrected for finite experimental resolution, correspond to vector ($V$), tensor ($T$), axial vector ($A$), and scalar ($S$) interactions for beta decay assuming spin and parity $2^+$ for both $Li^8$ and $Be^{8*}$. The theoretical curves for $T$ and $A$ are identical.

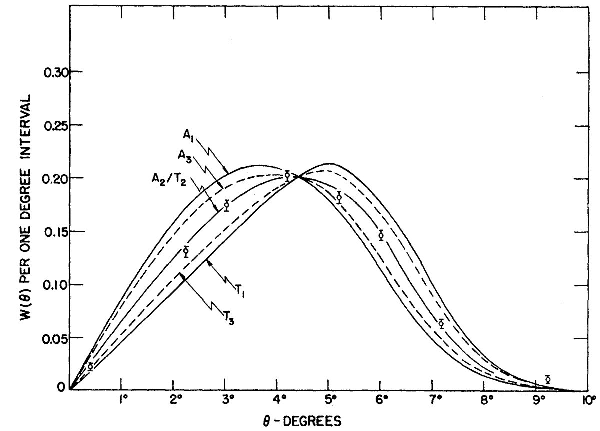


FIG. 2. The experimental points are the same as in Fig. 1. The theoretical curves apply to the following cases: $A_1$, $A_2$, $A_3$, axial vector interaction, $T_1$, $T_2$, $T_3$, tensor interaction both with $J^\pi(Li^8)=1^+$, $2^+$, and $3^+$, respectively.

produce intermediate cases. The actual theoretical distributions,[3] suitably modified for the conditions of the present experiment, are shown in Figs. 1 and 2, for various assumed values of the spin and parity of $Li^8$. Unfortunately, for the most probable assignment, $J^\pi=2^+$ for $Li^8$, the distributions for $T$ and $A$ are identical, so no distinction between these cases is possible in this experiment. On the other hand, any significant contribution of $S$ or $V$ interaction should be readily detectable. Early cloud chamber measurements[1] on the mean square perpendicular recoil momentum indicated a value twice that expected from the electron momentum alone. This result was consistent with an antineutrino momentum equal in average magnitude to that of the electron and with no correlation in the perpendicular components of the antineutrino and electron momenta. This is just what is now to be expected for both the $T$ and $A$ interactions. However, the detailed distributions were inconclusive because of the small number of alpha pairs photographed.

In the present experiment, the distribution in angle between the alpha particles was determined by counting techniques in order to obtain better statistics. The physical arrangement consisted of a $Li^8$ source, produced by deuteron bombardment of $Li^7$, placed midway between two aperture systems. The first was a pinhole collimator, 1.25 mm in diameter, subtending about 0.5 degrees at the source. For the other, a series of interchangeable annular apertures was provided, each subtending a hollow cone coaxial with the source and the pinhole. The cones so defined had radial widths of 0.5 degrees and mean opening angles ranging from 0.5 to 9 degrees. Coincidences between alpha particles passing through the two slit systems were recorded by means of two thin CsI scintillators, photomultipliers, and appropriate electronics. A crude magnetic analysis of the alpha particles passing through the pinhole collimator made it possible to reject all pairs of alpha particles except those whose energy corresponded approximately to the center of the 2.9-Mev state of $Be^8$. In all, some 6000 coincidences were recorded at eight different angles.

The results are shown by the open circles in Figs. 1 and 2, where the ordinates represent the number of coincidences observed per single alpha particle passing through the collimator and magnetic analyzer system, normalized to an angular interval of one degree. In comparing the observed coincidence distribution with the theoretical distributions, corrections were made for the finite angular resolution, for scattering in the source, and for the change in energy distribution due to energy loss in the source. These corrections have been folded into the theoretical curves of Figs. 1 and 2. The normalization of both the experimental points and the curves is absolute and independent. The agreement between the experimental points and the curve marked $A/T$ in Fig. 1 leaves little doubt that, if $J^\pi(Li^8)=2^+$, the beta-decay interaction in this case is either $A$ or $T$ or a mixture of $A$ and $T$. It would appear 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 $Li^8$ cannot be $1^+$ or $3^+$, except in the unlikely contingency that $A$ and $T$ interactions contribute equally. We conclude that $Li^8$ 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 $Li^8$ beta-decay interaction as indicated by Barnes et al.[4]

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## NATURE OF THE $Li^8$ BETA-DECAY INTERACTION *

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It has been established in the preceding Letter[1] that the spin and parity of $Li^8$ are $2^+$, and that the beta decay to the $2^+$ excited state of $Be^8$ 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 $Li^8$ is produced by bombarding a thin layer of $Li^7$ 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 $Li^8$ 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 $He^+/He^{++}$ 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 $Be^{8*}$ slightly broadened symmetrically, for all interactions, by the antineutrino momentum. Also to first order, the momentum of an alpha particle in the antiparallel configur-

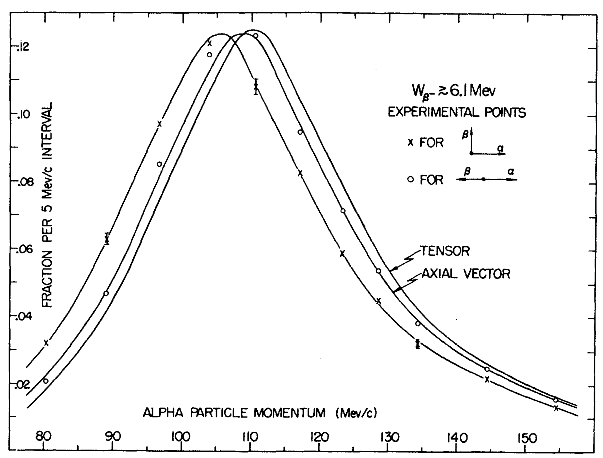


FIG. 1. Alpha-particle momentum spectra obtained in $\beta\alpha$-coincidence measurements on the decay of $Li^8$ . The crosses are experimental points for electrons with $W_\beta \gtrsim 6.1$ Mev perpendicular to the observed alpha particle; the open circles are for electrons with $W \gtrsim 6.1$ Mev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