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RESONANCE SCATTERING OF GAMMA QUANTA BY Li^7

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Correlation functions are found for resonance scattering of γ quanta with excitation of the $5/2^-$ (7.46 Mev) level in Li^7 for two cases of excitation: single-particle and rotational. In addition, the lifetime of the $1/2^-$ (0.477 Mev) state of this nucleus was determined.

THE present work concerns the investigation of resonance scattering of γ quanta by the Li^7 nucleus with excitation of the $1/2^-$ (0.477 Mev) and $5/2^-$ (7.46 Mev) levels.

Let us first consider the resonance scattering of γ quanta by the $5/2^-$ (7.46 Mev) level. It is clear that this level can be obtained in general either by single-particle or by collective excitation. We may expect that the correlation function relating the directions of the emitted and absorbed γ quanta in the process of resonance scattering will have different forms, depending on which of the mechanisms of excitation is assumed in the calculation. Comparison with the experimental data will then enable us to answer the question as to which of these mechanisms should be preferred.

In Fig. 1 we show the first few excited states of Li^7.[1] Let us assume that the $5/2^-$ (7.46 Mev) level is a $3f_{5/2}$ single-particle level. It can then be shown that to obtain energy values for all the lower lying levels which agree with the experimental data, one must assign to these levels the respective states $1p_{1/2}$, $2d_{3/2}$, $3f_{7/2}$, $3p_{3/2}$, starting from the ground level, if the calculation is made on the oscillator potential model, including spin orbit coupling and for an oscillator parameter with the value

$$r_0 = (\hbar / 2\mu\omega_0)^{1/2} = 1.8\cdot 10^{-13} \text{ cm}.$$

On the other hand, as has been shown,[2] this level can be considered as a rotational level if we treat the Li^7 as a rigid rotator consisting of an α particle and a triton, $Li^7 = (\alpha + t)$.

It is easy to see that in both cases of excitation the transition from the $5/2^-$ level to the ground $3/2^-$ level can in general occur by a radiative transition of type E2 + M1. However, according to the selection rules for the orbital angular momentum, in the case of a single-particle excitation the M1 transition is forbidden, whereas there is no such forbiddenness for collective excitation. Therefore, in the latter case the correlation function will differ from that which corresponds to a pure quadrupole transition of type E2. In order to find the form of this function we use the expression for the quadrupole moment operator of the Li^7 nucleus given in reference 2,

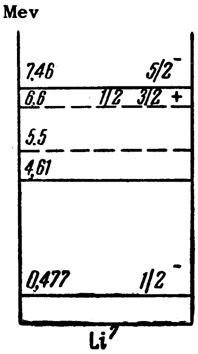

FIG. 1

$$Q_0 = \tfrac{68}{49}\,\overline{r^2}, \qquad (1)$$

where $\overline{r^2}$ is the mean-squared separation of the α particle and the triton. In addition, we must determine the operator for the magnetic moment of the rigid rotator $(\alpha + t)$.

For this purpose we construct an ellipsoid of revolution which is equivalent to this rotator, so that its quadrupole moment, computed in the hydrodynamic approximation, coincides with the quadrupole moment (1), i.e.,

$$3ZR^2\beta/\sqrt{5\pi} = \tfrac{68}{49}\,\overline{r^2}, \qquad (2)$$

where Z = 3, R is the equilibrium radius of the sphere, and β is a parameter determining the deformation of the Li^7 nucleus.

On the other hand, the operator for the magnetic moment of a nucleus which is deformed to the shape of an ellipsoid of revolution with deformation parameter β has the form (cf. the paper of Davydov and Filippov[3]):

$$\mathfrak{M}_p = \frac{e\hbar}{2MC} g \left\{ \frac{1}{2}\sqrt{\frac{3}{\pi}} J_p + \beta \frac{5\sqrt{6}}{7\pi} \sum_{\nu} (21p-\nu, \nu \mid 1p) D^2_{p-\nu,0}(\theta_i) J_\nu \right\}, \qquad (3)$$

where J_p is the spherical part of the total angular momentum vector of the nucleus, g is the gyromagnetic ratio, equal to $\sim Z/A$, $D^2_{p-\nu,0}(\theta_i)$ is the well-known matrix of transformation of the spherical functions, $\theta_i = (\theta_1, \theta_2, \theta_3)$ are the Euler angles.

Using formulas (1) and (3), we can find the correlation function for the case where the $5/2^-$ (7.46 Mev) level is assumed to be a rotational level. It is easy to see that this function will depend on R^2. Substituting the value $\beta = 0.56$ which was found in the paper of Gonchar, Inopin, and Tsytko[4] in formula (3), we obtain $R^2 = 1.1\overline{r^2}$.

If we take for $(\overline{r^2})^{1/2}$ the value 2.71×10^{-13} cm, which was used in reference 2, we finally obtain for the correlation function

$$I(\theta) \sim [1 + 1.22P_2(\cos\theta) + 2.77P_4(\cos\theta)], \qquad (4)$$

where θ is the angle between the absorbed and emitted γ quanta.

Curves showing the correlation functions obtained on the assumptions of single-particle and collective excitation are shown in Fig. 2. As one sees, these curves are symmetric around 90°, but their shapes differ essentially from one another. Therefore, experimental investigation of the correlation of γ quanta can make possible a solution of the question as to which assumption is closer to reality.

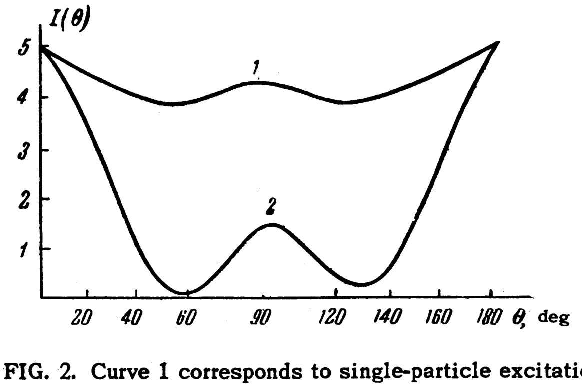

FIG. 2. Curve 1 corresponds to single-particle excitation, curve 2 to collective excitation.

We note that the sequence of levels shown in Fig. 1 can be obtained also on the assumption that the excitation of the nucleus occurs because of a change in the relative motion of the triton and the α particle. In this case, the correlation function turns out to be the same as for the case of single-particle excitation. Therefore, on the basis of an analysis of data concerning resonance scattering of γ quanta by the 7.56 Mev level, one cannot obtain information as to whether we have a single nucleon or a single triton excitation in the nucleus. But, as we shall show below, such information concerning the structure of the Li^7 nucleus can be obtained if we consider the resonance scattering in the first excited state $1/2^-$ (0.47 Mev) of this nucleus. This level corresponds to $l = 1$, $j = 1/2$ both on the single particle and the α-triton model. Then, since the ground state has $l = 1$, $j = 3/2$, we may conclude that the excited $p_{1/2}$ level is obtained on the first model as a result of a rotation of the spin of the nucleon, and on the second model by a rotation of the triton spin with respect to the corresponding orbital angular momentum. This assumption is the more likely to be valid if the excitation energy corresponding to the $p_{1/2}$ level is sufficiently small.

The lifetime of the $p_{1/2}$ state, from experiments on resonance scattering of γ quanta by this level of Li^7, is $(1.09 \pm 0.07) \times 10^{-13}$ sec.[5] It is easy to see that, on both models for the Li^7 nucleus, both E2 and M1 transitions are permissible, but, as the calculation shows, the probability for E2 transition is two orders of magnitude lower than the probability for M1 transition. In addition, the M1 transition contains both orbital and spin magnetic terms. However, the contribution of the orbital term to the transition probability is very small, since the spin term plays the major role in an M1 transition. Here it is assumed that only those nucleons participate in the process which are outside the closed shell in Li^7.

On the basis of the assumption of single-nucleon excitation, we obtained for the lifetime of the $1/2^-$ (0.49 Mev) state of Li^7 the value 1.5×10^{-13} sec, whereas the α-triton model gives 0.96×10^{-13} sec. The latter value is in good agreement with the experimental value 1.09×10^{-13} sec. Thus we see that the assumption that the $1/2^-$ (0.47 Mev) level of Li^7 is the result of a rotation of the triton spin and not of a nucleon is in better agreement with the experimental data.

As for the correlation function, it is almost constant, not dependent on the angle between the γ quanta, because of the fact that this transition is basically a pure spin transition.

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