OBSERVATION OF INTERFERENCE OF THE PHOTOEFFECT AND INTERNAL CONVERSION IN RESONANT ABSORPTION OF M1 GAMMA QUANTA BY Sn^{119}

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The possibility of interference between the processes of photoeffect and internal conversion in resonant absorption of gamma quanta was first considered in [1, 2], where it was shown that the asymmetry of Ta^{181} is due just to this phenomenon. It was noted that the interference can be observed in absorption spectra only in the case of gamma transitions of multipolarity E1, when the expression for the total absorption cross section σ_t is

$$\sigma_t = \sigma_{ph} + f'\sigma_0[(1 + \beta x)/(1 + x^2)], \tag{1}$$

where σ_{ph} is the photoeffect cross section, f' the Debye-Waller factor for the absorber nuclei, σ_0 the gamma-quantum resonance-absorption cross section, $x = 2(E - E_0)/\Gamma$ the difference between the gamma-quantum energy and the resonant energy in units of the half-width of the absorption-spectrum line, and β a numerical coefficient that determines the contribution of the interference term to the total absorption cross section.

The conclusions of the theoretical calculations were confirmed by measurements of the forms of the spectra of resonant absorption of E1 gamma quanta by Dy^{161} [3]. Further development of the theory of interference phenomena in nuclear gamma resonance [4] has shown that under definite conditions this effect can appear also for gamma transitions of other multipolarities. To observe interference in this case it is necessary to separate the electron emission direction. In particular, for M1 gamma transitions the interference coefficient takes the form

$$\beta_{M1} = d \cos \theta \tag{2}$$

(θ - angle between γ-quantum and electron momenta).

The numerical value of the factor d depends on the character of the electronic transition. For example, for conversion transitions from s-subshells, particularly from the K-shell, the value of d is close to zero.

A convenient object for an experimental verification of the effects predicted in [4] is the M1 γ transition of Sn^{119}. The energy of this transition (23.8 meV) is lower than the binding energy of the K-shell electrons, giving grounds for expecting an appreciable interference effect in this case.

From the form of the angular dependence (2) it follows that the coefficient β for M1 γ transitions has opposite signs for electrons emitted "forward" ($0 \le \theta \le \pi/2$) and "backward" ($\pi/2 \le \theta \le \pi$) relative to the propagation direction of the gamma quanta. Thus, by registering the electrons emitted from a thin layer of absorber atoms in a plane perpendicular to the gamma-ray beam it is possible to observe the interference asymmetry of the spectrum. Its sign will depend on whether the electrons registered come from the side of the absorber facing the source or from the opposite side. The magnitude of the asymmetry is determined by the value of β averaged over the "forward" or "backward" electron emission direction.

It is convenient to use a resonant counter [5] for measurements of this kind. The resonant counters prepared by us for this investigation contained one layer of resonant matter - $CaSnO_3$ - deposited on a thin beryllium foil. The thickness of the resonant coatings ranged from 0.1 to 0.7 mg/cm^2. The counter construction has made it possible to carry out the irradiation both from the substrate side and from the side of the resonant layer. In the former case there was registered the counting rate N_1 of the "forward" electrons, and in the latter case the rate N_2 of the "backward" electrons. The measurements were made with a $BaSnO_3$ source.

The Mossbauer spectrum measured with the aid of the resonant counter is a curve having a maximum at the point when the emission and absorption lines coincide, and the γ-quantum count N_0 at the resonance maximum exceeds the background level by several times (Fig. 1). The low counting level in regions far from the resonance makes it possible to increase the

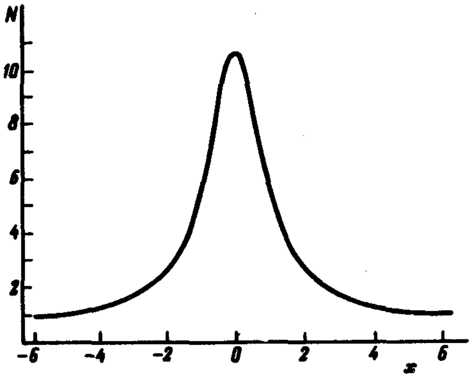

Fig.1

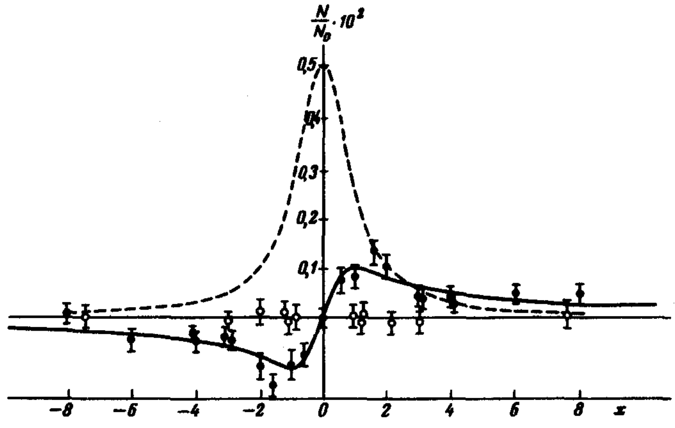

Fig.2

Fig. 1. Mossbauer spectrum of counter with 0.4 mg/cm^2 resonant counter. Here and in Fig. 2, the abscissas are the source velocities in units of x.

Fig. 2. Relative intensity of asymmetrical component of absorption spectrum, corresponding to selection of electrons emitted "forward" (dark points). Solid curve - interference term $\beta x/(1 + x^2)$ ($\beta = 2\times10^{-3}$). Dashed curve - cross section of resonant absorption $1/(1 + x^2)$ (1:200 scale). Light points - series of control measurements.

accuracy of the determined interference term, which decreases more slowly than the resonant-absorption cross section with increasing x.

We used a constant-velocity setup in which the counts N(+v) and N(-v) were determined in one measurement at two points of the spectrum, symmetrical relative to zero velocity. The relative placements of the source and counter were varied periodically to determine N_1 and N_2. Since the absorption maximum for a given resonant pair is located near zero velocity (according to our data, the shift of the $CaSnO_3$ spectrum is +0.018 mm/sec), it follows that $\Delta N(v) = [N(+v) - N(-v)]/N_0$ contains double the interference term. The double difference $\Delta_v^- = \Delta N_1(v) - \Delta N_2(v)$ characterizes the change of the symmetry of the spectrum when the electron emission direction is reversed. The numerical value of Δ_v^- is determined in the main by the value of the asymmetric component of the spectrum, which reverses the sign of the asymmetry when the electron emission direction is reversed. Figure 2 shows the experimental intensities of this componenet relative to the intensity of gamma-quantum absorption at the maximum of the resonance. The solid curve in this figure shows the energy dependence of the interference term $\beta x/(1 + x^2)$ at $\beta = 2\times10^{-3}$. The position of the experimental points agrees well with the course of this curve. The observed asymmetry corresponds to the coefficient $\beta = (2 \pm 0.5)\times10^{-3}$.

To verify the results, we performed a series of control experiments with resonant counters containing to resonant layers facing in opposite directions. In such counters, the number of electrons emitted "forward" and "backward" relative to the gamma-quantum direction is approximately the same for all relative placements of the counter and source, and there should be no interference asymmetry of the spectrum, as was indeed demonstrated experimentally (light points in Fig. 2).

It should be noted that the observed asymmetry of the spectrum is somewhat undervalued, owing to the presence of back-scattering of the electrons. An estimate of the influence of the back-scattering [6] shows that this attenuation reaches 30 - 50%. Taking this fact into account, the value assumed for the interference coefficient averaged over the "forward" electron emission directions ($0 \leq \theta \leq \pi/2$) should be $\beta = +(3 \pm 1)\times10^{-3}$.

We can thus regard it as established that the interference of the internal conversion and of the photoeffect take place also in the case of M1 gamma transitions, and that the properties of this phenomenon agree with those predicted in [4].

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ION LIFETIME IN THE TOKAMAK-3 MACHINE

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In closed magnetic traps of the Tokamak type, where the plasma loop is heated by current flowing through it and is stabilized by a strong longitudinal magnetic field, an important characteristic of the thermal insulation of the plasma is the average time of retention of the thermal energy in the ionic component, τ_{Ei}. By introducing this quantity, we can write down the equation of energy balance for the ions per unit volume, in the form

$$0{,}4 \cdot 10^{-17} \frac{n^2}{AT_i^{1/2}} = \frac{3}{2} nk \frac{dT_i}{dt} + \frac{3}{2} nk \frac{T_i}{\tau_{Ei}}, \qquad (1)$$

where A is the atomic weight of the material (hydrogen or deuterium), T_i the ion temperature in °K, and n is the plasma density. The left-hand term of the equation represents the energy transferred from the electrons to the ions by Coulomb collisions per second and per cm^3. This term does not include the electron temperature T_e, since the heat flux from the electrons to the ions depends very little on T_e in the range $T_e/T_i = 1.6$ to 10. Under the conditions of the experiment, the ratio T_e/T_i always lies in this interval. Equation (1) is valid in the case when the ions are heated mainly by heat exchange with electrons vial Coulomb collisions. Many experimental facts indicate that this assumption is valid if the plasma density is not too low (cf., e.g., [1]).

The figure shows the variation of the quantities T_i, n, and τ_{Ei} during the time of the discharge pulse in the T-3 Tokamak, for the central zone of the plasma pinch. The values of τ_{Ei} were calculated with Eq. (1), in which we substituted the ion temperature measured by analyzing the energy spectrum of the charge-exchange atoms, and the density was determined from radio-interferometry data. It follows from (1) that in the stationary state, i.e., in the time interval when the temperature is close to the maximum, we have

$$\tau_{Ei} \approx 50A(T_i^{3/2})/n.$$

It follows hence, in particular that the ratio of τ_{Ei} to the average time interval between two Coulomb ion-ion collisions is a constant quantity for the given species of ions, and is independent of T_i or of n.

The loss of thermal energy from the ionic component of the plasma are due to (i) thermal conductivity, (ii) diffusion, and (iii) charge exchange of the ions with the residual gas. Consequently

$$\frac{1}{\tau_{Ei}} = \frac{1}{\tau_t} + \frac{1}{\tau_d} + \frac{1}{\tau_c}, \qquad (2)$$