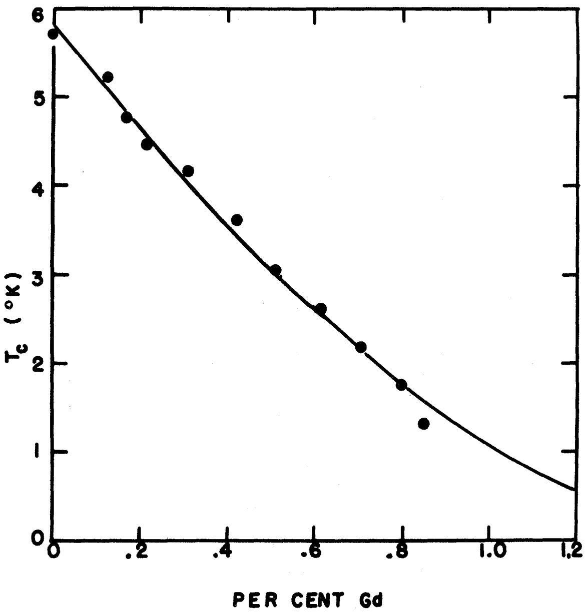

FIG. 3. Superconducting transition temperatures of La-Gd alloys. The points are the data of Matthias, Suhl, and Corenzwit and the solid curve is theoretical.

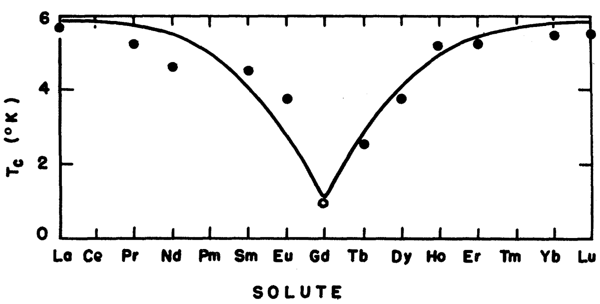

FIG. 4. Superconducting transition temperatures of alloys of La and 1% solute indicated. The points are the data of Matthias, Suhl, and Corenzwit and the solid curve is theoretical. The point for Gd is taken from the curve of Fig. 3.

ed in a manner suggested by Pippard[13] for impurity scattering of electrons.

In his model $|M_K|^2$ depends on κl in the same manner as the phonon mean free path (κ is the longitudinal wave number and l is the electronic mean free path). A decrease in l results in a decrease in $|M_K|^2$ and hence in T_c.

The ferromagnetic impurity effect has also been treated recently by Herring[14] and by Matthias and Suhl.[15]

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[1] C. Zener, Phys. Rev. 81, 440 (1951).
[2] N. F. Mott and K. W. H. Stevens, Phil. Mag. 2, 1364 (1957).
[3] P. G. DeGennes and J. Friedel, J. Phys. Chem. Solids 4, 71 (1958).
[4] Tadao Kasuya, Progr. Theoret. Phys. Japan 16, 58 (1956).
[5] Legvold, Spedding, Barson, and Elliott, Revs. Modern Phys. 25, 129 (1953).
[6] R. V. Colvin, M. S. thesis, Iowa State College, 1958 (unpublished).
[7] M. Curry, M. S. thesis, Iowa State College, 1958 (unpublished).
[8] See also B. R. Coles, Suppl. Phil. Mag. 7, 40 (1958) for such a separation for the rare earths.
[9] M. Louis Néel, Z. Elektrochem. 45, 378 (1939).
[10] Matthias, Suhl, and Corenzwit, Phys. Rev. Lett. 1, 92 (1958).
[11] Bardeen, Cooper, and Schrieffer, Phys. Rev. 108, 1175 (1957).
[12] Anderson, Legvold, and Spedding, Phys. Rev. 109, 243 (1958).
[13] A. B. Pippard, J. Phys. Chem. Solids 3, 175 (1957).
[14] C. Herring, paper presented at the K. Onnes Conference at Leiden in June, 1958 (unpublished). See also Matthias, Suhl, and Corenzwit, Phys. Rev. Lett. 1, 152(E) (1958).
[15] B. T. Matthias and H. Suhl, paper at the International Conference on Electronic Properties of Metals at Low Temperatures, Geneva, New York, August, 1958 (unpublished).

TEST OF TIME-REVERSAL INVARIANCE OF THE BETA INTERACTION IN THE DECAY OF FREE POLARIZED NEUTRONS*

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Jackson, Treiman, and Wyld[1] have pointed out that the electron momentum, $\vec{p}_e$, the antineutrino momentum, $\vec{p}_{\bar{\nu}}$, and the polarization of the nucleus, $\langle\vec{J}\rangle/J$, may exhibit, in the decay of oriented nuclei, a correlation of the form

$$1 + \mathfrak{D}(\langle\vec{J}\rangle/J)\cdot(\vec{p}_e/E_e)\times(\vec{p}_{\bar{\nu}}/E_{\bar{\nu}})$$

if, and only if, the interaction responsible for beta decay is not invariant under time reversal.

Other three-vector-correlation experiments that would test time-reversal invariance have been suggested[1-3] and in part already carried out.[4] However, a search for the correlation mentioned above in the decay of free polarized neutrons appears to be of considerable interest since this process affords a particularly sensitive test, and its interpretation requires no knowledge of nuclear matrix elements and virtually no Coulomb corrections. One has simply

$$\mathfrak{D} = -\frac{2\,\mathrm{Im}(C_V C_A^* + C_V' C_A'^*)}{|C_V|^2 + |C_V'|^2 + 3(|C_A|^2 + |C_A'|^2)}, \quad (1)$$

assuming, as is consistent with recent experiments,[5] that no couplings of S and T type occur in beta decay.

In continuation of our work on the decay of polarized neutrons,[6] we have carried out an experiment to set an upper limit for $\mathfrak{D}$ in this process. This experiment was performed by making a slight modification in the apparatus used to measure the correlation[5] between the spin of the neutron and the direction of emission of the antineutrino. Its principle will be explained with reference to Figs. 1 (a) and 1 (b). Figure 1 (a) represents the "normal", Fig. 1 (b) the "time-reversed" situation. Consider the plane of the figure as the x-y plane, and a neutron polarized along the $+z$ axis decaying, at the point indicated by x, with $\vec{p}_e$ along $+x$ and $\vec{p}_{\bar{\nu}}$ along $+y$. Assuming these momenta to have about equal magnitudes, the slit system indicated in Fig. 1 (a) will transmit the recoil proton ($\vec{p}_p$) to the proton detector, thus enabling it to make a coincidence with the electron. In the "time-reversed" situation, $\vec{p}_e$ and $\vec{p}_{\bar{\nu}}$ will appear reversed, and the neutron spin $\vec{J}$ will point along $-z$, so that the slits and the two detectors will have to assume the positions indicated in Fig.

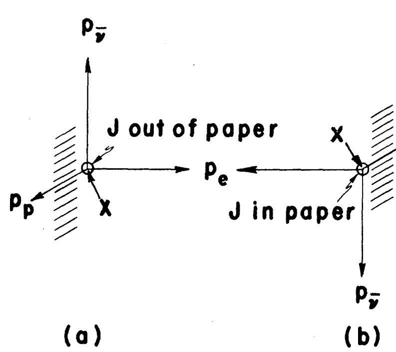

FIG. 1. Schematic drawing of arrangement for "time-reversed" measurements.

Table I. Results of measurements on W, the correlation between antineutrino momentum, $\vec{p}_{\bar{\nu}}$, electron momentum, $\vec{p}_e$, and neutron spin, $\langle \vec{J} \rangle$,

$$W = 1 + \mathfrak{D}\frac{\langle \vec{J} \rangle}{J} \cdot \frac{\vec{p}_e}{E_e} \times \frac{\vec{p}_{\bar{\nu}}}{E_{\bar{\nu}}}.$$

Beta energy	150 - 650 Mev
Observed asymmetry	-0.015 ±0.017
Correction factor for angular spread of antineutrinos	2.2
Polarization of neutrons $\langle \vec{J} \rangle / J$	0.87
Mean p_e/E_e	0.8
$\mathfrak{D}$	-0.04 ±0.07

1 (b) to give a coincidence. The coincidence rates per neutron should be the same with both arrangements if the process is invariant under time reversal. In practice, it will suffice to compare coincidence rates for neutrons polarized in the $+z$ and $-z$ directions, since the two arrangements indicated can be made to coincide by a rotation around the z axis, an operation which is still assumed to leave physical laws invariant.

To perform the actual experiment, the slit system shown in Fig. 1 of reference 5 was rotated by 90° along a line normal to the face of the beta counter indicated in that figure, so that recoils associated with antineutrinos emitted perpendicularly to the neutron spin were preferentially collimated onto the proton counter. All other features and the operating conditions were essentially unchanged with respect to those described. In consequence of a recent re-activation of the proton detector, the ratio of coincidences to background (at about 0.3 coincidences/min) had the rather favorable value of 3/1. The results of the measurements are indicated in Table I, where the errors given in the first line are purely statistical. The error in $\mathfrak{D}$ includes an uncertainty of ± 0.03 because of possible misalignment of the neutron spin which brings in a contribution from the correlation between the antineutrino momentum and the neutron spin. The preliminary result of a similar experiment[8] is in agreement with our result.

Expression (1) could yield a nonzero result if there was a phase difference, other than 0 or π, between any of the four constants. To express the experimental result in terms of a single phase angle θ, 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 θ does not differ from π 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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[1]Jackson, Treiman, and Wyld, Phys. Rev. 106, 517 (1957).

[2]R. B. Curtis and R. R. Lewis, Phys. Rev. 107, 1381 (1957).

[3]M. Morita and R. Saito Morita, Phys. Rev. 107, 1316 (1957).

[4]Ambler, Hayward, Hoppes, and Hudson, Phys. Rev. 110, 787 (1958).

[5]Burgy, Krohn, Novey, Ringo, and Telegdi, Phys. Rev. 110, 1214 (1958).

[6]See also T. B. Novey, Proceedings of the International Congress on Nuclear Physics, Paris, July, 1958 (unpublished).

[7]Sosnowski, Spivak, et al., Rochester Conference on High-Energy Physics, CERN, July, 1958 (unpublished).

[8]Clark, Robson, and Nathans, Phys. Rev. Lett. 1, 100 (1958).

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 α 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