INVESTIGATION OF THE DEPENDENCE OF THE $\beta\gamma$ CORRELATION ON THE ELECTRON VELOCITY IN THE β DECAY OF Co^{60} AND Au^{198}

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The dependence of the $\beta\gamma$-correlation coefficient on the electron v/c ratio was studied for circularly polarized γ quanta in Co^{60} and Au^{198} β decays. It is shown that for Co^{60} and energies > 150 keV the correlation coefficient is slightly smaller than $-v/3c$. Within the limits of experimental error, the coefficient for Au^{198} depends linearly on v/c. This is in accordance with the interpretation of Au^{198} β decay as a Coulomb transition.

IT is believed at present that the theory of weak interactions proposed by Feynman and Gell-Mann[1] is valid, since its conclusions are confirmed in all the accumulated experimental material, although not always with sufficient accuracy. Nevertheless, a verification of the conclusions of this theory for the β decay of the nucleus is very important, since we can then obtain new information on the structure of nuclei and nucleons on the basis of the present theory.

Studies have recently been made in which deviations from the predictions of the theory have been found; these differences have not yet been properly explained. Spivak et al.[2] showed that the longitudinal polarization of electrons differs from the value $-v/c$ required by the theory. The authors suggested that this deviation is due to the influence of the nuclear structure, but thus far there have been no suggestions which would account for the size of these deviations. It is very probable that the absence of such suggestions is connected with the insufficiency of the experimental material; it is therefore important to measure more accurately other effects in β decay so as to verify various proposed reasons for the deviations.

With this aim in mind, we measured the dependence of the $\beta\gamma$-correlation coefficient on v/c for the electron in the β decays of Co^{60} and Au^{198} (circularly polarized γ quanta).

The correlation between the electron momentum and the circularly polarized γ quanta was, as is known, one of the first phenomena by which the nonconservation of parity in β decay was established. A large number of experiments have been devoted to the measurement of this correlation in different nuclei. The general form of the correlation is

$$W(\theta) = 1 + \tau A \cos\theta,$$

where θ is the angle between the directions of emission of the β electron and the γ quantum, and $\tau = \pm 1$ corresponds to the sign of the circularly polarized γ quantum.

The correlation coefficient A has been calculated in [3,4]. Calculations have been made for both the allowed transitions and the first forbidden transitions. Moreover, Morita[5] calculated the contribution of the matrix elements of the second forbidden transitions in the allowed transitions.

The existing experimental data on Co^{60} are quite contradictory. Measurements made in a number of experiments[6,7] showed that, in any case, for electron energies of ~ 150 keV, the correlation coefficient is $-v/3c$, as also follows from the theory. It should be mentioned, however, that in these experiments a broad interval of the spectrum was separated out and the measured value of the correlation coefficient was then referred to the value of v/c averaged over the entire separated part of the spectrum.

It is obvious that such averaged data do not give the actual shape of the correlation coefficient vs. electron velocity curve, and since the calculations of the polarization efficiency of the γ polarimeter are not very accurate, possible deviations in the correlation coefficient dependence on v/c will be smoothed over as a result of the averaging.

A number of authors[8-10] therefore carried out measurements in which a relatively narrow energy interval for the electrons was separated, so that it was possible to measure directly the dependence on the electron velocity. Such studies are very difficult, since the measurements of the circular polarization of the γ quanta involve a lengthy accu-

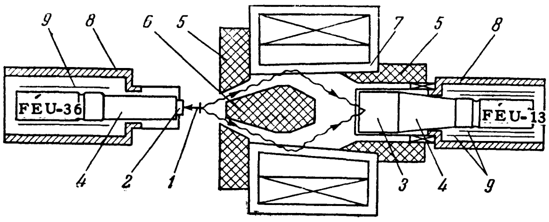

FIG. 1. Experimental layout. 1 – Source; 2 – stilbene crystal; 3 – NaI (Tl) crystal; 4 – light pipe; 5 – lead collimator; 6 – lead shield; 7 – analyzing magnet; 8 – Armco-iron shield; 9 – permalloy shield.

mulation of statistics in view of the small transmission of the polarimeter while a decrease in the electron counting rate strongly affects the accuracy of the results.

Page et al[8], who investigated Co^{60}, separated the energy with the aid of a magnetic lens. The authors found that the correlation coefficient was $-1/3$ and did not depend on v/c. The statistical accuracy of these measurements, however, was not great and in the electron energy region ~ 200 keV, where the data were averaged, the results do not contradict the earlier measurements.

Similar measurements were made by Steffen[9], who used a scintillation method to separate the electrons of given energy, and by Jäger[10], who used a magnetic lens for this purpose. The data of these authors do not contradict the conclusions of Page et al,[8] but in view of the poor statistical accuracy, the question as to whether there is a deviation in the shape of the dependence of the correlation coefficient on v/c remains unanswered.

The β decay of Au^{198} has also been studied in a number of experiments. The decay scheme has been studied in detail, and it has been established that there is a first forbidden transition ($2^- \rightarrow 2^+$), i.e., a non-unique one.

Alikhanov, Eliseev, and Lyubimov[11] recently showed that the longitudinal polarization of the Au^{198} electrons in the region of ~ 145 keV differs from the value $-v/c$ by $\sim 20\%$. Moreover, Spivak et al[2] found that the longitudinal polarization of the Au^{198} electrons is -0.94 v/c in the 240-keV region.

For non-unique first forbidden transitions the shape of the spectrum should be correlated to the value of the longitudinal polarization of the electrons,[3,12] and we can therefore expect deviations of this order of magnitude in the shape of the spectrum in this energy region.

Unfortunately, no studies have been made of the shape of the Au^{198} β spectrum in the region ~ 145 keV, but it follows from [13] that close to 180 keV there is no deviation, to an accuracy of $\sim 2\%$, between the β spectrum and the allowed spectrum. (At 180 keV the authors observed a deviation of $\sim 5.5\%$ between the shape of the spectrum and the allowed spectrum and attributed it to a superposition of the β spectrum with end-point energy 282 keV and to scattering in the source.) It is therefore unlikely that there is a deviation of $\sim 20\%$ in the 145-keV region.

Hence, the deviation of the value of the longitudinal polarization of Au^{198} electrons from the value $-v/c$ has not yet found its proper explanation.

As already indicated above, it is interesting to check how the observed deviation in the longitudinal polarization of the electron is correlated with the dependence on the velocity for other effects associated with the nonconservation of parity, in particular, for the $\beta\gamma$ correlation coefficient. Measurements of this correlation in Au^{198} have already been made by Steffen,[14] but the spread of the experimental points on the plot of the correlation against v/c in his work is rather large and exceeds the statistical error indicated there, so that it is of interest to measure this dependence as accurately as possible.

1. EXPERIMENTAL METHOD

We measured the circular polarization of the γ quanta by the method of scattering the γ quanta forward on magnetized iron. The geometry of the experiment (see Fig. 1) was taken the same as in our previous work.[15] The mean scattering angle of the γ quanta here was $\sim 50°$.

The scattered γ quanta were recorded by a 70×70 mm NaI (Tl) crystal connected by a light pipe 100 mm long to an FÉU-13 photomultiplier. The energy resolution for the Cs^{137} γ line was $\sim 20\%$. The β electrons were recorded by a stilbene crystal 4 mm thick in the case of Co^{60} and

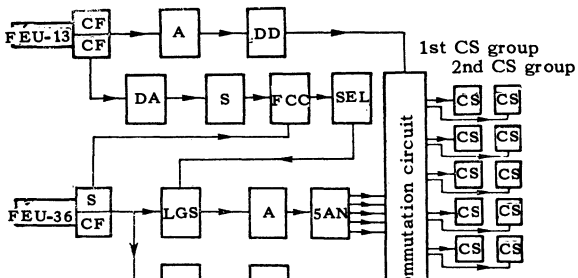

FIG. 2. Block diagram of apparatus: CF – cathode follower; S – signal shaping; DA – distributed amplifier; A – amplifier; DD – differential discriminator; FCC – fast coincidence circuit; SEL – selection circuit; LGS – linear gating selection circuit CS – counting circuit; 5AN – five-channel amplitude analyzer;

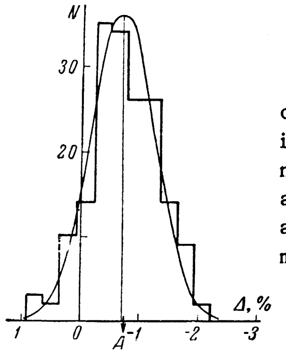

FIG. 3. Statistical distribution of the measurements for v/c = 0.52 in Co^{60} during one hour. Point A denotes the value of Δ determined from all the measurements. The ordinate axis gives the number of measurements.

10 mm thick in the case of Au^{198}. The distance between the source and the detector was 20 mm. The solid angle in which the β electrons were recorded was 4% of 4π.

We paid special attention to the magnetic shielding of the photomultipliers. The FÉU-13 photomultiplier in the γ channel was shielded by a double permalloy shield and a thick Armco-iron shield. Moreover, we used a compensation winding in the γ channel. As a result, the influence of the stray magnetic field during the current reversal in the magnet was reduced to 0.15% of the amplitude in the γ channel and $\sim 0.05\%$ of the amplitude in the β channel. The photomultiplier outputs were connected to a fast-slow coincidence circuit with a resolving time of 6×10^{-9} sec.

Since for the given solid angle the counting rate in the β channel was $(4-5) \times 10^5$ counts/sec, the ordinary fast-slow coincidence circuit could not be used. We used the method in which the pulses are selected from the photomultiplier dynode in the β channel by the pulse from the fast coincidence circuit, as described in [15]. The selected pulse was applied to a five-channel amplitude analyzer and then to the counting circuits. A block diagram of the equipment is shown in Fig. 2.

Thus, the correlation at five points of the β spectrum was measured simultaneously, which considerably improved the relative accuracy of the measurements. Furthermore, the single counts of the β channel pulses were recorded in order to check the stability in this channel.

The direction of magnetization was automatically reversed every 3.5 min. The time intervals were set by a quartz generator with an accuracy better than 10^{-4}. Between the counting intervals, there was a pause of ~ 8 sec during which the direction of the current in the magnet was automatically reversed.

The counts for each magnetization direction were recorded by a separate group of counting circuits and the results of the measurements were recorded every hour.

1. Co^{60}. The Co^{60} source was prepared by electrolytic separation from a sulfuric acid solution on an aluminum base 1.5 $\mu g/cm^2$ whose upper surface was sputtered with copper $\sim 10\ \mu g/cm^2$ thick. The surface density of the source was ~ 0.7 mg/cm^2. Its activity was about 250 μCu.

In the measurements of the correlation in the γ channel, the energy interval between 450 and 750 keV, which contained the photo-peak of the scattered γ quanta, was separated. In the β channel, four contiguous intervals between 90 and 250 keV were separated. The background of random coincidences was 11%.

The results of the measurements were calculated in the usual form

$$\Delta = 2(I_1 - I_2)/(I_1 + I_2), \qquad I_{1,2} = R_{\text{coin}}/R_\gamma\theta_\beta.$$

The subscripts 1 and 2 refer here to the different directions of magnetization; R_{coin} and R_γ are the counting rates for coincidences and single pulses of the γ channel; θ_β is a correction for the effect of the magnetic field in the β channel determined for each channel of the multichannel analyzer (the value of this correction is less than 0.03%).

These results were checked statistically. In view of the fact that the number of measurements was large (~ 150 recorded points), we constructed the statistical distribution for each channel and found the best fit between the Gaussian curve corresponding to the expected statistical spread and the experimental histogram (see Fig. 3). The center of the curve found in this way again yields the same resultant value and gives additional confidence as to the correctness of the results.

The results of the measurements are shown in Fig. 4. The straight line corresponding to the correlation coefficient $-v/3c$ was plotted in accordance with the calculated polarization efficiency of the γ polarimeter, correlation geometry, and random coincidence background.

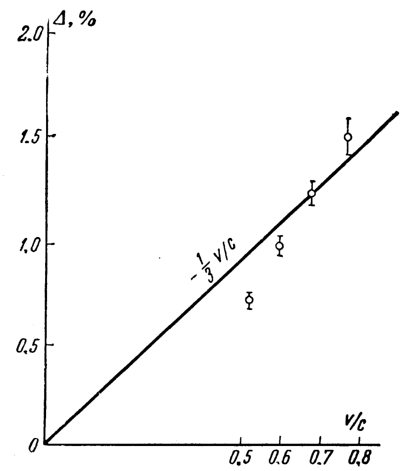

FIG. 4. Results of the measurements of the Co^{60} correlation coefficient.

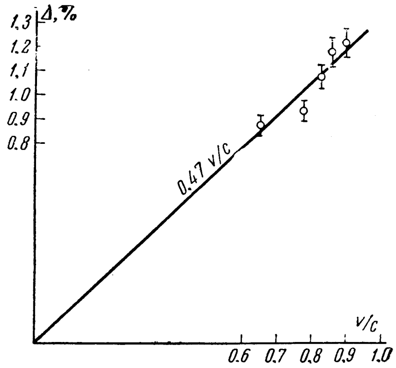

FIG. 5. Results of the measurements of the Au^{198} correlation coefficient.

As seen from Fig. 4, the results of Page et al[8] indicating the absence of a dependence on v/c are entirely incompatible with ours. As a matter of fact, in the low-energy region the points lie below the calculated line and the size of the deviation is four times the statistical error. We considered the factors which could have caused such a deviation. These could be a) multiple scattering of electrons in the source and b) multiple scattering in air.

An estimate of single and multiple scattering in the source was made by Wegener's method,[16] and the estimate of the scattering in air was made by the theory of Molière.[17] The obtained data indicate that under the given conditions the correction for electron scattering should be no greater than ~5% of the correlation value, i.e., these factors apparently cannot explain the shape of the correlation coefficient vs. v/c plot.

2. Au^{198}. The Au^{198} source was prepared by the sputtering of gold in vacuo on an aluminum base of density ~ 1 mg/cm^2 with subsequent irradiation in a reactor. The surface density of the source was ~100 μg/cm^2 and its activity was between 100 and 300 μCu. The photopeak of scattered γ quanta was separated in the γ channel measurements.

An interval between 180 and 800 keV was separated from the β spectrum by the multichannel analyzer. Unfortunately, the lower-energy β electrons could not be recorded, since the spectrum in this region was greatly enriched by electrons scattered and reflected from the stilbene surface, and therefore the dependence on the velocity was strongly distorted.

The results of the measurements were calculated and analyzed similarly to the results for Co^{60}. The analyzed data are shown in Fig. 5 in the form of a plot of the correlation coefficient versus v/c. The straight line corresponds to the correlation coefficient

$$A = +0.47 \pm 0.03,$$

which is an improvement on the accuracy of Steffen's data.[14]

Within the limits of experimental error, no deviation from a linear dependence on v/c was found.

2. DISCUSSION OF RESULTS

The results of our measurements of the $\beta\gamma$ correlation in Co^{60} is thus in complete disagreement with the data of Page et al.[8] As regards the deviation of the correlation coefficient from $-v/3c$ in the region below 150 keV, any interpretation is quite difficult. One can only say that the investigated β transition is strongly damped (log ft = 7.4), which indicates that the basic matrix element is small. As a result, the role of the matrix elements of the second forbiddenness increases strongly so that it is possible that terms dependent on the energy occur. In this case, one should expect an anisotropy in the $\beta\gamma$ angular correlation, but, as was shown by Subba Rao,[18] there is no such anisotropy. Generally speaking, the absence of an anisotropy can be explained by a chance dropping out of the corresponding matrix elements. Accurate measurements of the Co^{60} spectrum shape for the region below 100 keV have not been made. The longitudinal polarization of the Co^{60} electrons has been measured by many authors, but the accuracy was not great.

The results of the measurements on Au^{198} confirm the conclusions of Steffen[14] that this transition is a Coulomb or ξ transition, i.e., it is described by the first terms of the expansion of the transition matrix element in the parameter $\xi = \alpha Z/2R$, where R and Z are the radius and charge of the nucleus, and α is the fine-structure constant. In view of this, the deviations of the longitudinal polarization from v/c observed in [11,2] require separate interpretation.

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

[2] L. A. Mikaélyan and P. E. Spivak, JETP **37**, 1168 (1959), Soviet Phys. JETP 10, 831 (1960); Spivak, Mikaélyan, Kutikov, and Apalin, JETP **39**, 1479 (1960), Soviet Phys. JETP **12**, 1027 (1961).

[3] Alder, Stech, and Winther, Phys. Rev. **107**, 728 (1957).

[4] A. Z. Dolginov, JETP **35**, 178 (1958), Soviet Phys. JETP **8**, 123 (1959).
[5] M. Morita, Nuclear Phys. **14**, 106 (1959).
[6] F. Boehm and A. H. Wapstra, Phys. Rev. **106**, 1364 (1957).
[7] Appel, Schopper, and Bloom, Phys. Rev. **109**, 2211 (1958).
[8] Page, Pettersson, and Lindqvist, Phys. Rev. **112**, 893 (1958).
[9] R. M. Steffen, Phys. Rev. **115**, 980 (1959).
[10] P. Jäger, Z. Physik **158**, 214 (1960).
[11] Alikhanov, Eliseev, and Lyubimov, JETP **39**, 587 (1960), Soviet Phys. JETP **12**, 414 (1961).
[12] B. V. Geshkenbeĭn and A. P. Rudik, JETP **38**, 1894 (1960), Soviet Phys. JETP **11**, 1361 (1960).
[13] Porter, Freedman, Novey, and Wagner, Phys. Rev. **103**, 921 (1956).
[14] R. M. Steffen, Phys. Rev. **118**, 763 (1960).
[15] V. M. Lobashov and V. A. Nazarenko, JETP **41**, 1433 (1961), Soviet Phys. JETP **14**, 1023 (1962).
[16] H. Wegener, Z. Physik **151**, 252 (1958).
[17] G. Molière, Z. Naturforsch. **3a**, 78 (1948).
[18] B. N. Subba Rao, Nuovo cimento **20**, 178 (1961).

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