This case is of particular interest since, as was noted by Lewis[6] and Fujita et al,[7] the Yamada hypothesis permits limits to be set on the violation of time-reversal invariance.

The additional term arising from the assumption that the $\beta$ decay coupling constants are complex affects the correction factor and narrows down the range of possible fits to the experimental spectrum shape.

We have measured the longitudinal polarization of electrons of average energy $\overline{E} = 125$ and 350 kev using the apparatus and technique previously described.[1]

The source of Ra(D + E) of 5 millicurie intensity was approximately 0.8 mg/cm$^2$ thick. We obtained $-\langle\sigma\rangle\, c/v = 0.733 \pm 0.06$ and $0.725 \pm 0.06$ (average: $0.73 \pm 0.04$) for $\overline{E} = 125$ and 390 kev respectively.

Geshkenbein, Nemirovskaia, and Rudik,[8] drawing on the above mentioned papers, calculated the longitudinal polarization for RaE electrons for the VA and ST covariants allowing for parity nonconservation, and assuming time reversal invariance either to be valid or to be violated.

In the case of the VA covariants, the two parameters entering into the correction factor are

$$x = (iC_V/C_A)\int \mathbf{r} \Big/ \int [\sigma\times\mathbf{r}], \qquad y = (C_V/C_A)\int \alpha \Big/ \int [\sigma\times\mathbf{r}].$$

Under the assumption of time reversal invariance ($F^2 = 0$) the parameter x is limited by the spectrum shape to lie in the range $2 > x > 0.2$, and the theoretically-possible values for $-\langle\sigma\rangle\, c/v$ at $E = 250$ kev lie between 0.67 and 0.835. The experimental value $0.73 \pm 0.04$ lies within these narrow limits which serves as confirmation of Yamada's hypothesis and limits x to the range $2 > x > 1$, i.e., reduces the uncertainty in x by a factor of 5. The magnitude of the polarization is very sensitive to time reversal invariance violation. Taking the same range of values $2 > x > 1$ and $F^2 = 6 \times 10^{-3}$, $F < 0$ (where F is the imaginary part of $C_A$) we have: $0.63 > -\langle\sigma\rangle\, c/v > 0.57$ and for $F > 0$: $0.85 > -\langle\sigma\rangle\, c/v > 0.79$. Both cases are in disagreement with experiment.

However, it is possible to fit the experiment with $F^2 = 6 \times 10^{-3}$, $F < 0$ provided $0.2 < x < 0.5$; the polarization then lies in the range $0.71 > -\langle\sigma\rangle\, c/v > 0.67$ and $x = 0.2$ is the minimum value of the parameter x that will yield a fit for the spectrum. From this the maximum possible value of F and, consequently, of time reversal invariance violation turns out to be less than 7.5% which coresponds to an angle $\Delta\theta$ between A and V of $\sim 4.5°$. At this time this appears to be the most precise determination of time reversal invariance.

A greater precision would be possible if an independent determination (e.g., by use of shell model calculations) were made of at least the order of magnitude of the parameter x or if the energy dependence in the range from 100 to 700 kev of the longitudinal polarization of RaE electrons were measured.


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## *A NOTE ON d-d REACTIONS*


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RECENTLY D. I. Blokhintsev[1] made the suggestion that the formation of "sub-barrier" fragments in the disintegration of nuclei by high energy nucleons can be explained by assuming that during the motion of the nucleons in the nucleus a close agglomeration of nucleons can result from fluctuations. As a result of a direct collision of the incident particle with such a cluster, "sub-barrier" fragments are produced. The results were compared with experiments on the scattering of 675-Mev protons by light nuclei.

A test of these ideas can be made with a variety of nuclear reactions, including the d + d reactions at these same energies. These reactions can proceed via the following channels:

$$d + d\ (1),\quad d + n + p\ (2),\quad 2n + 2p\ (3),$$
$$He^3 + n\ (4),\quad H^3 + p\ (5),\quad He^4 + \gamma\ (6). \qquad (1)$$

If we denote the total cross section for the d + d reaction by $\sigma_t$, and the probability that it proceeds via the i-th channel by $W_i$, the cross sections for the reactions enumerated above can be written as $\sigma_i = \sigma_t W_i$, where $\sigma_i$ is the cross section for the i-th reaction, and each $W_i$ can be expressed as

$$W_1 = W_d^2,\quad W_2 = 2W_d(1 - W_d),\quad W_3 = (1 - W_d)^2,$$
$$W_4 = W_{He^3},\quad W_5 = W_{H^3},\quad W_6 = W_{He^4}.$$

Here $W_d$ is the probability for finding the two nucleons in the deuteron so close to one another that the impinging high energy particle cannot break up the deuteron and transfers its energy to the system as a whole;[1] $W_{He^3}$ is the probability that in the "intermediate" state of the reaction a tightly bound system of two protons and a neutron is formed (this probability is different from that considered in Blokhintsev's paper); the probabilities $W_{H^3}$ and $W_{He^4}$ are defined similarly.

If we use the numerical value $W_d \approx 7 \times 10^{-3}$, we find for the ratio of the first three reactions: $\sigma_1/\sigma_3 \approx 5 \times 10^{-5}$, $\sigma_2/\sigma_3 \approx 1.4 \times 10^{-2}$.

Concerning the other reactions one can only assert that the ratio $\sigma_4/\sigma_5$ will be close to unity, its value being dependent on the extent to which the nuclear forces are charge independent at high energies, as is indicated by the experimental data.[2] Apparently at these energies the reactions are due mainly to indirect processes. The determination of their cross sections would enable one to estimate the role of indirect interactions in these processes.

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