β-γ *CORRELATION IN* β *DECAYS OF* Mn^{56} *AND* F^{20}

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Submitted to JETP editor August 8, 1961; resubmitted February 5, 1962

J. Exptl. Theoret. Phys. (U.S.S.R.) 42, 370-374 (February, 1962)

The anisotropy coefficient $A_2 = +0.022 \pm 0.003$ is obtained in the β-γ angular correlation for the allowed $Mn^{56} \rightarrow Fe^{56}$ transition. The anisotropy of the β-γ angular correlation is compared with that for circularly polarized γ quanta. It is shown that existing theoretical estimates of the second-forbidden matrix elements can account for the observed anomalies. Measurement of the β-γ polarization correlation in F^{20} β decay indicates a spin and parity assignment 2^+ to the F^{20} ground state, the ratio of the transition matrix elements being $|M_F|/|M_{GT}| < 0.2$.

GELL-MANN[1] has shown that the hypothesis of vector current conservation in β decay has a number of experimentally verifiable consequences. Among these is the appearance in allowed β transitions of a special second-forbidden matrix element called "weak magnetism" by analogy with electrodynamics. In some cases the magnitude of this matrix element can be calculated and compared with experiment.

The measurement of β-γ angular correlation anisotropy in allowed transitions is one method of determining the contribution of second-forbidden matrix elements. The especially important cases are those in which the principal β^- transition matrix element corresponds to a high inhibition for some reason. The relative contribution of higher-order terms can then be expected to increase and be measurable with considerable accuracy.

Some cases are now known in which the foregoing hypothesis appears to be justified. One of these is the considerable β-γ anisotropy observed in the β^+ decays of Na^{22}[2,3] and Co^{56}.[4] Both transitions are highly retarded; the reason remains unclear. It should be noted that the observed anisotropy is considerably greater than the theoretical results obtained by Gell-Mann[1] and Morita.[5]

The investigation of analogous effects in other β transitions, especially β^- transitions, is obviously of interest as a means of facilitating the interpretation of the observations. We have therefore measured the β-γ angular correlation in the β decay of Mn^{56}.

The $Mn^{56} \rightarrow Fe^{56}$ decay scheme has been thoroughly studied and energy-level spins and parities have been established very reliably.[6] We investigated the β transition with 2.86-MeV endpoint going to the first excited level of Fe^{56}, from which the ground state is reached by the emission of an 845-keV γ ray. The sequence of spins and parities is

$$3^+ \xrightarrow{\beta} 2^+ \xrightarrow{\gamma} 0^+.$$

Log ft = 7.2 for this transition; thus the principal matrix element is that of a highly inhibited transition, probably as a result of l-forbiddenness.[7]

The angular correlation was measured with apparatus similar to that described in [2,8], except that a vacuum chamber was not used because of the high β-electron energy ($E_\beta > 1$ MeV). A source was prepared by using a neutron flux of $\sim 10^{13}$/cm^2-sec to irradiate a lyer of MnF_2 (containing Mn^{55}) deposited on an aluminum backing (1 mg/cm^2). The surface density of the source was ~ 8 mg/cm^2.

A stilbene crystal and FÉU-36 photomultiplier were used to detect β electrons, while γ rays were registered with a 70 $\times$ 70 mm NaI(Tl) crystal and FÉU-13 photomultiplier. Armco and Permalloy shields protected the photomultipliers from stray magnetic fields. The effect of scattered γ quanta was reduced by surrounding the NaI(Tl) crystal with a lead shield and collimator 60 mm long. The photomultipliers were connected to a fast-slow coincidence circuit with resolving time $\tau = 6 \times 10^{-9}$ sec. The random coincidence background was 3 — 6%.

The Mn^{56} β spectrum is known to consist of three components with the endpoints 2.86, 1.05, and 0.7 MeV. In order to avoid the registration of the 1.05-MeV component the β discriminator was set to accept electrons with energies above

1.1 MeV. The γ discriminator was set for the interval 600 — 900 keV, including only the 845-keV photopeak.

The given discrimination levels completely excluded the possibility of spurious asymmetry associated with registration by the β detector of γ quanta back-scattered by the NaI (Tl) crystal, since the energy of such back-scattered γ quanta could not exceed 250 keV. A Plexiglas shield in front of the γ detector also prevented the registration of energetic β particles scattered from the crystal into the β detector.

The position of the γ counter was changed every 3.5 minutes. Corrections for decay were introduced on the basis of $T_{1/2} = 2.576$ hours. The coincidence-counting rate, corrected for decay, was divided by the product of the single counting rates of β and γ pulses also corrected for decay. These corrections for noncentrality of the source amounted to $\sim 0.5\%$.

The observed angular anisotropy is given by

$$W(\theta) = 1 + A_2 \cos^2\theta, \qquad (1)$$

where θ is the angle between the emitted β electron and γ quantum. The value of the coefficient A_2 was obtained by least squares:

$$A_2 = +(0.022 \pm 0.003).$$

No corrections were made for inner bremsstrahlung or for multiple scattering. The final result was corrected for asymmetry due to γ-γ coincidences ($\sim 0.2\%$). Thus the β transition $3^+ \to 2^+$ in Mn^{56} reveals appreciable anisotropy of the β-γ angular correlation.

We also measured the correlation between the direction of the β electron and the circular polarization of the γ quantum for the same branch of Mn^{56} decay. The apparatus has been described elsewhere.[9] The results of the measurements were computed and analyzed similarly.

The coincidence circuit accepted β electrons in the energy range from 1 to 2.5 MeV (with v/c varying from 0.94 to 0.98). The correlation for the Gamow-Teller transition is calculated uniquely and equals $-v/3c$ for the given sequence of energy-level spins. The measurements yielded the correlation coefficient $-(0.80 \pm 0.06)\,v/3c$.

It is interesting to compare the β-γ angular and polarization correlations, assuming that anisotropy of the angular correlation results from second-forbidden matrix elements.[5] From Morita's[5] Eqs. (27) and (28), neglecting terms $\sim 1/W$, we obtain for the β-γ angular correlation

$$W(\theta) = 1 + \frac{1}{7}\frac{p^2}{W} K \cos^2\theta \qquad (2)$$

and for the β-γ polarization correlation

$$W(\theta, \tau) = 1 - \frac{\tau}{3}\frac{v}{c}\,[1 - KW]\cos\theta. \qquad (3)$$

Here θ is the angle between the electron and the γ quantum; p and W are the electron momentum and energy, respectively; $\tau = \pm 1$ represents right- and left-hand circular polarization of the γ quantum, respectively.

In the notation of [5] we have

$$K = \frac{1}{3}\left[\pm\lambda \frac{M[\bar{\alpha}\bar{r}]}{M(\bar{\sigma})} + 2\frac{iM(\gamma_5\bar{r})}{M(\bar{\sigma})}\right] + \lambda\frac{M(A_{ij})}{M(\bar{\sigma})},$$

$$\lambda = \frac{C_V}{C_A}. \qquad (4)^*$$

Putting $A_2 = \pm 0.022 = Kp^2/7W$ in (1), we obtain K = + 0.04; for the β-γ polarization correlation we thus have

$$W(\theta) = 1 - \frac{\tau}{3}\frac{p}{W}(1 - 0.04W)\cos\theta. \qquad (5)$$

For energies from 1 to 2 MeV the term in parentheses is 0.82, which is in general agreement with our measurements.

The anisotropy of the angular correlation and the anomalous value of the polarization correlation can therefore be accounted for by a contribution from second-forbidden relativistic matrix elements. The large value of this contribution is evidently associated with the fact that the factors causing suppression of the principal transition matrix element do not affect second-forbidden matrix elements.

It is known that the measurement of the correlation between β particles and the circular polarization of subsequently emitted γ rays can be used to determine the contribution of the Fermi matrix element in j-j transitions. The hypothesis that the vector current is conserved requires fulfillment of the isotopic spin selection rules for the Fermi matrix element, i.e., $M_F \approx 0$ when $\Delta T \neq 0$.

It has been shown experimentally[10,11] that in addition to the facts confirming the fulfillment of these selection rules there are cases where the Fermi matrix element in j-j transitions is very large despite a change of isotopic spin (Sc^{46} and Ar^{41}, for example). It is therefore of interest to evaluate the Fermi matrix element in j-j transitions for the β decay of light nuclei, where the isotopic spin selection should be fulfilled very accurately.

We have measured the β-γ polarization correlation in F^{20} β decay. It should be noted that extremely conflicting data exist regarding the spin of the F^{20} ground state.

* $[\alpha r] = \alpha \times r$

Spins and parities of levels in β transition	Correlation coefficient	
	Theory	Experiment
$2^+ \to 2^+$	$+\frac{1}{6}\frac{\lambda\sqrt{6}+1}{1+\lambda^2}$	0.14±0.07
$3^+ \to 2^+$	$-1/3$	
$1^+ \to 2^+$	$+1/2$	

Investigations of the β spectrum in [12,13] have shown that a β transition to the first excited Ne^{20} level is allowed, in agreement with the measured value log ft = 5.0. Since the first excited Ne^{20} level has spin and parity 2^+, we can assign spins and parities 1^+, 2^+, and 3^+ with equal probability to the F^{20} ground state.

In an investigation of the angular distribution of protons from the reaction $F^{19}(d, p)F^{20}$ Bromley et al[14] found that this is mainly a stripping reaction and that spin and parity 1^+ should be assigned to the ground state. This conflicts with other investigations in which it was found that the β transition to the ground level is highly forbidden. It appears from the results in [15] that stripping makes only a small contribution and that the result 1^+ obtained in [14] is not required.

We have shown in earlier work[9] that a measurement of the β-γ polarization correlation can be used to determine the spins of levels involved in β transitions. Our apparatus was also described in [9].

Since the half-life of F^{20} is 10.7 sec, we used a continuous supply of a gaseous fluorine compound that had been irradiated in a reactor. A stream of hydrogen passed continuously through a vessel containing a liquid fluorocarbon subjected to a flux of $\sim 10^{13}$ neutrons/cm^2-sec. Free fluorine recoil atoms from the reaction $F^{19}(n, \gamma)F^{20}$ combined with the hydrogen to form HF. This hydrogen fluoride was entrained by the hydrogen stream and passed through polyethylene tubes to the correlation-measuring apparatus, where it was deposited on a copper foil cooled by dry ice. In this way we obtained a F^{20} source of $\sim 30\ \mu$Cu activity. The γ spectrum of the source showed the absence of other activities to within $\sim (2-3)\%$. The correlation was measured in the β-electron energy interval 1 — 4 MeV.

The theoretical and experimental correlation coefficients for different spins of the β-active nucleus are given in the table. The experimental value is satisfied only by 2^+. We thus have

$$\lambda = \frac{C_V}{C_A}\frac{M_F}{M_{GT}} = -0.12\,^{+0.21}_{-0.10},$$

where C_V and C_A are the vector and axial-vector β-interaction constants, respectively; M_F and M_{GT} are the Fermi and Gamow-Teller nuclear matrix elements.

The isotopic spin changes in the transition $F^{20} \to Ne^{20}$. The smallness of the Fermi matrix element therefore confirms the isotopic spin selection rules.

In conclusion the authors wish to thank Professor D. M. Kaminker for his continuous interest, and V. V. Andryukevich, G. D. Chuklin, and V. B. Belyakov for assistance in the preparation of the apparatus and measurements. Thanks are also due to N. V. Timofeev and V. I. L'vova for providing the specimens of fluorocarbon compounds.

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Translated by I. Emin
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