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ISOBARIC SPIN IN PHOTONUCLEAR REACTIONS

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Abstract: Present evidence for isobaric spin splitting of the photonuclear giant dipole resonance is discussed on some examples. In particular, it is shown that the experiments on ^{11}B are inconclusive.
For ^{90}Zr the ratio of integrated cross sections for the two isospin components is predicted, together with the corresponding ratio for some reaction channels.

1. Introduction

It is generally believed that the photonuclear reactions provide a good tool for the investigation of the isobaric analogue states in the continuum at excitations between 10 and 30 MeV. This is because the photonuclear giant resonance is almost entirely due to electric dipole transitions implying an isobaric spin selection rule $\Delta T = 0$ or 1 (no $T = 0$ to $T = 0$ transitions). However, it turns out that it is not easy to distinguish experimentally the two types of states, neither is the reaction mechanism well understood.

In what follows, some basic features concerning the isobaric spin composition of the photonuclear giant resonance will be discussed, and a few typical experimental examples will be shown for the purpose of illustration.

2. The energy difference between the centroids of the two types of isobaric spin excitations

We shall be considering only non-self-conjugate nuclei with isobaric spin of the ground state equal to $T_0 = T_z$. Accordingly, there will be two types of dipole excitations $T_{<} = T_0$ and $T_{>} = T_0 + 1$. As it is known, a low symmetry of the isobaric-spin wave function is connected with a high symmetry of the space and spin wave functions, and vice versa (Hund's rule). A high symmetry of the space-spin function means that nucleons come in average closer to each other than in the case of low symmetry. Due to the attractive character of the nuclear forces one therefore expects the states of higher T to be located at a higher energy as compared to the states of lower T (for atoms the effect on energy is just the opposite due to the repulsion of Coulomb forces). Empirically this effect results in the symmetry term of the Weizsäcker mass formula. Formally the symmetry effect in one nucleon excitations can be incorporated in the Hamiltonian by introducing the Lane term

$$\frac{4\vec{t}\vec{T}U_1}{A},$$

which was originally used for the charge exchange scattering, where $\vec{T}$ and $\vec{t}$ are the isobaric spin operators for the target nucleus and the projectile, respectively. For the energy difference between the two types of states one obtains

$$E(T_{>}) - E(T_{<}) = \frac{4U_1}{A}(\langle T_{>}|\vec{t}\vec{T}|T_{>}\rangle - \\ - \langle T_{<}|\vec{t}\vec{T}|T_{<}\rangle) = \frac{4U_1}{A}(T^{<} + 1). \tag{1}$$

It is convenient to express the above value with the difference in the nuclear interaction U of a neutron and an equivalent proton with the nucleus:

$$U = \langle nA \,|\, \frac{4\vec{t}\vec{T}}{A} U_1 \,|\, nA\rangle - \langle pC \,|\, \frac{4\vec{t}\vec{T}}{A} U_1 \,|\, pC\rangle = T_{<}\frac{4U_1}{A}. \tag{2}$$

Finally, we obtain:

$$E(T_{>}) - E(T_{<}) = \frac{T_{<} + 1}{T_{<}} U. \tag{3}$$

Above, notation used for the study of charge exchange scattering has been adopted, $|\, pC\rangle$ denoting the state of the proton plus the target nucleus, and $|\, nA\rangle$ a neutron plus the analogue state of the residual nucleus.

3. The relative strengths of the two isobaric-spin components

We write the photonuclear absorption cross section for the E1 radiation in the form (Thompson scattering not included):

$$\sigma_{on}(E1) = \frac{16\,\pi^3}{9}\frac{1}{137}\,(E_n - E_0 \mid \langle\psi_n \| \sum_{i=1}^{A} e_i\, r_i\, Y^1(i) \,\|\, \psi_0\rangle\mid^2 \tag{4}$$

where the reduction of the matrix element applies only to the space and spin coordinates. The notation $e_i = \frac{N}{A}$ for protons and $e_i = -\frac{Z}{A}$ for neutrons is used. The transition matrix element can be divided into an isoscalar and an isovector part. The isovector part reads*

$$\langle\psi_n \mid \sum_i \tau_3(i)\, r_i Y^1(i) \mid \psi_0\rangle. \tag{5}$$

Considering the $T_<$ and $T_>$ components being separated, one obtains

$$\frac{\mid \langle T_0 + 1 \mid \sum_i \tau_3(i)\, r_i\, Y^1(i) \mid T_0\rangle \mid^2}{\mid \langle T_0 \mid \sum_i \tau_3(i)\, r_i\, Y^1(i) \mid T_0\rangle \mid^2} =$$

$$= \frac{\begin{pmatrix} T_0+1 & 1 & T_0 \\ -T_0 & 0 & T_0 \end{pmatrix}^2}{\begin{pmatrix} T_0 & 1 & T_0 \\ -T_0 & 0 & T_0 \end{pmatrix}^2} \frac{\mid\langle T_0 + 1 \,\|\, \sum_i \tau_3(i)\, r_i\, Y^1(i) \,\|\, T_0\rangle\mid^2}{\mid\langle T_0 \,\|\, \sum_i \tau_3(i)\, r_i\, Y^1(i) \,\|\, T_0\rangle\mid^2} \tag{6}$$

with

$$\frac{\begin{pmatrix} T_0+1 & 1 & T_0 \\ -T_0 & 0 & T_0 \end{pmatrix}^2}{\begin{pmatrix} T_0 & 1 & T_0 \\ -T_0 & 0 & T_0 \end{pmatrix}^2} = \frac{1}{T_0}. \tag{7}$$

The ratio of the reduced matrix elements

$$\frac{\mid\langle T_0 + 1 \,\|\, \sum_i \tau_3(i)\, r_i\, Y^1(i) \,\|\, T_0\rangle\mid^2}{\mid\langle T_0 \,\|\, \sum_i \tau_3(i)\, r_i\, Y^1(i) \,\|\, T_0\rangle\mid^2} \tag{8}$$

* As it will be shown later in the discussion of the nucleus ^{90}Zr, the scalar term is considerably smaller.

is model dependent and is expected to vary from 1 (for $T_z = 0$) to about $\frac{1}{150}$ (for ^{208}Pb)[1].

In a single particle shell model picture one would expect the ratio of the transition matrix elements (6) to be equal to zero in a selfconjugate nucleus, since no $T = 0$ to $T = 0$ transitions are allowed. On the contrary, in the case

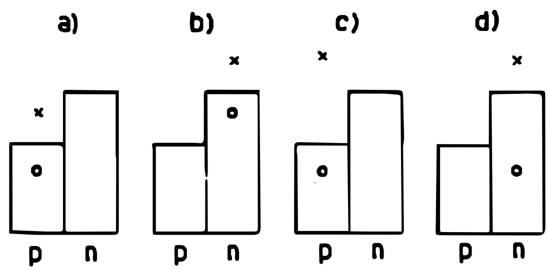

Fig. 1. Types of single particle dipole excitations. States a) and b) have pure T_0 isospin, while states c) and d) have mixed isospins T_0 and $T_0 + 1$. For instance, the state c) can be written as

$$\left(\frac{2T_0+1}{2T_0+2}\right)^{1/2} |T_0, T_0\rangle + \left(\frac{1}{2T_0+2}\right)^{1/2} |T_0+1, T_0\rangle.$$

of ^{208}Pb there would be no $T_0 \Rightarrow T_0 + 1$ transitions (neglecting the ones involving $3\hbar\omega$) due to the fact that the excess neutrons in the ^{208}Pb ground state completely fill one of the harmonic oscillator levels. Therefore, all dipole excitations are of the type a) and b) of Fig. 1, involving only the isobaric spin $T_< = T_0$. By the above model only a quantitative understanding is provided. For more reliable estimates one should use more realistic wave functions.

4. *Experimental evidence*

^{11}B. — Some experiments have been performed recently with the aim to measure the isospin splitting of the giant dipole resonance in ^{11}B[2,3]. The experiments involve the detection of gamma rays emitted after the photodisintegration of ^{11}B. An apparently negative result[2] concerning the existence of the $T_>$ component of the giant resonance was discussed by Hayward et al.[4] and the experimental data were shown to be inconclusive.

Patrick et al.[3] measured deexcitation gamma rays with a better precision at 5 different bremsstrahlung end-point energies, and were able to extract a rough energy dependence of the cross sections to three individual excited states of residual nuclei ^{10}Be and ^{10}B. The states involved are the 3.59 MeV ($J^{\pi} = 2^+$, $T = 0$) and the 5.17 MeV ($J^{\pi} = 2^+$, $T = 1$) states in ^{10}B, and the 3.37 MeV ($J = 2^+$, $T = 1$) state in ^{10}Be (Figs. 2 and 3). According to the authors, their experimental data show that the giant dipole resonance of ^{11}B consists

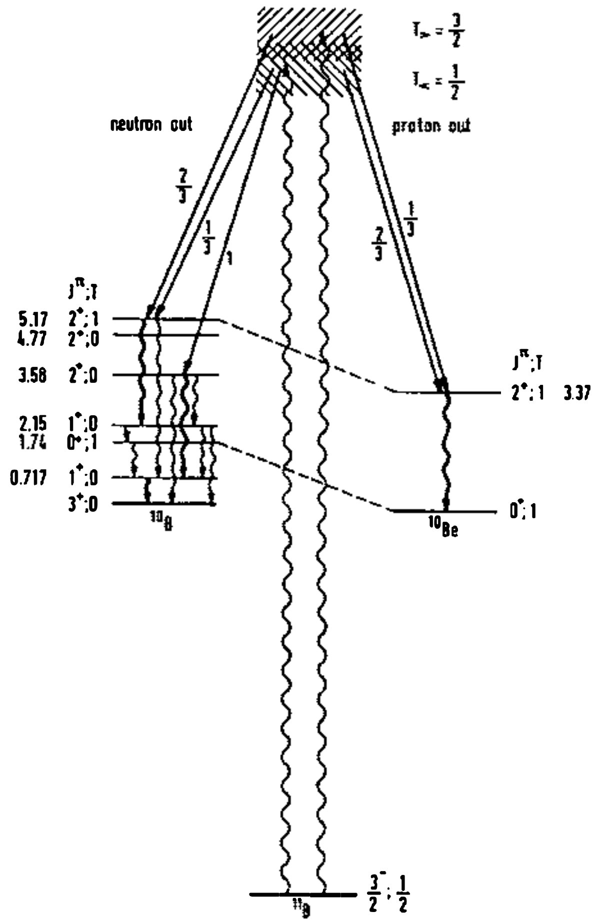

Fig. 2. The energy and decay scheme for the reactions ^{11}B (γ, ^n_p γ') involved in the experiment of Ref.[3]. Figures shown along with the particle emission lines equal to the square of coupling coefficients.

mainly of $T_< = \frac{1}{2}$ states in the lower energy region and of $T_> = \frac{3}{2}$ states in the higher energy region.

Isospin conservation implies that the $T = 0$ state of ^{10}B can only be populated from the $T_< = \frac{1}{2}$ component of the giant resonance. From the coupling coefficients (see Fig. 2) we expect the $T_> = \frac{3}{2}$ component to populate the

$T = 1$ ^{10}B state to a larger extent than the $T = 1$ ^{10}Be state. In this way one could justify the comparison only between the partial cross sections to the two ^{10}B states for the purpose of estimation of the extent to which the ^{11}B giant resonance is divided into two regions of different isospin, as it was done by the authors of Ref. [3]. It should also be kept in mind that the $T = 1$ states can be populated from the $T_<$ component as well. Therefore a unique conclusion about the location of the $T_>$ resonance cannot strictly be obtained from such an experiment.

The interpretation of Ref. [3], according to which the giant resonance is divided into two fairly separate isospin components, is based on the assumption that the $T_<$ component should be restricted to the energy region below about 20 MeV, and the $T_>$ component to the region above this energy. However, this assumption is by no way justified.

It is possible to construct a fairly good picture of the total photoabsorption cross section for the nucleus ^{11}B from the known experimental cross sections $\sigma(\gamma, p_{total})$[5] and $\sigma(\gamma, n) + \sigma(\gamma, np) + 2\sigma(\gamma, 2n)$[6] (Fig. 3). It is seen from Fig. 3 that there is practically no radiation strength left for the energy region below 20 MeV. The centre of gravity of the giant resonance $\int E\sigma_{\gamma,\mathrm{abs}}\,\mathrm{d}E/\int\sigma_{\gamma,\mathrm{abs}}\,\mathrm{d}E$ lies in the vicinity of 25 MeV. We note that the calculation of Spicer and Fraser[7], to which the data of Ref.[3] were compared, yields an incorrect value of 21 MeV for the centre of gravity of the giant resonance in ^{11}B.

From the preceding discussion we expect the ratio of the integrated absorption cross sections for the $T_>$ and the $T_<$ component to have a value of about 2 or less.*. Without affecting the arguments which follow, one can afford to be fairly generous, and allow any value between $\frac{1}{2}$ and 2 for the ratio of the two integrated cross sections, (theory[7] predicts a value of 1.2 for the ratio of the integrated $T_>$ to the integrated $T_<$ cross section).

In Fig. 3 the absorption cross section for ^{11}B is, for the sake of simplicity, divided by two vertical lines into three energy regions of equal integrated cross sections. Assuming the two isospin components being separated we find that the lower vertical line at 23 MeV would represent the separation line between the components $T_<$ and $T_>$ in the case that a value of 2 were taken for the ratio $R = \int\sigma_{T_>}\,\mathrm{d}E/\int\sigma_{T_<}\,\mathrm{d}E$. For the other limiting case $R = \frac{1}{2}$, the separation line would move to 26.5 MeV. In other words, we can say that if the ^{11}B giant resonance were divided into two separate isospin components, the separation line would lie somewhere in the energy interval 23 — 26.5 MeV, unless the ratio R is far larger from the one expected.

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* There is an indication from the experiments on ^{26}Mg[8,9,10] that the above ratio may be larger than $1/T_0$ for the nuclei with low T_0. However, this would not alter the inconclusiveness of the present experimental data for ^{11}B.

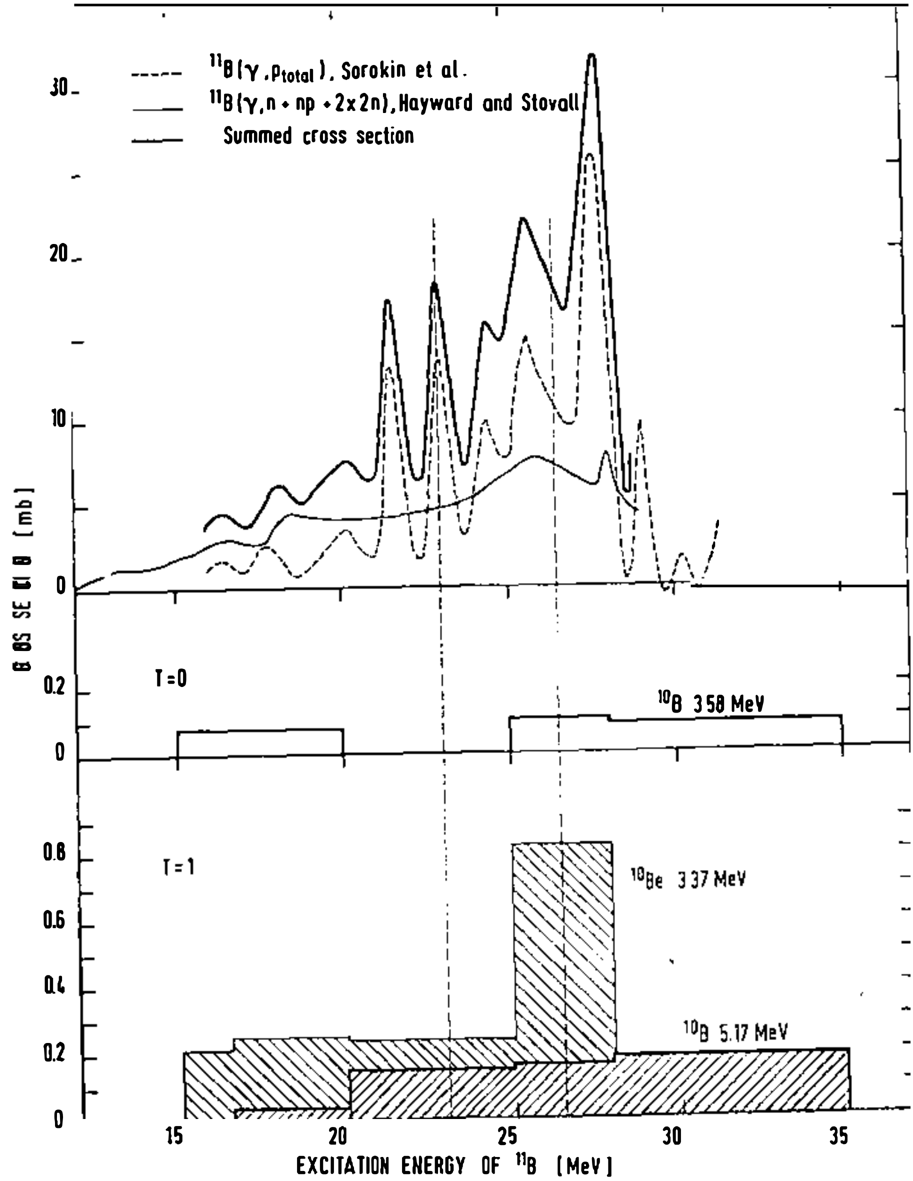

Fig. 3. The upper diagram shows the photoneutron and photoproton cross sections together with the sum of both. The cross sections to three different states of the residual nuclei (lower diagrams) are taken from Ref.[3]. The vertical lines are drawn so as to separate the summed cross section into three energy regions of equal integrated cross sections.

It is seen from Fig. 3 and numerically from Table 1 that the ratio of integrated cross sections for the 5.17 MeV state and for the 3.58 MeV state is about the same in the higher energy region as in the lower energy region, if the energy which separates the two regions lies in the interval between 23 MeV and 26.5 MeV.

We, therefore, conclude that within the limits of the experimental accuracy of Ref.[3] there is no evidence for an isospin splitting in the giant resonance of ^{11}B*. On the contrary, the experimental results suggest a uniform distribution of the $T_<$ and $T_>$ radiation strengths over the giant resonance region. The latter interpretation should be taken with caution as far as the $T_>$ component is concerned, since it is not clear how much is the cross section to the 5.17 MeV ($T = 1$) ^{10}B state affected by the transitions from the $T_<$ isospin component of the giant resonance in ^{11}B.

Table 1

Ratio of integrated cross sections for the states of ^{10}B with isospin $T = 0$ and $T = 1$, in the lower and the higher energy regions

Assumed ratio of integrated photoabsorption cross sections for the two isospin components $R = \frac{\int \sigma_{T_>} dE_\gamma}{\int \sigma_{T_<} dE_\gamma}$	Position of the line of separation, defining the »lower« and the »higher« energy regions	Ratio of $\frac{\text{Integrated cross section to the 5.17 MeV } (T=1) \text{ state}}{\text{Integrated cross section to the 3.58 MeV } (T=0) \text{ state}}$	
		»Lower« energy region	»Higher« energy region
2	23.0 MeV	1.6 ± 0.4**	2.1 ± 0.8
$\frac{1}{2}$	26.5 MeV	2.2 ± 0.5	1 7 ± 0.9

^{26}*Mg*. — The isobaric-spin splitting of the photonuclear giant resonance is clearly demonstrated in the experiment of Wu, Firk and Berman[5]. They studied the energy spectra of neutrons resulting from the irradiation of ^{26}Mg with bremsstrahlung gamma rays of two different end-point energies. The two isobaric-spin components of the giant dipole resonance have $T_< = 1$ and $T_> = 2$. The $T_> = 2$ component cannot decay to the $T = \frac{1}{2}$ ground state of ^{25}Mg while it can decay to $T = \frac{3}{2}$ states at 7.8 MeV (Fig. 4). In the energy spectrum of neutrons irradiated with the bremsstrahlung of an end-point energy of 23.1 MeV is the upper peak of the giant resonance missing, indicating the absence of neutrons decaying from the states above 19 MeV and

* We note that consideration of the cross section to the 3.37 MeV ($T = 1$) ^{10}Be state would not affect the above conclusion.

** The errors were obtained from the typical values quoted in Ref. [1].

leaving the residual nucleus ^{25}Mg in its ground state. In fact, the high energy part of the neutron spectrum is similar to the one obtained with an end-point energy of 18.9 MeV. From the difference of the low-energy parts the contribution of neutrons decaying to the $T = \frac{3}{2}$ states of ^{25}Mg is deduced. The difference spectrum seems to agree with the (γ, n)[9] and (e, e')[11] results.

A relatively large $(\gamma, 2n)$ cross section[10] confirms the experimental results of Wu et al. The $T_> = 2$ state of ^{26}Mg decays also into the continuum $T = \frac{3}{2}$ states of ^{25}Mg which in turn decay either through the emission of another neutron into $T = 0$ ^{24}Mg states (violating the isospin selection rule) or through gamma emission into lower states of ^{25}Mg.

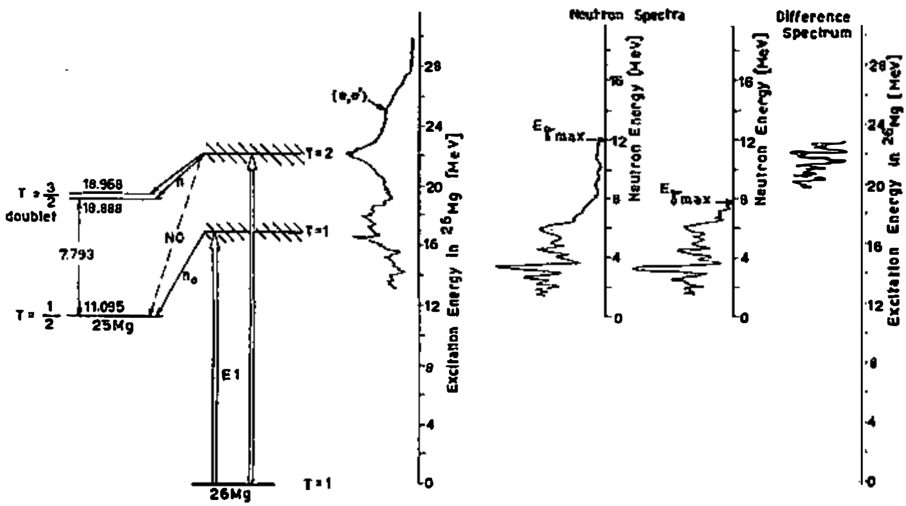

Fig. 4. The energy level diagram shows the location of dipole states in ^{26}Mg. The results of an (e, e') experiment[11] are also shown. The energy spectra of photoneutrons are plotted for two different bremsstrahlung end-point energies[9]. They were used to obtain the difference spectrum (the last on the right hand side) by assuming transitions to the first $T = —$ (7.7926 MeV) state in ^{25}Mg.

^{90}Zr. — Theoretical studies[1, 12–15] are mainly dealing with the total strength of the two types of isobaric dipole excitations and their energy splitting, while experimentally[16–19] one obtains a sum of cross sections for a few reaction channels only. It is important to study the cross sections for individual reaction channels independently, since they often show a selectivity with respect to the isobaric spin.

At present good experimental data exist for the (γ, n), $(\gamma, 2n)$[16] and (p, γ_0)[18, 17] cross sections. Data for other proton channels and the (γ, np) reaction are in the process of evaluation[19, 20]. The (γ, n) cross section consists of a resonance peaking at about 16.5 MeV and some structure at 21 MeV (Fig. 5). The latter is sometimes interpreted as the $T_>$ component of the giant resonance.

Besides the known $T_>$ resonances in the (p, γ_0) reaction[21] at energies $E_x = 14.4$ and 16.3 MeV there is also some evidence for $T_>$ states at excitation energies of about 21 MeV[18, 17]. However, the ratio $R(\gamma, p_0) = \int \sigma_{\gamma, p_0}(T_>)\, dE / \int \sigma_{\gamma, p_0}(T_<)\, dE$ is much smaller than $\frac{1}{T_0}$.

A simplified treatment of the dipole excitations in the nucleus ^{90}Zr will be given here. For convenience protons and neutrons in doubly unoccupied levels

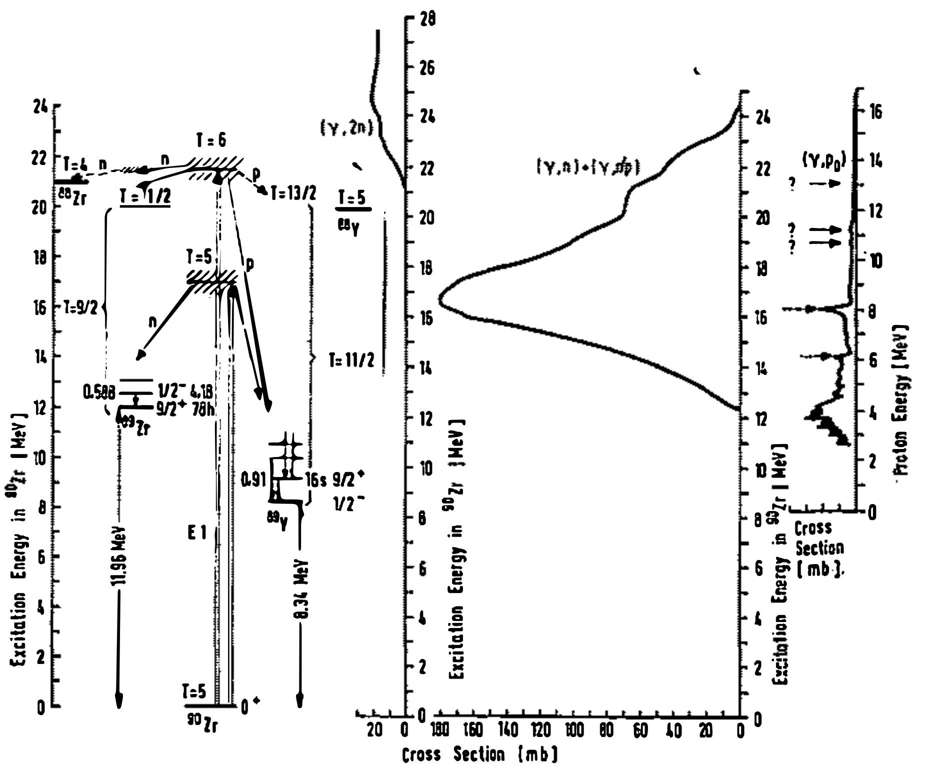

Fig. 5. The energy level diagram for the photonuclear reactions on ^{90}Zr. The $(\gamma, 2n)$ and (γ, n) cross sections are taken from Ref.[16]. The (γ, p_0) cross section is obtained through detailed balance from the inverse reaction[17] (integrated over angles).

and proton and neutron holes in doubly occupied subshells (i. e. excitations of c-d type of Fig. 1) will be expressed in terms of isoscalar $|s\rangle$ and isovector $|v\rangle$ functions[14]

$$|s\rangle = \frac{1}{\sqrt{2}}(|n^{-1}n\rangle - |p^{-1}p\rangle),$$
$$|v\rangle = \frac{1}{\sqrt{2}}(|n^{-1}n\rangle + |p^{-1}p\rangle), \tag{9}$$

$$|n^{-1}n\rangle = \frac{1}{\sqrt{2}}(|v\rangle + |s\rangle),$$
$$|p^{-1}p\rangle = \frac{1}{\sqrt{2}}(|v\rangle - |s\rangle). \tag{10}$$

Dipole excitations of the c-d type can be written using (4) and (10) as

$$(\frac{N}{A}|p^{-1}p\rangle + |-\frac{Z}{A}||n^{-1}n\rangle)|\psi_0\rangle = (|v\rangle - \frac{2T_0}{A}|s\rangle)|\psi_0\rangle, \tag{11}$$

where ψ_0 stands for the ground state. The c-d type states can be treated separately since they are orthogonal to the states of the a-b type. Expressing the above product functions in terms of eigenfunctions of total isobaric spin, one obtains

$$|v\rangle|\psi_0\rangle = \rangle\left(\frac{1}{T_0+1}\right)^{\frac{1}{2}}|T_0+1, T_0\rangle - \left(\frac{T_0}{T_0+1}\right)^{\frac{1}{2}}|T_0, T_0\rangle$$
$$\frac{2T_0}{A}|s\rangle|\psi_0\rangle = \rangle\frac{2T_0}{A}|T_0, T_0\rangle. \tag{12}$$

We neglect the dipole strength contribution due to the scalar function (second line of expressions (12)) which amounts to only about 1% (note the orthogonality of $|s\rangle$ and $|v\rangle$).

Consequently, one finds that for excitations of types c-d (see Fig. 1) there will be a value of 1 to T_0 for the ratio of $T_0 + 1$ to the T_0 dipole strength. It should be noted that for ^{90}Zr, the sum of dipole matrix elements of types a-b (having isobaric spin T_0 only) is slightly greater than the corresponding sum for excitations of types c-d (see e.g.[14] for ^{88}Sr), yielding a value of ≈ 0.08 for the overall ratio of the $T_0 + 1$ to the T_0 dipole strength. For the corresponding ratio of integrated cross sections one obtains $R = \int\sigma(T_>)\,dE/\int\sigma(T_<)\,dE \approx 0.10$.

Before proceeding to the treatment of individual reaction channels we write the ratio of integrated cross sections for the two isospin components in terms of partial widths

$$R(\gamma, p_i) = \frac{\int \sigma^{>}(\gamma, p_i)\,dE}{\int \sigma^{<}(\gamma, p_i)\,dE} = \frac{\int \sigma_i(T_>)\,dE \cdot \frac{\Gamma^{>}_{pi}}{\Gamma^{>}_i}}{\int \sigma_i(T_<)\,dE \cdot \frac{\Gamma^{<}_{pi}}{\Gamma^{<}_i}}, \qquad \Gamma_i = \Gamma_{pi} + \Gamma_{ni} \quad (13)$$

for proton channels, and equivalently for neutron channels. With the subscript i we denote a set of channels belonging to the same particle level and the same hole subshell. Labels p and n apply to protons and neutrons, respectively. The use of a ratio of cross sections for a reaction channel is convenient because there is a number of factors in the partial widths which is common for neutron and proton channels of the same i, and may also be common for channels with different isobaric spin and same i.

$^{90}Zr\ (\gamma, p_0)\ ^{89}Y$. Since the spin of the residual nucleus is $\frac{1^-}{2}$, only s and d proton channels are accessible through this reaction. The excitations are of the type c-d for which the ratio $\int \sigma_i(T_>)\,dE / \int \sigma_i(T_<)\,dE$ is ≈ 0.25 (using $E(T_<) = 17$ MeV and $E(T_>) = 21.5$ MeV). Due to the large number of open proton channels, one expects $\Gamma^{>}_{pi}/\Gamma^{>}_i \approx 1$. We shall assume that the dipole states decay statistically and that the ratio of partial widths can be replaced by the ratio of transmission coefficient sums $\Gamma_{pi}/\Gamma_i = \Sigma T_{pi}/\Sigma T_i$ (the sum includes all the channels with the label i). Using the same formulae for transmission coefficients and level densities as in ref.[17] we obtain $\Gamma_{pi}/\Gamma_i \approx 0.2$ resulting in a value of about 1.2 for $R(\gamma, p_i)$. However, i includes all channels with $1/2^-$ proton holes and s and d protons (channels with ^{89}Y in its ground state represent just one of the possibilities). Due to the higher excitation energy there are more proton channels available for the $T_>$ resonance than for the $T_<$ one. Using the same statistical arguments as before we find $R(\gamma, p_0) \approx \frac{1}{40} R(\gamma, p_i) \approx 0.04$. A rough comparison to the experiment can be made by considering the marked areas on fig. 5 as possible $T_>$ resonances from which one would obtain $R(\gamma, p_0) \approx 0.06$. In evaluating the experimental value of $R(\gamma, p_0)$ only the (γ, p_0) cross section above $E_x \approx 13$ MeV was taken into account since in the lower energy region neutron channels are not open.

$^{90}Zr\,(\gamma, n)\,^{89}Zr\,(T = 11/2)$. The threshold for this reaction is at 20.0 MeV (Fig. 5). Taking into account the transmission coefficients and the value for $E(T_>)$ of 21.5 MeV one gets for the reaction (γ, n) to the $T = 11/2$ state about the same number of open channels as for the reaction (γ, p_0). There are only isospin coupling coefficients which are different for the two reactions. As a consequence we expect the $T_>$ part of the integrated (γ, n) cross section to be about $(2T_0 + 1)$ times larger than its (γ, p_0) counterpart. The later being of the order of magnitude of 100 keV · mb it yields for the integrated photoneutron cross section to the $T = 11/2$ state a value of about 1 MeV · mb which is not large enough to explain the structure in (γ, n) experimental data[16] in the energy region of 20 — 23 MeV. It is noted that nuclei ^{89}Y, ^{91}Zr, ^{92}Zr and ^{94}Zr show less structure in the region of excitations between 20 and 23 MeV although the thresholds for isospin allowed neutron decays* of the $T_>$ resonance are lower than in the case of ^{90}Zr. We, therefore, conclude that the structure appearing at 20 — 23 MeV in photoneutron cross section for ^{90}Zr must mainly be of some other origin. Also, an interpretation in terms of a quadrupole resonance would be difficult to relate to the experimental angular distribution (see Ref.[17] for angular distributions).

^{90}Zr $(\gamma, 2n)$ ^{88}Zr and ^{90}Zr (γ, np) ^{88}Y. The cross sections for these reactions could also contain some $T_>$ strength. In the case of $(\gamma, 2n)$ a neutron would be emitted from the $T_>$ dipole state leaving the residual nucleus ^{89}Y in a $T = 11/2$ state. This process would be followed by either gamma-ray or isospin forbidden neutron emission (proton channels in ^{89}Zr are essentially closed at excitations of 1 or 2 MeV above the threshold). It is, however typical for the $(\gamma, 2n)$ cross section not to drop to zero even when isotopic spin allowed $(\gamma, n + p)$ channels become open. It is concluded that the giant resonance high energy tail is composed of the $T_<$ component with a superposition of $T_>$ states, in a similar fashion as the two known $T_>$ resonances are superimposed on a $T_<$ continum in the lower energy region. For the (γ, np) reaction[19] a very low cross section is obtained in agreement with small transmission coefficients.

Other (γ, p) channels. Unless the $T_>$ resonance lies considerably higher than 21.5 MeV we would not expect it to decay through any other neutron channels apart from the ones mentioned earlier. Therefore we expect the corresponding $T_>$ component to decay through d and g proton channels leaving the nucleus ^{89}Y in its excited states. Therefore it would be interesting to measure the gamma-ray activity of the isomeric state 0.91 MeV ($J^{\pi} = 9/2^+$, $\tau_{1/2} = 16s$) in ^{89}Y, formed during the irradiation of ^{90}Zr with bremsstrahlung gamma rays of different end-point energies. In this way a summed cross section could be extracted which would be roughly proportional to the total high momentum proton cross section and which should include the main part of the $T_>$ dipole strength.

We draw the following conclusions about the $T_0 + 1$ component of the giant dipole resonance in ^{90}Zr:

— the total integrated cross section for the $T_<$ component should be about 10 times larger than its $T_>$ counterpart,

* Here the sum of $\sigma(\gamma, n)$, $\sigma(\gamma, np)$ and $\sigma(\gamma, 2n)$ should be considered since the threshold for the last two reactions is mostly rather low.

— the integrated (γ, n) cross section for the excitations of the $T_>$ type should have a small value of the order of 1 MeV · mb.

— the $(\gamma, 2n)$ cross section is mainly of the $T_<$ type. The $T_<$ resonance extends to high energies. $T_>$ states are superimposed on its high-energy tail, and

— the $T_>$ resonance decays mainly through high momentum proton channels leaving the nucleus ^{89}Y in its excited states. It could be detected by measuring the activity of the first excited isomeric state of ^{89}Y obtained by the irradiation of the nucleus ^{90}Zr with gamma rays of different end-point energies.

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IZOBARNI SPIN V FOTOJEDRSKIH REAKCIJAH

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Vsebina

V prvem delu sta na kratko povzeti splošna ocena razmerja jakosti obeh izotopsko-spinskih komponent fotojedrske dipolne veleresonance in ocena nujnega energijskega razmaka.

Za razumevanje meritev je potreben študij posameznih reakcijskih kanalov, kajti nekateri kanali kažejo močno izospinsko selektivnost.

Posebej so obravnavana nekatera jedra. Pokazano je, da se iz dosedanjih meritev na ^{11}B ne da sklepati na izospinski razcep pri tem jedru. Podrobneje je obravnavano jedro ^{90}Zr. Ocenjen je delež posameznih izospinskih komponent v dipolni veleresonanci, kakor tudi v posameznih reakcijskih kanalih. Te ocene se z dosedanjimi meritvami ujemajo.