MEASUREMENT OF THE GYROMAGNETIC RATIO OF THE W^{182} NUCLEUS IN THE FIRST EXCITED STATE

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The gyromagnetic ratio of the 100-keV level of the W^{182} nucleus is measured by means of the perturbation of the $\gamma\gamma$ correlation of the 229—100 keV cascade by an external magnetic field of 35,000 gauss. The coefficients of the "unperturbed" correlation functions are $A_2 = 0.087 \pm 0.008$ and $A_2 = 0.108 \pm 0.008$ for a solid and liquid source respectively. The angular shifts of the correlation function are 4°10′ for the solid and 5°53′ for the liquid source; this corresponds to $g = 0.247 \pm 0.037$ and $g = 0.323 \pm 0.048$. The mean value of the gyromagnetic ratio for the two measurements is $g = 0.285 \pm 0.042$.

PRESENT-DAY nuclear models have reached such a stage of development that further refinement requires not only knowledge of the alpha and beta decay probabilities with the excitation of collective motion, knowledge of the excitation of Coulomb rotational levels etc, but also knowledge of a number of other quantities sensitive to specific features of the nuclei. Such quantities are, in the first place, the moments of inertia and the magnetic moments (and consequently the gyromagnetic ratios) of nuclei in the ground and excited states.

New nuclear models have been worked out in recent years which are modifications of the shell and collective models. Thus, in the theory of nuclei lacking axial symmetry proposed by Davydov and Filippov [1] the coupling is considered between the collective and single-particle motions of the nucleons in the nucleus, whereas it had been hitherto assumed that there is no interaction whatever between these two forms of motion. Migdal, [2] Belyaev [3], and Solov'ev [4] have applied the methods of the Bogolyubov theory of superfluidity to the description of the motion of the nucleons in the nucleus.

The interesting results of the latter models require experimental data which would be a check on the conclusions of the theory. Therefore, experiments connected with a direct determination of nuclear parameters sensitive to specific assumptions of the models, such as magnetic moments and gyromagnetic ratios of the ground and excited states, take on special significance.

The majority of the presently known gyromagnetic ratios and nuclear magnetic moments has been calculated from the experimentally measured gamma-transition probabilities in nuclei. [5-7] However, data indirectly obtained to some extent lost their value because it had been assumed in calculating the gyromagnetic ratios that the single-particle and collective motions of the nucleons in the nucleus were completely separated, an assumption which was merely a rough approximation. [1]

In this connection interest was aroused by the direct method of measuring gyromagnetic ratios of nuclei in the excited state, proposed by Brady and Deutsch. [8] The theory of this method was worked out by Alder [9,10] and Lloyd, [11] and in 1953 the Zürich group first measured the gyromagnetic ratio of the first excited state of the Cd^{111} nucleus. [12] Subsequently a number of original papers were published, and also several reviews devoted to direct methods of measuring gyromagnetic ratios of excited nuclei. [13,14]

The following two methods exist for determining the gyromagnetic ratio of nuclei in the excited state: the method of $\gamma\gamma$ correlation and the method of Coulomb excitation. Both methods employ one and the same physical phenomenon—the interaction of the nuclear magnetic moment with an external magnetic field; however, in approach they differ from each other considerably. In both instances the precession of the nuclear magnetic moment in the external field leads to a distortion of the angular distribution of the gamma quanta (of the correlation function of the $\gamma\gamma$ cascade). Let us consider a more general case of the effect of an external magnetic field on the correlation function of the $\gamma\gamma$ cascade.

There exists a definite correlation between the directions of emission of two successive gamma quanta which form a cascade by means of which the excited nucleus is de-excited. This means that if the counting rates of the time coincidences of quanta γ_1 and γ_2 are measured, a certain distribution is obtained which depends on the angle between the emission directions of γ_1 and γ_2, i.e., a correlation function $W(\theta)$. The latter can be represented in the form

$$W(\theta) = \sum_k A_k P_k(\cos\theta) = \sum_k a_k \cos k\theta, \qquad (1)$$

where A_k and a_k are anisotropy coefficients depending on the spins of the ground and excited state and on the multipolarity of the gamma transitions. P_k are the even Legendre polynomials.

If a magnetic field is applied perpendicular to the plane in which the gamma quanta are registered, then during the time between the instants of emission of quanta γ_1 and γ_2 the nucleus will on account of the precession turn through some angle $\Delta\theta = \omega\tau$ (τ is the mean lifetime of the nucleus in the excited state, ω is the Larmor precession frequency) and the angle between the directions of emission of γ_1 and γ_2 will become $\theta + \Delta\theta$.

The correlation function perturbed by the magnetic field can be readily obtained by integrating the expression

$$W(\theta, H) = \int_{\tau_1}^{\tau_2} W[(\theta + \Delta\theta), H = 0]\, e^{-t/\tau}\, dt. \qquad (2)$$

The integration is carried out under the assumption that $\tau \ll \tau_R$ (τ_R is the resolving time of the coincidence circuit), and under the assumption that no terms with $k > 2$ enter into expansion (1). Integrating (2), we obtain

$$W(\theta, H) = \sum_k \frac{a_k}{\sqrt{1 + (k\omega\tau)^2}} \cos k(\theta + \Delta\theta_k),$$

$$\Delta\theta_k = \frac{1}{k}\operatorname{arctg}(k\omega\tau), \qquad (3)^*$$

the Larmor precession frequency being

$$\omega = \mu H / I\hbar = gH\mu_{nuc} / \hbar, \qquad (4)$$

where H is the magnetic field intensity, I is the spin of the investigated state, g is the gyromagnetic ratio of this state, μ is the nuclear magnetic moment, and μ_{nuc} is the nuclear magneton.

From (3) it can be seen that in a magnetic field the angular distribution function has been shifted by an angle $\Delta\theta$, and the anisotropy of the distribution has decreased; by measuring the azimuthal shift or the decrease in the anisotropy of the correlation function, it is possible to determine the value of ω, from which it is easy to calculate the gyromagnetic ratio g.

The Coulomb excitation method, while also employing the precession of the nuclear magnetic moment in an external magnetic field, differs from the $\gamma\gamma$-correlation method in the way the investigated nucleus is excited and in the method of registering its precession. In this case the nucleus is excited by electromagnetic interaction with an incident charged particle. Since a preferred direction exists in this case (the point from which the measurement of the precession angle is started and which coincides with the direction of the charged-particle beam), in order to observe the azimuthal shift of the angular distribution and the weakening of its anisotropy in an external magnetic field it is sufficient to measure the angular distribution of the gamma quanta corresponding to transition from the investigated state to the ground state. The value of the gyromagnetic ratio can be found from relations (3) which remain valid in this case.

A number of circumstances complicate greatly the experiments for measuring the gyromagnetic ratios of excited nuclei. In a real source of gamma quanta there always exist local electrical and magnetic fields which themselves perturb the angular distributions of gamma quanta, and whose effect it is very difficult to take into account. On the other hand, knowledge of the magnitude of the perturbation of the angular distribution caused by the interaction of the local fields with the magnetic moment of the nucleus is essential, since the character of the perturbations introduced by the local fields and by the applied magnetic field is identical.

Recently more or less successful attempts have been made to take these "internal" fields into account. The action of the electrical fields is taken into account by introducing so-called "attenuation coefficients" G_k, whose magnitude depends on the chemical composition and the state of aggregation of the source (target) material; to account for the interaction of the local magnetic fields a certain effective field $H_{eff} = \beta H$ is introduced, where β is a correction factor related to the paramagnetic properties of the material of the gamma source.[15]

The methodical difficulties connected, on the one hand, with the registration of coincidences (the increase of the background of false coincidences for $\tau_R \geq 10^{-6}$ to an extent that the number of false coincidences begins to be larger than the number of true coincidences), and also the difficulties in obtaining magnetic fields with intensities exceeding 40,000 G, and the "equalizing" action of the mag-

*arctg = $\tan^{-1}$.

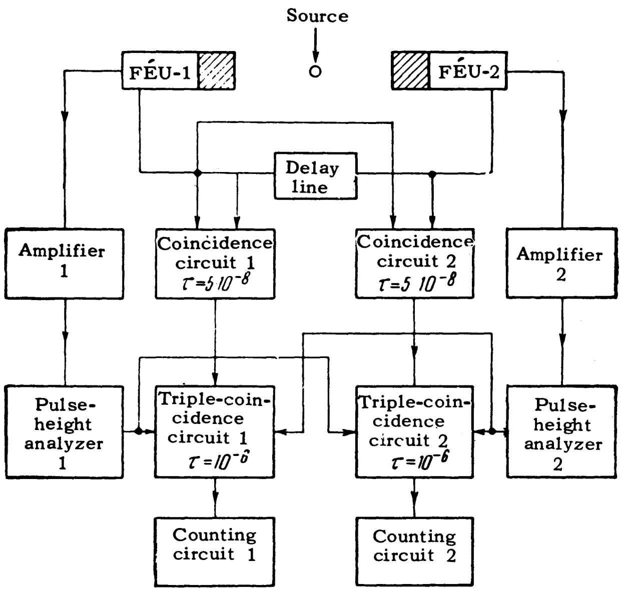

FIG. 1. Block diagram of the electronics. Coincidence circuit 1 registers random coincidences, 2 registers the total number of coincidences.

netic field on the angular distribution of gamma quanta, on the other hand, limit the above methods of measuring the gyromagnetic ratios of excited nuclei; reliable measurements of gyromagnetic ratios can thus be obtained for excited states whose mean lifetimes are within the limits of 10^{-7}—10^{-10} sec, provided the anisotropy of the corresponding angular distribution is sufficiently large. (The upper limit of the lifetime of the excited state of 10^{-7} sec apparently does not extend entirely to the Coulomb-excitation method.)

We have built a device which permits us to measure the gyromagnetic ratios of nuclei in the excited state both by the method of Coulomb excitation and also by the $\gamma\gamma$ correlation. The main components of the device are: a two-channel goniometer, electronic registration apparatus, and an electromagnet producing in the gap a magnetic field of 35,000 G. The magnet core is made of "Armco" iron. The core gap can be varied from 0 to 30 mm. The gamma detectors consist of 30 × 15 mm NaI (Tl) scintillators with FÉU-42 photomultipliers. In order to weaken the effect of the magnetic field on the photomultipliers a three-layer magnetic screen is used, and 200-mm organic-glass light guides make it possible to remove the photomultipliers outside the limits of the stray field, retaining at the same time a sufficient gamma-detector count.

The gamma detector pulses enter into a fast-slow coincidence circuit whose block diagram is shown in Fig. 1. The "fast" coincidence resolution time is $2\tau_R = 10^{-7}$ sec. In the "slow" channels the pulses undergo amplification and pulse-height selection with the aid of linear amplifiers and single-channel pulse-height analyzers. The position of the discriminator "window" and its width are chosen such that only pulses corresponding to gamma quanta producing the investigated cascade (in the case of Coulomb excitation gamma quanta corresponding to a transition from the investigated level to the ground state) enter the "slow" coincidence cell ($\tau'_R = 10^{-6}$ sec). Very strict demands are made on the pulse-height analyzers used in this work. We have, therefore, employed specially constructed discriminators which assure the stability of the position and width of the window within 0.03 V under a load of $(2-3) \times 10^4$ pulse/sec.

The gyromagnetic ratio of the first excited state of the even-even W^{182} nucleus was measured by the $\gamma\gamma$ correlation method. Natural metallic tantalum neutron-irradiated in the water-moderated water-cooled reactor of the Physics Institute of the Ukrainian Academy of Sciences served as the gamma source.

In view of the fact that the gamma spectrum appearing in the decay of Ta^{182} is very complex, the form of the correlation function is distorted on account of the considerable number of false coincidences due to "outside" gamma transitions with close energy ($E_\gamma = 222$ keV).

We measured the correlation function of the 229—100 keV cascade which for a solid polycrystalline source turned out to be $W(\theta) = 1 + (0.016 \pm 0.002) \cos 2\theta$ (without subtracting the background due to false coincidences). From a comparison of the relative intensities of the corresponding gamma transitions in the decay scheme of Ta^{182} [16] we could estimate the isotropic background of false coincidences from disturbing gamma transitions and obtain a correlation function of the 229—100 keV cascade in the form $W(\theta) = 1 + (0.087 \pm 0.009) P_2(\cos \theta)$. From a comparison of the experimentally obtained anisotropy with the coefficient A_2 given by the $\gamma\gamma$-correlation theory, the value of the attenuation coefficient was calculated to be $G_2 = 0.82$.

The gyromagnetic ratio of the 100-keV excited state of W^{182} was measured from the shift of the correlation function in a 35,000-G magnetic field. The results of the measurement are shown in Fig. 2. Reduction of the obtained data by the least-squares method showed that the shift of the correlation function amounts to $\Delta\theta = 4°10'$. The value of the gyromagnetic ratio corresponding to this shift is $g = 0.247 \pm 0.037$.

Supplementary note (December 12, 1962). A sec-

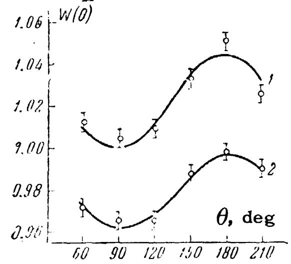

FIG. 2. Measurement results: curve 1 corresponds to the unperturbed correlation function of the 229–100 keV cascade, curve 2 corresponds to the correlation function of the same cascade in a magnetic field H = 35,000 G.

ond series of measurements was carried out using a liquid source. Activated metallic tantalum was dissolved in a mixture of equal amounts of hydrofluoric and nitric acid.

In the absence of the magnetic field the unperturbed correlation function of the 229—100 keV cascade turned out to be $W(\theta) = 1 + (0.0205 \pm 0.0015) \cos 2\theta$ or, after subtracting the background, $W(\theta) = 1 + (0.108 \pm 0.008) P_2 \cos \theta$. Comparison of the obtained coefficient A_2 with the anisotropy coefficient of the correlation function of the $4^+-2^+-0^+$ cascade shows that there is practically no weakening of the correlation by the internal fields of the source.

The angular shift of the correlation function measured in a 35,000-G magnetic field amounted to 5°53′, corresponding to a gyromagnetic ratio $g = 0.323 \pm 0.048$.

The values of the gyromagnetic ratio of the first excited state of W^{182} obtained in both measurements coincide within the experimental errors, and it will apparently be sensible to use as the result the average of the two measurements of the gyromagnetic ratio $g = 0.285 \pm 0.042$. This value is in agreement with the calculated value $g = 0.26$ obtained on the basis of the superfluid model.[17]

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