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MICROSCOPIC DESCRIPTION OF THE (p,n) SPECTRA AT E_p = 200 MeV

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The charge exchange reaction (p, n) at intermediate proton energies is a very useful tool for the study of the effective interactions and the nuclear structure in the spin-isospin channel [1-4]. For such energies a description of the cross section in terms of the distorted wave impulse approximation with the free N-N t-matrix seems well founded [5]. The observed spectra are characterized by the dominance of spin-flip particle-hole transitions compared to those without spin-flip which can be explained in the framework of the one-meson exchange model [6]. From the observed neutron spectra at $\theta \simeq 0°$ one gets evidence of Gamov-Teller resonances (GTR) in a large number of nuclei throughout the periodic table, and by means of normalization to the β-decay the relation between the observed cross sections for $L = 0$ $(S = 1)$ and the GT matrix elements has been established. In this way an estimate of the total GT strength for transitions with excitation energies up to 30 MeV was obtained. The comparison between these data and the model-independent sum rule showed, that this energy region contains not more than 50-65% of the expected GT strength [4], i.e., one sees a quenching of the low-lying branch of the spin-isospin excitations in nuclei. Quantitative estimates of this effect in middle and heavy nuclei are rather uncertain due to the uncertainty in estimating the background in the region of the continuous spectrum. Such a background may arise both from particle-hole transitions with $L > 0$ and from contributions of many-particle processes (2p-2h transitions, etc.).

The effect of quenching of the low-lying GT transitions with small transferred momentum has been discussed intensively in the literature. Among the possible explanations, the most popular has been the hypothesis of the coupling between the GTR and the Δ-isobar-nucleon hole excitations, which are expected to lie at an energy $E_x \sim 300$ MeV [7]. An important source of quenching may also be the coupling between CTR and the multipair excitations which leads to a considerable transfer of GT strength to the high-energy region up to $E_x \sim 45$ MeV [8]. In the framework of the theory of finite Fermi-systems (TFFS) the quenching effect is connected with the phenomenological quantity $e_q[\sigma\tau]$, the local quasi-particle charge with respect to the spin-isospin field [9]. Its deviation from unity is conditioned by the nonconservation of the axial-vector current and for low-lying excitations it is possible to parametrize this charge as $e_q[\sigma\tau] = 1 - 2\xi_s$, where the quantity ξ_s is believed to be universal for all spin-flip transitions at low energy and small momentum transfers. The best estimate of $e_q[\sigma\tau]$ can be obtained from the total observed GT strength in the low-lying part of the excitation spectrum ($E_x \leq$ 30 MeV). Thus, a theoretical calculation of the background under the GTR, or more precisely, in the region of $E_x \leq$ 30 MeV, is important for getting a quantitative estimate of the quenching effect.

The first estimate of the background in ^{48}Ca was given in ref. /10/ in which the contribution to the (p, n) spectra was calculated for spin-flip particle-hole (p-h) transitions with $\Delta L \leq 3$ without taking the effective interactions into account. The calculated background under the GTR from p-h transitions with L from 1 to 3 appeared to be about three times smaller than the one which the experimentalists separate as the flat part of the neutron spectrum. As a result, the estimate of the total GT strength was enlarged by ~25%. Analogous calculations were made for ^{90}Zr /11/. It should be noted that it is important to take into account the effective interactions (among these the one-pion exchange) which lead to the formation of resonances in the excitation spectra and the noticeable transfer of the strength of transitions with L > 0 to the excitation energy region above the GTR. This effect is particularly remarkable for charge-exchange excitations with spin parities $J^{\pi} = 0^-$, 1^-, 2^+ and 3^+ as shown in ref. /12/. Taking into account the effective interactions naturally leads to diminishing the background under the GTR, since the main collective resonances with L > 0 energetically lie above the GTR.

In this work we present microscopic calculations of the neutron spectra for the reactions $^{90}Zr(p, n)^{90}Nb$ and $^{208}Pb(p, n)^{208}Bi$ at E_p = 200 MeV. We may formulate the model used here as follows:

i) The cross section for small angles and small excitation energies is given by the one-step quasi-elastic scattering process and may be described in the distorted wave impulse approximation (DWIA).

ii) The effective interaction between the projectile and target nucleons is the one of ref. /5/, but the spin-orbit and tensor components were omitted, because it was found by calculations with pure ph-configurations that they do not change noticeably the total cross sections at small angles in the vicinity of the GTR.

iii) The contributions of spin-flip transitions with multipolarities $0 \leq L \leq 7$ as well as the contribution from the IAS were considered.

The strength functions of charge-exchange transitions were calculated in the TFFS with the continuum taken completely into account. As effective quasiparticle interactions there were used the zero range $\sigma\tau$-interaction with the Landau-Migdal

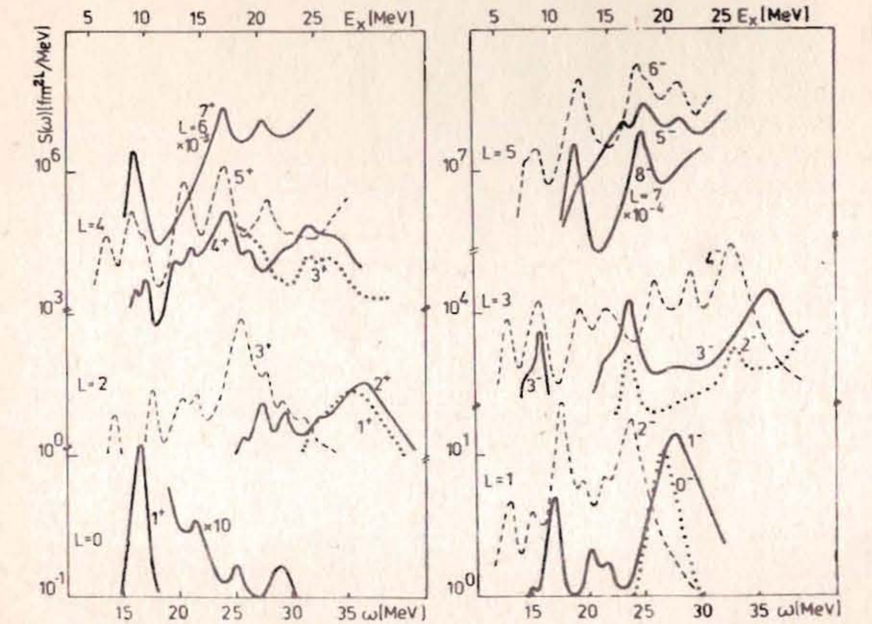

Fig.1. The strength functions for the charge-exchange spin-flip transitions $^{90}Zr \to ^{90}Nb$ in the external fields $V^0_{JLS} = r^L[\sigma \times Y_L]^J$ calculated for $e_q[\sigma\tau] = 1.0$ For details of the calculations see ref. /12,14/. The energy is $\omega = -Q(p, n)$.

constant $g' = 1.1$ (G'_0 = 330 MeV fm^3) and the renormalized one-pion exchange tensor interaction. In the description of the excitations with natural parity also the density-dependent isovector interactions were included. A detailed description of the method was given in ref. /12/. For each set of J and $L = J, J\pm1$ the local resonances were extracted (see fig.1 for ^{90}Zr) and their transition densities were obtained and used in calculations of the reaction cross sections.

In the strength functions for the spin-flip excitations in ^{90}Zr more than 40 bound states and resonances were located, with angular momenta J from 0 to 8 (L = 0-7) in the energy interval $0 < -Q \leq 40$ MeV, and differential cross sections were calculated for them. A detailed discussion of these calculations is given in refs. /13,14/. In this energy interval besides the GT transitions also transitions with L from 1 to 3 contribute to the cross section at small θ, the contributions from other transitions decrease fast with increasing L. Analogous calculations for ^{208}Pb were performed in papers /12-14/.

Finally, the cross sections for each resonance were folded with Breit-Wigner shape functions to obtain the continuous energy spectra and compare them with the experimental ones. The partial widths typical for the resonance structure of the observed spectra were used in this procedure. For all spin-flip transitions the quantity e_q^2 appears as an external factor in the cross section. The magnitude of e_q is determined from the assumption that in the vicinity of the GTR and below it all the observed cross section is given by the one-step reaction mechanism, i.e., an upper limit is actually found for the e_q value.

The energy spectra calculated with $e_q[\sigma\tau] = 0.8$ for all spin-multipole transitions are shown in figs. 2 and 3. Such value of $e_q[\sigma\tau]$ means that the (ph) branch of the low-lying spin-flip excitations exhausts only 64% of the possible shell-model transition strength (quenching effect).

As was expected, the GT transitions dominate the spectra at small angles in the region of $-Q \leq 25$ MeV, and the cross sections for the IAS are small. In ^{90}Zr at $\theta = 0°$ of the total calculated cross section $\sigma_t \simeq 89$ mb/sr below $-Q = 20$ MeV the contribution of GT transitions amounts to $\sigma_{GT} \simeq 81$ mb/sr, the rest being shared between the IAS, $\sigma_{IAS} \simeq 5$ mb/sr, and transitions with $L > 0$ (background), $\sigma_b \approx 3$ mb/sr. The corresponding values in ^{208}Pb at $\theta = 0°$ below $-Q = 25$ MeV are: $\sigma_t \simeq$ $\simeq 173$ mb/sr, $\sigma_{GT} \simeq 143$ mb/sr, $\sigma_{IAS} \simeq 18$ mb/sr and $\sigma_b = 12$ mb/sr. Thus, in both nuclei at $\theta = 0°$ the background under the GTR occurred to be rather small, that agrees with the results obtained in refs. [10,11].

The energy integrated ($0 \leq -Q \leq 40$ MeV, $e_q = 0.8$) theoretical GT cross sections at $\theta = 0°$ are found to be 114 and 192 mb/sr in ^{90}Zr and ^{208}Pb, respectively, of which approximately a quarter is displayed above the GTR.

For spin-dipole transitions in ^{90}Zr the energy integrated cross sections calculated with $e_q[\sigma\tau] = 0.8$, amount to 11.8, 30 and 48.4 mb/sr for $\theta = 0°$, 2.5° and 4.5°, respectively, while the corresponding values in ^{208}Pb are 26, 85.6 and 130 mb/sr. The main strength of these transitions in both nuclei is located in the region $20 \leq -Q \leq 30$ MeV.

A noticeable contribution to the cross section at small angles from spin-flip resonances with $L = 2$ and 3 we obtained only above the GTR. The estimated with $e_q = 0.8$ energy integrated cross sections for them are about 10 and 22 mb/sr in ^{90}Zr and ^{208}Pb, respectively. But these estimates might be changed upon inclusion of tensor interactions in the reaction calculations. At present our model explains only about half of the observed cross section above the GTR.

In accordance with calculations [12] for ^{90}Zr in the neighbourhood of GTR the magnitude of the GT matrix element with the e_q^2 quenching factor included is $M_{GT}^2 = 14.7$, i.e., it ex-

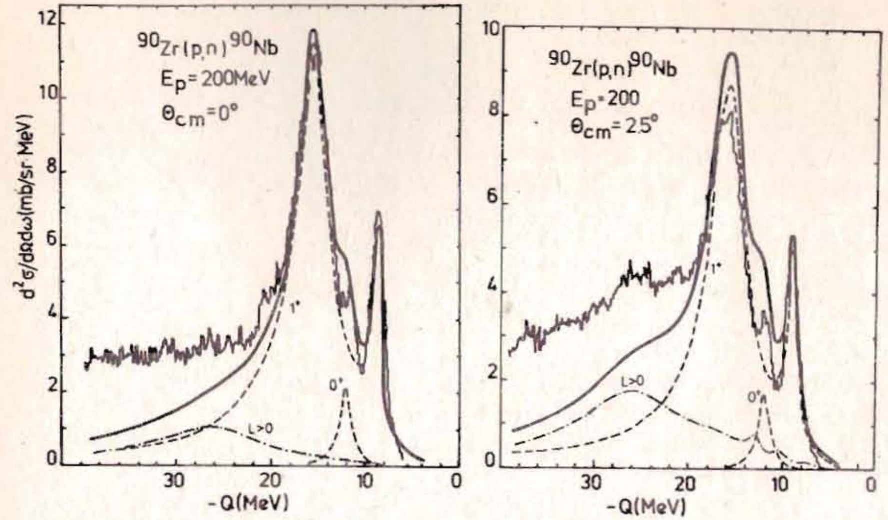

Fig. 2. Comparison between calculated and experimental neutron spectra at small angles for the reaction ^{90}Zr(p, n)^{90}Nb at $E_p = 200$ MeV. The contributions from GT transitions (1$^+$), IAS (0$^+$) and the background of spin-multipole transitions with $L > 0$ are separated. The total cross section is shown with full line.

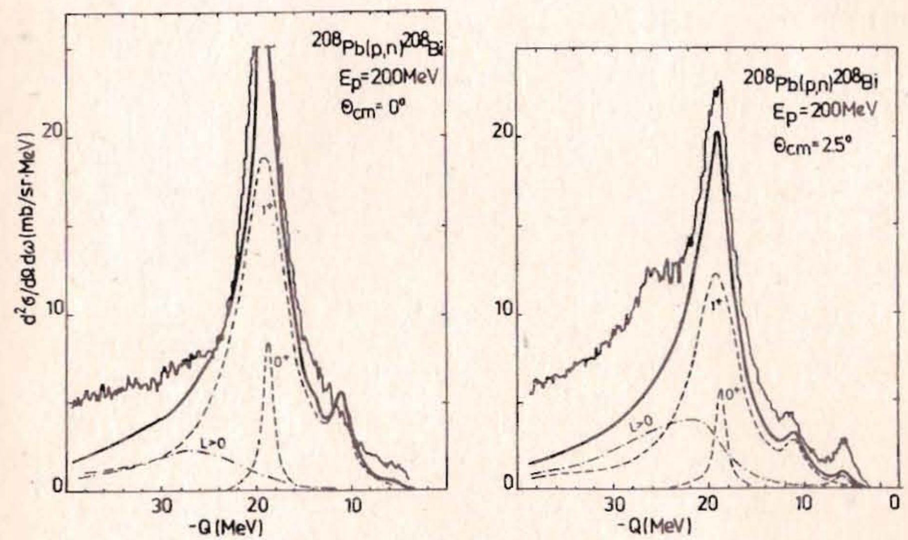

Fig. 3. The same as in fig. 2 for the reaction ^{208}Pb(p,n)^{208}Bi at $E_p = 200$ MeV.

hausts 49% of the sum rule 3(N-Z). Below the GTR only 7.5% of this sum rule is found.

The magnitude of M^2_{GT} for ^{208}Pb calculated with inclusion of the quenching effect is $\simeq$ 47.2 in the vicinity of the GTR, i.e., about 36% of the sum rule 3(N-Z). Below GTR about 8% of the total GT strength is found.

The one-step mechanism with quenching factor e^2_q = 0.64, thus, allows for a good description of the observed neutron spectra in the interval $-Q <$ 20-25 MeV. An important part of the missed GT strength might be distributed above the GTR up to Fermi energy ϵ_F where the density of complex states ($2p-2h$ -type) is very high [8].

The value $e_q[\sigma\tau]$ = 0.8 obtained above siggests the necessity of renormalization of all isovector axial-vector vertices for low-energy processes accompanied by a small q-transfer. In β-decay the quenching effect may lead to renormalization of the axial coupling constant of weak interactions in nuclei $g_A \to (g_A)_{nm} = e_q \cdot g_A \simeq 1.0$ (in units of g_V). This is supported by model-independent analysis of β-decay data for mirror nuclei [15]. Analogously, the πN coupling constant is renormalized in nuclei by a factor of e^2_q = 0.64 in qualitative agreement with the conclusions of ref. [16].

In conclusion the authors want to thank C.Gaarde for providing us with experimental spectra and for fruitful discussion.

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Банг Е. и др. E4-84-837

Микроскопическое описание спектров (p, n) реакции при $E_p = 200$ МэВ

Представлены микроскопические расчеты нейтронных спектров для реакций $^{90}Zr(p,n)^{90}Nb$ и $^{208}Pb(p,n)^{208}Bi$ при $E_p = 200$ МэВ. Расчеты показали, что одноступенчатый механизм реакции хорошо описывает нейтронные спектры для малых углов рассеяния в интервале $0 < -Q \le 20-25$ МэВ и при более высоких энергиях возбуждения одноступенчатые процессы объясняют приблизительно половину наблюдаемого сечения.

Работа выполнена в Лаборатории теоретической физики ОИЯИ.

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Microscopic Description of the (p, n) Spectra at $E_p = 200$ MeV

Microscopic calculations of the neutron spectra for the reactions $^{90}Zr(p,n)^{90}Nb$ and $^{208}Pb(p,n)^{208}Bi$ at $E_p = 200$ MeV are presented. It was obtained, that the one-step mechanism allows for a good description of the neutron spectra for small angles in the interval $0 < -Q \le 20-25$ MeV, and for a higher excitation energy one-step processes explain only about half of the observed cross sections.

The investigation has been performed at the Laboratory of Theoretical Physics, JINR.

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