CIRCULAR POLARIZATION OF INTERNAL BREMSSTRAHLUNG ACCOMPANYING K-CAPTURE IN Fe^{55}

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The circular polarization of the internal bremsstrahlung accompanying K-capture in Fe^{55} was measured by scattering in magnetized iron. The technique of the measurements was based on the azimuthal dependence of the Compton scattering cross section of gamma quanta on polarized electrons. Within the limits of error 100 percent polarization of the bremsstrahlung quanta was obtained independent of the radiation energy.

INTRODUCTION

A consequence of parity nonconservation in beta decay is that internal bremsstrahlung accompanying electron capture must be circularly polarized.[1,2] The degree of circular polarization according to the two-component neutrino theory must be 100 percent independent of the energy of bremsstrahlung quanta (for not too low energies).[2] It can now be considered established that the beta-decay interaction has primarily the character of the V-A interaction.[3,4] The possible admixture of S-T interaction would reduce the degree of circular polarization of bremsstrahlung. This circumstance makes it possible to discover the admixture of S-T components in the beta-decay interaction.

Experiments measuring the circular polarization of internal bremsstrahlung accompanying K-capture were done with Ge^{71} and A^{37} in references 5 to 7. In the first case the degree of polarization was found to be much less than 100%, which, in the opinion of the authors, was connected with the presence of admixtures of extraneous radiation from the source. In measurements with A^{37}, 100% polarization of bremsstrahlung was obtained within the limits of error, and for the quantity $|C_T|^2/|C_A|^2$, characterizing the admixture of the T invariant, Miskel and Mann[6] give an upper limit of 8%. The present work measures the circular polarization of internal bremsstrahlung of Fe^{55} ($T_{1/2}$ = 2.6 years, transition energy 220 kev).

EXPERIMENTAL SETUP AND MEASUREMENTS

a. Polarimeter. The azimuthal dependence of the Compton scattering cross section of circularly polarized gamma quanta on polarized electrons was used for measuring the circular polarization. This method was first proposed by Beard and Rose[8] and used for investigation of circular polarization of gamma rays by Beltrametti and Vitale in reference 9. It is based on the fact that during scattering of circularly polarized gamma quanta on electrons whose spins are perpendicular to the direction of gamma ray propagation, anisotropy arises in the scattering cross section, depending on the direction of electron spin orientation. The scattering cross section for this case ($\mathbf{k}_0 \perp \mathbf{s}$, where $\mathbf{k}_0$ is the impulse of the primary photon and $\mathbf{s}$ is the electron spin) is

$$\sigma(\vartheta, \varphi) = \sigma_0 - P\frac{r_0^2}{2}\frac{k^2}{k_0^2}(1-\cos\vartheta)\, sk \sin\vartheta \cos\varphi = \frac{r_0^2}{2}[\Delta_0 - P\Delta\cos\varphi].$$

Here ϑ is the scattering angle, φ is the angle between the planes $(\mathbf{k}_0\mathbf{k})$ and $(\mathbf{k}_0\mathbf{s})$, σ_0 is the usual Klein-Nishina cross section, and P is the degree of circular polarization ($P > 0$ for right circular polarization and $P < 0$ for left circular polarization[10]). Maximum relative azimuthal anisotropy was observed with the optimal angle of scattering ϑ_{max} which was obtained from the maximum condition Δ/Δ_0.[8-10]

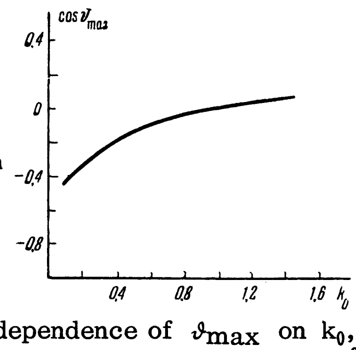

FIG. 1. The dependence on energy of the scattering angle for which the azimuthal anisotropy is maximal.

Figure 1 shows the dependence of ϑ_{max} on k_0, the energy of the primary radiation in units of mc^2.

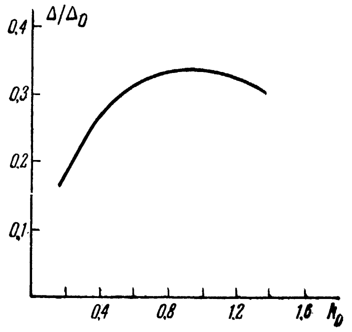

FIG. 2. The dependence on energy of the azimuthal anisotropy for the optimal scattering angle ϑ_{max}.

It is clear from the graph that if the gamma energy is $E_0 > 510$ kev, the optimal scattering angle $\vartheta_{max} < 90°$, but if $E_0 < 510$ kev, then $\vartheta_{max} > 90°$. The dependence of relative anisotropy Δ/Δ_0 for the optimal scattering angle on the energy of the primary gamma quanta is shown in Figure 2. For investigating radiation from Fe^{55} the scattering angle $\vartheta \sim 100°$ was chosen.

b. Source. The Fe^{55} source ($\sim$ 50 millicuries) was obtained by irradiating in a reactor target material enriched in the isotope Fe^{54} to 82.8%. Besides the isotope Fe^{55}, the isotopes Fe^{59} and Mn^{54} are formed; the latter is obtained through the reaction $Fe^{54}(n, p) Mn^{54}$. Since the yield of internal bremsstrahlung in K-capture is very small (for Fe^{55} the yield is $\sim 3 \times 10^{-5}$ quantum/decay)[11] the purity of the source is of particular significance. The chemical purification of the source from Mn^{54} was done in the chemical laboratory of the Institute.* The source (iron oxide) was then placed in a Plexiglas container. The measurements were begun 15 months after irradiation, which corresponds to ten Fe^{59} half lives ($T_{1/2}$ = 45 days). The experimentally observed spectrum of bremsstrahlung is shown in Fig. 3 (N is the counting rate in arbitrary units).

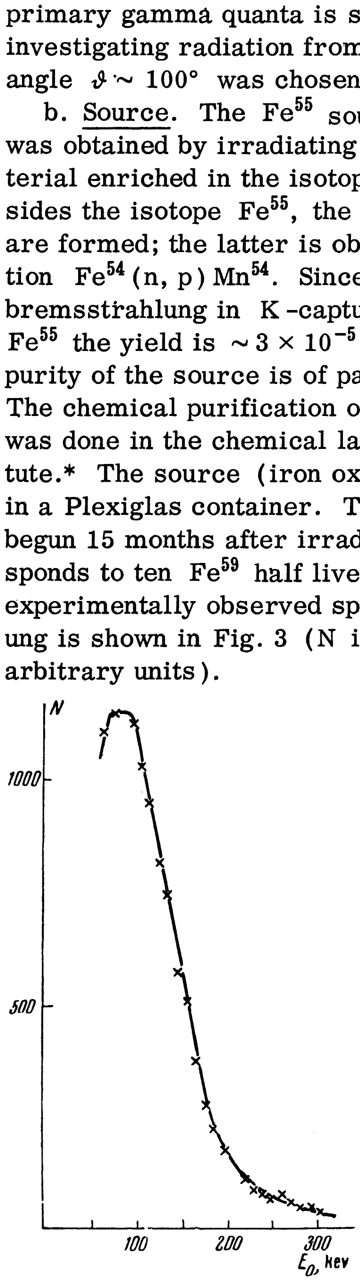

FIG. 3. Spectrum of internal bremsstrahlung of Fe^{55}.

*Chemical purification was done by N. I. Mertts, to whom the author is grateful.

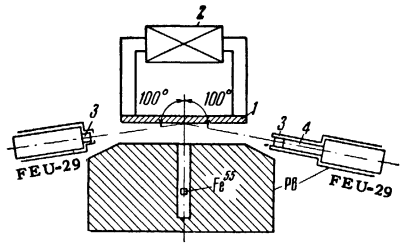

FIG. 4. Schematic diagram 1) permendur scattering disc, 2) magnetizing coil, 3) NaI(Tl) crystals, 4) light pipe.

c. Experimental Setup. Figure 4 shows schematically the experimental setup for measuring the circular polarization of gamma quanta. A disc of permendur which is part of a solid core magnet made of Armco iron serves as the scatterer. The induction in the permendur was 20 000 gauss. The scattered gamma quanta were analyzed by two scintillation spectrometers with FEU-29 photomultipliers and NaI(Tl) crystals. Using two scintillation spectrometers made it possible to increase the collecting power of the equipment by a factor of two. Shielding of the multiplier from the magnetic field of the scatterer was done with a permalloy shield and a three-layered iron shield around the photomultiplier. In addition, a light pipe 10 cm long was installed on one photomultiplier. Sources of Cs^{137} and Hg^{203} were used to check the magnetic shielding. For this a narrow discriminator window was set on the side of the photopeak, and the dependence of the counting rate on the direction of the current in the magnetizing coil was measured. Under these conditions the influence of the magnetic field was less than 0.3%.

d. Measurements and Results. A single-channel discriminator was used to detect a certain region of the spectrum of scattered radiation, and the number of scattered gamma quanta in both spectrometers was measured for opposite directions of the field (which was changed every 5 or 10 minutes). More than 10^5 pulses in each spectrometer were accumulated for the chosen direction of the field in order to obtain each point. The following magnitude was calculated: $\eta = 2(N_1 - N_2)/(N_1 + N_2 - 2N_0)$, where N_1 is the count in the spectrometer when the magnetic field is directed toward the counter, N_2 is the count for the opposite direction of the field, N_0 is the count without the scatterer (including background and direct gamma radiation through the lead shielding). In calculating η, in addition to corrections included in the quantity N_0, it is necessary to correct for scattered radiation caused by Fe^{59}. Since all the measurements take place in the region of soft gamma rays, it is difficult to separate scattered gamma radiation of Fe^{55} from scattered radiation of Fe^{59}. In order to determine the con-

	Energy region of primary gamma quanta, kev	N_1	N_2	Experimental value of η, %	Calculated value of η for 100% polarization, percent
FEU-1	85—110	107138	105886	2.6 ± 1.0	2.57
	110—140	160148	158206	2.9 ± 0.8	2.97
	140—175	119424	117842	3.3 ± 0.9	3.49
	175—220	195051	192054	4.0 ± 0.8	3.95
FEU-2	80—110	129736	128092	2.4 ± 0.7	2.57
	110—140	115960	114215	2.8 ± 0.8	2.98
	130—170	135647	133394	3.6 ± 0.8	3.49
	170—215	145955	143076	3.9 ± 0.8	3.94

tribution of scattering from Fe^{59} to the region of energies under consideration, the iron source was replaced by a Co^{60} source whose gamma-ray spectrum is similar to the Fe^{59} spectrum. In the hard part of the spectrum of scattered radiation where there are no gamma rays from Fe^{55} it is possible to normalize both sources and thus determine the contribution of Fe^{59} in the region of energies that is of interest to us. The results obtained are shown in the table and include corrections which are from 10 to 20% in various parts of the spectrum.

From the table it can be seen that, within the limits of error, the circular polarization does not, in accordance with theoretical expectations, depend on the energy of the radiation under investigation. Averaging all the determinations of P, we obtain $P = 0.98 \pm 0.10$.

The expression for the degree of circular polarization of internal bremsstrahlung accompanying K-capture according to the two-component theory has the following form:[2]

$$P(k) = p(k) \times \frac{\sum_f \{|\langle 1\rangle_{fi}|^2 (|C_V|^2 - |C_S|^2) + |\langle \sigma\rangle_{fi}|^2 (|C_A|^2 - |C_T|^2)\}}{\sum_f \{|\langle 1\rangle_{fi}|^2 (|C_V|^2 + |C_S|^2) + |\langle \sigma\rangle_{fi}|^2 (|C_A|^2 + |C_T|^2)\}},$$

where p(k) is a function depending on energy and is equal to 1 for not too low energies.

The transition under investigation, $Fe^{55} \to Mn^{55}$ $(3/2^- \to 5/2^-)$, is a transition of the Gamow-Teller type and therefore the last expression reduces to

$$P = (|C_A|^2 - |C_T|^2)/(|C_A|^2 + |C_T|^2).$$

Hence, knowing P, it is possible to determine the admixture of the T variant in beta-decay interaction if we consider that this interaction is primarily axial-vector. From the data the upper limit of the admixture $|C_T|^2/|C_A|^2 \leq 6\%$ is obtained.

In conclusion I wish to take this opportunity to express my sincere gratitude to V. S. Shpinel' for his constant interest in this work.

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