BETA-GAMMA ANGULAR CORRELATION IN Ba^{139} *DECAY AND THE RELATIVE SIGN OF THE BETA-INTERACTION COUPLING CONSTANTS*

N. A. VLASOV and V. P. RUDAKOV

Submitted to JETP editor July 11, 1958

J. Exptl. Theoret. Phys. (U.S.S.R.) **36**, 24-27 (January, 1959)

The differential β-γ angular correlation was measured for the cascade $E_\beta = 2.23$ Mev and $E_\gamma = 0.163$ Mev in the decay of Ba^{139}. The anisotropy coefficient was found to be $a = +0.058 \pm 0.023$ for β particles with total energy $4mc^2$. This result is compared with calculations based on the independent-particle model. The theoretical result is in agreement with experiment only if the ratio g_V/g_A is negative.

THE existing data on the ratio of the Fermi and Gamow-Teller β-interaction coupling constants come from an analysis of ft values in allowed transitions.[1] Such an analysis, however, gives only the absolute value of the ratio. The relative sign of the coupling constants can be determined from the shape of the β spectrum in forbidden transitions only. Thus a calculation of ratios of matrix elements for the β transitions becomes a necessary involvement. Morita, Fujita, and Yamada[2] analyzed, in calculations based on the independent particle model, the shape of the forbidden β spectra of Fe^{59}, Rb^{87}, Te^{99}, and Cs^{137}. They have shown that it agrees only with a negative g_S/g_T ratio. This conclusion was confirmed in a later work by Fujita[3] in which the same spectra were analyzed with the strong-coupling Bohr-Mottelson model. Lee-Whiting[4] deduced the opposite result ($g_S/g_T > 0$) from a study of the shape of the β spectrum of RaE. However, Takebe, Nakamura, and Taketani[5] have shown that it is impossible to determine the sign of g_S/g_T from an analysis of the spectrum shape of RaE.

All these attempts at a determination of the relative sign of the coupling constants were based on the assumption that only the scalar and tensor covariants contribute to the β interaction. It has recently become apparent that the main covariants are the vector and axial vector.[6] Clearly the problem of the relative sign requires further study.

The relative sign may be determined from data on β-γ angular correlation. Dolginov[7] has shown that the anisotropy coefficient a in the expression for β-γ angular correlation $W(\theta) = 1 + a\cos^2\theta$ may be expressed as an explicit function of the coupling-constant ratios (g_S/g_T or g_V/g_A) and certain ratios of β-transition matrix elements. For example, for $\Delta J = 1$ first-forbidden β transitions the expression for the coefficient a contains only three ratios x, y, and z of matrix elements:[7]

$$x = \int \psi^*_{j_1\mu_1} r\,(\sigma \mathbf{Y}^0_{1\Lambda})\,\psi_{j_0\mu_0}\,d\mathbf{r} \Big/ \int \psi^*_{j_1\mu_1} r Y_{1\Lambda} \psi_{j_0\mu_0}\,d\mathbf{r};$$

$$y = -i \int \psi^*_{j_1\mu_1} (\alpha \mathbf{Y}^{-1}_{1\Lambda})\,\psi_{j_0\mu_0}\,d\mathbf{r} \Big/ \int \psi^*_{j_1\mu_1} r Y_{1\Lambda} \psi_{j_0\mu_0}\,d\mathbf{r};$$

$$z = C^{j_1\mu_1}_{1\Lambda j_0\mu_0} \int \psi^*_{j_1\mu_1} r\,(\sigma \mathbf{Y}^{-1}_{r\Lambda})\,\psi_{j_0\mu_0}\,d\mathbf{r} \Big/ C^{j_1\mu_1}_{2\Lambda j_0\mu_0} \int \psi^*_{j_1\mu_1} r Y_{1\Lambda} \psi_{j_0\mu_0}\,d\mathbf{r}.$$

To calculate x and z it is sufficient to assume that the nuclear levels involved in the β transition are described by the independent-particle model. Furthermore, only the angular momentum l of the odd nucleon in the nucleus is needed in the calculation of x and z. The computation of the third ratio y requires more detailed assumptions about the structure of the nucleus. However, as will be shown below, the uncertainties in y do not preclude the possibility of determining the relative sign of the ratio of coupling constants. Dolginov[7] listed the β decays of In^{117}, Ba^{139}, Ce^{141}, and possibly Hg^{203} and Tl^{208} as being of interest in this connection. We measured the differential β-γ angular correlation in the decay of Ba^{139}. An analysis of the results based on formulas given by Dolginov shows that the ratio g_V/g_A is negative.

The β-γ angular correlation was studied for the cascade:[8]

$$({}^7/{}_2{}^-) \xrightarrow{\beta} ({}^5/{}_2{}^+) \xrightarrow{\gamma} ({}^7/{}_2{}^+).$$

The end point energy of the β-spectrum is 2.23 Mev, the energy of the γ-rays is 0.163 Mev.

According to the shell model[9] Ba^{139} has one $f_{7/2}$ neutron outside a closed shell of 82 neutrons which β-decays into a $d_{5/2}$ proton of La^{139}. The transition from the $d_{5/2}$ level to the $g_{7/2}$ ground state of La^{139} proceeds via magnetic dipole radiation with a small admixture (4%) of electric quadrupole.[10] The structure of the Ba^{139} nucleus, namely (82 + 1) neutrons and an even (56) number of protons, raises the hope that a description of the ground state of this nucleus in terms of the independent particle model is justified. Existing data on Coulomb excitation of the 163-kev level of La^{139},[11] on the lifetime of this state,[12] on the multipole order of the γ transition,[10] and on the ft value of the β transition indicate that the 163-kev level of La^{139} also has a single-particle character.

Ba^{139} was obtained in the cyclotron from the $Ba^{138}(d,p)$ reaction and was chemically rid of the other active elements produced simultaneously. Practically no unwanted radiation was present in the purified samples. The measuring apparatus used was the standard type for this kind of experiment; a schematic diagram is given in Fig. 1. The

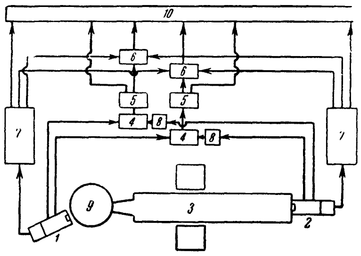

FIG. 1. Schematic diagram of experimental setup. 1,2) photomultipliers, 3) magnetic lens spectrometer, 4) fast-coincidence circuits, 5) amplifiers, 6) slow-coincidence circuits, 7) pulse-height analyzers, 8) variable-delay lines, 9) sample under study, 10) scaler circuit and electromechanical counters.

electrons were analyzed with a lens spectrometer of 5% resolution and detected by a photomultiplier with a plastic scintillator. A similar detector was used for the γ rays. The two counters were arranged in a fast-slow coincidence circuit. The resolving time of the coincidence scheme was 2.5×10^{-9} sec for 100% efficiency in the chosen range of incident pulse height. The counts of the β and γ counters and accidental coincidences were registered simultaneously with true coincidences. The measurements were performed for two positions of the γ-counter: at 180° and at 90° with respect to the direction of emission of the β particle.

The correlation measurements for Ba^{139} were performed for electrons with total energy $4mc^2$. Since the half-life of Ba^{139} is only 85 minutes, the measurements were performed in 30 series, each of 2 or 3 hours duration. The results of all series are consistent within statistical error. The anisotropy coefficient, averaged over all 30 series, is

$$a = \{N(\pi) - N(\pi/2)\}/N(\pi/2) = 0.058 \pm 0.023.$$

The indicated error is statistical. Results of control experiments with Sc^{46} and Sb^{124} indicate the absence of any systematic errors. In the case of Sc^{46} the angular distribution of the 0.89 and 1.12-Mev γ rays is isotropic with respect to the β electron ($E_\beta = 0.36$ Mev). As result of our measurement we found $a = 0.005 \pm 0.020$. In the case of Sb^{124} the differential angular correlation for the cascade $E_{\beta\,\mathrm{end}} = 2.317$ Mev, $E_\gamma = 0.603$ Mev was measured for two values of β-particle energy, $3mc^2$ and $4mc^2$. The values of a were -0.12 ± 0.03 and -0.34 ± 0.03, in agreement with previous measurements.[13]

The calculation of the anisotropy coefficient a was performed for a mixture of vector and axial vector as well as scalar and tensor covariants. It was assumed that

$$g_S = -g_S'; \ g_T = -g_T'; \ g_V = g_V'; \quad g_A = g_A',$$

where the primed constants refer to parity nonconservation. The calculation was performed for a mixture of magnetic dipole (96%) and electric quadrupole (4%) radiations.

The result of the calculation gives a as a function of the coupling-constant ratios (g_S/g_T or g_V/g_A) and the ratio y of matrix elements. For the other two ratios of matrix elements numerical values $x = 0.7$ and $z = 0.9$ were obtained.

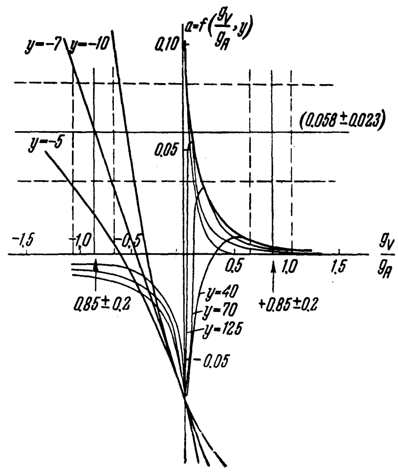

FIG. 2. Dependence of the anisotropy coefficient on the ratio of the vector and axial vector interaction coupling constants.

In Fig. 2 the dependence of the coefficient a is given as a function of g_V/g_A for various values of the parameter y. The horizontal lines give the experimentally determined limits for a and the vertical lines give the known limits on $|g_V/g_A|$.[1] Falling within the allowed region, for $g_V/g_A < 0$, is the curve for $y = -5$. For positive g_V/g_A there exists no value of y in agreement with

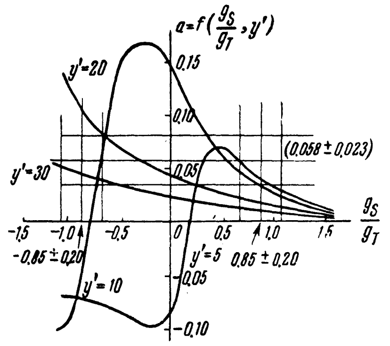

FIG. 3. Dependence of the anisotropy coefficient on the ratio of the scalar and tensor interaction coupling constants.

a = 0.058. This means that the ratio g_V/g_A is negative. It should be noted that varying x and z between 0.1 and 5 does not lead to values of a in agreement with experiment for positive g_V/g_A.

In Fig. 3 the analogous curves are given for a mixture of scalar and tensor covariants. In this case there exist curves in agreement with a positive or negative ratio g_S/g_T and no conclusions are possible.

The authors are grateful to A. Z. Dolginov for his kindness in communicating the results of his calculations and discussing the results, to S. P. Kalinin for constant interest in this work and collaboration in its completion, and also to L. A. Sliv and I. S. Shapiro for discussion of results.

[1] J. B. Gerhart, Phys. Rev. **95**, 288 (1954).

[2] Morita, Fujita, and Yamada, Progr. Theoret. Phys. (Japan) **10**, 630 (1953).

[3] J. Fujita, Progr. Theoret. Phys. (Japan) **13**, 260 (1955).

[4] G. E. Lee-Whiting, Phys. Rev. **97**, 463 (1955).

[5] Takebe, Nakamura, and Taketani, Progr. Theoret. Phys. (Japan) **14**, 317 (1955).

[6] R. P. Feynman and M. Gell-Mann, Phys. Rev. **109**, 193 (1958).

[7] A. Z. Dolginov and I. N. Toptygin, Izv. Akad. Nauk SSSR, Ser. Fiz. **20**, 1377 (1956) [Columbia Tech. Transl. **20**, 1260 (1956)]. A. Z. Dolginov, Nucl. Phys. **5**, 512 (1958). A. Z. Dolginov and N. P. Popov, Nucl. Phys. **7**, 591 (1958).

[8] A. Mitchell and E. Hebb, Phys. Rev. **95**, 727 (1954).

[9] P. F. A. Klinkenberg, Revs. Modern Phys. **24**, 63 (1952).

[10] Ambler, Hudson, and Temmer, Phys. Rev. **101**, 196 (1956).

[11] N. P. Heydenburg and G. M. Temmer, Phys. Rev. **100**, 150 (1955).

[12] T. R. Gerholm and H. DeWaard, Physica **21**, 601 (1955).

[13] D. T. Stevenson and M. Deutsch, Phys. Rev. **83**, 1202 (1951).

Translated by A. M. Bincer
4