UDC 530.145; 539.1;539.18

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ADVANCED MULTICONFIGURATION MODEL OF DECAY OF THE MULTIPOLE GIANT RESONANCES IN THE NUCLEI

It is presented an advanced generalized multiconfiguration approach to describe a decay of high-excited states (the multipole giant resonances), which is based on the mutual using the shell models (with extended basis) and microscopic model of pre-equilibrium decay with statistical account for complex configurations 2p2h, 3p3h etc. The new model is applied to an analysis of the reaction (μ^-n) on the nucleus ^{40}Ca.

1. INTRODUCTION

As it is well known, the multipole giant resonances are the highly excited states of nuclei, which are interpretive as the collective coherent vibrations with a participance of large number of nucleons [1-8]. Experimentally, the multipole giant resonances are manifested as the wide maximums in the dependence of cross-section of the nuclear reactions on the incident particle energy r in the spectrum of incident particles. A classification of the multipole giant resonances as the states of collective type is usually fulfilled on the quantum numbers of vibration excitations: entire angle momentum (J*)* and parity π (J^π). The multipole giant resonances are observed in the spectra of majority of nuclei and situated ,as a rule, in the continuous spectrum of excitations in a nucleus (with width of order of several MeV). Two main theoretical approaches to a description of the multipole giant resonances are usually used [1-5]. In the phenomenological theories it is supposed that the strong collectivization of states allows to apply the hydrodynamic models to the description of vibrations of the nuclear form and volume. The microscopic theory is in fact based on the shell model of a nucleus. It is well known different versions of the quasiparticle-phonon model of a nucleus, designed for describing littlie-quasiparticle components of the wave functions for low, intermediate and high excitation energies (see [2,3,6]). In the simple interpretation an excitation of the multipole giant resonances is the result of transition of the nucleons from one closed shell to another one, i.e. the multipole giant resonances is the result of the coherent summation of many particle-hole (p-h) transitions with the necessary corresponding momentum and parity.

As a rule, the multipole giant resonances are situated under the excitation energies, which exceed the thresholds of emission of the particles from a nucleus. Studying the multipole giant resonances decay channels allows to reveal the mechanisms of its forming, connection with other excitations etc. The interaction of a nucleus with external field with forming the multipole giant resonances occurs during several stages. There is a production of the p-h excitation which is corresponding to the 1p-1h states over the Fermi surface (the first stage). Then the excited pair interacts with nuclear nucleons with the creating another 1p-1h excited state or two p-h pairs (2p-2h state; second stage). Then the 3p-3h and more complicated states are created till the statistical equilibrium takes a place. The full width of the multipole giant resonances is provided by the direct decay to continuum ($\Gamma^\uparrow$) and decay of the 1p-1h configurations on more complicated multi-particle ($\Gamma^\downarrow$) ones. The mixing with complex configurations leads to the loss of the coherence and creating states of the compound nucleus. It's known that an account of complex configurations has significant meaning for adequate explanation of the widths, structure and decay properties of the multipole giant resonances (see [2-5]). Here we present generalized multiconfiguration model to describe a decay of high-excited states, which is based on the mutual using the shell models (with limited basis) and microscopic Zhivopistsev-Slivnov model [5] of the pre-equilibrium decay with statistical account for complex 2p2h, 3p3h configurations etc. The model is applied to analysis of reaction (μ^-n) on the nucleus ^{40}Ca. The comparison with experimental and other theoretical data is presented.

2. GENERALIZED MULTICONFIGURATION MODEL OF THE MULTIPOLE GIANT RESONANCES DECAY

The multipole giant resonances are treated on the basis of the multiparticle shell model. Process of creation of the collective state (of the multipole giant resonance) and an emission process of nucleons are described by the diagram in fig.1.

Here V_μ is effective Hamiltonian of interaction, resulted in capture of muon by nucleus with transformation of proton to neutron and emission by antineutrino. Isobaric analogs of isospin and spin-isospin resonances of finite nucleus are excited. The diagrams for photonuclear reactions look to be analogous; $\tilde{\Gamma}^n_{22}$ is the full vertex part (full amplitude of interaction, which transfers the interacting p-h pair to the finite npnh state. The full vertex Γ $\tilde{\Gamma}^n_{22}$ is defined by the system of equations within quantum Green function modified approach [3,5].

All possible configurations are divided on two groups: i). group of complicated configurations "n_1", which must be considered within shell model with account for residual interaction; ii). statistical group "n_2" of complex configurations with large state density p(n,E)>> and strong overlapping the states

$G_n >> D_{n-1} > D_n$ (D_n is an averaged distance between states with 2n exciton; G_n is an averaged width). Matrix elements of bond <n|V|n'> are small and characterized by a little dispersion. To take into account a collectivity of separated complex configurations for input state a diagonalization of residual interaction on the increased basis (ph,ph+phonon, ph+2 phonon) is used. All complex configurations are considered within the pre-equilibrium decay model by Feschbach-Zhivopistsev et al [5] with additional account of "n_1" group configurations. The input wave functions of the multipole giant resonances for nuclei with closed or almost closed shells are found from diagonalization of residual interaction on the effective 1p1h basis [9-15].

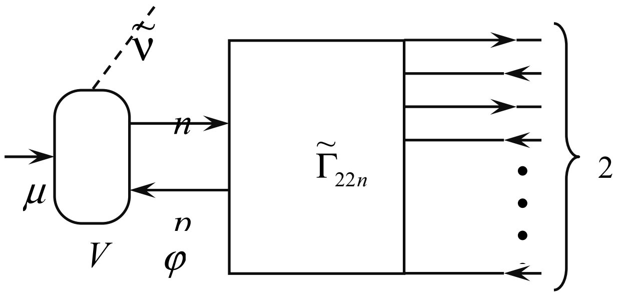

Fig. 1. Diagram of process for production of the collective state (multipole giant resonances) and emission of nucleons (or more complex particles).

Statistical multistep negative muon capture through scalar intermediate states of compound nucleus is important. Intensities of nucleon spectra can be written by standard way [1,2]. In particular, an intensity of nucleonic spectra is defined as follows:

$$\frac{dI}{d\varepsilon_f}(E_\mu, l, \varepsilon_f, J\pi) =$$

$$= \sum_{\substack{n=1,\\ \Delta n=1}} \frac{\Gamma_n^{\uparrow}(l,\varepsilon_f,J\pi)}{\Gamma_n(J\pi)} \cdot \left[\prod_{k=1}^{n-1} \frac{\Gamma_k^{\downarrow}(J\pi)}{\Gamma_k(J\pi)}\right] \cdot \Lambda_\mu(E_\mu, J\pi) \qquad (1)$$

where

$$\Gamma_n^{\uparrow}(l,\varepsilon_f,J\pi) = 2\pi \cdot <|< \varphi_{N_n}(J\pi) \,|\, I_{N_n,N_B+1} \,| \cdot$$
$$\cdot [\varphi^{(+)}(l,\varepsilon_f)\varphi_{N_B}(U_B, I_B)]_{J\pi} >|^2 > \rho(l,\varepsilon_f)\rho^{(b)}(N_B, U_B, I_B)$$

$$\Gamma_k^{\uparrow}(J\pi) = \sum_{l,f} \int d\varepsilon_f \Gamma_k^{\uparrow}(l,\varepsilon_f,J\pi)$$

$$\Gamma_k(J\pi) = \Gamma_k^{\uparrow}(J\pi) + \Gamma_k^{\downarrow}(J\pi)$$

$$\Gamma_k^{\downarrow}(J\pi) = 2\pi \cdot <|< \varphi_{N_k}(J\pi) \,|\, I_{N_k,N_k+1} \,|\, \varphi_{N_{k+1}}(J\pi) >|^2 >$$
$$> \rho^{(b)}(N_{k+1}, J\pi, E_\mu)$$

$$E_\mu = \varepsilon_f + U_B + B_N$$

Here l is the orbital moment of the emission nucleon, ε_f is its energy; B_N is the bond energy of nucleon in the compound nucleus; $\Lambda_\mu(E_\mu, J\pi)$ is probability of μ-capture with excitation of the state $\phi_{in}(E_\mu, J\pi)$ with energy E_μ, spin J and parity π. In oppositeness to standard theories [2,5], we take into account an interference between contributions of separated "dangerous" configurations. From the other side, above indicated features of the statistical group of configurations arte not fulfilled for the "dangerous" configurations. However, the value $\Gamma_n^{\downarrow}(n_1)$ for some dangerous configuration is weakly dependent upon the energy. Indeed, configuration n_1 is the superposition of the large number of configurations, i.e. [2]:

$$\Gamma_n^{\downarrow}(n_1) = \sum_{n+1} \frac{|< n_1 \,|\, I_{n_1,n+1} \,|\, n+1 >|^2}{(E_\mu - E_{n+1})^2 + \Gamma_{n+1}^2/4}$$

Generally, the expressions for the n-step contribution to the emission spectrum are modified as follows:

$$\frac{dI}{d\varepsilon_f}(E_\mu, l, \varepsilon_f, J\pi) = \Big(\frac{\Gamma_{n_2}^{\uparrow}(l,\varepsilon,J\pi)}{\Gamma_{n_2}(J\pi)} \cdot \frac{\Gamma_{n-1,n_2}(J\pi)}{\Gamma_{n-1}(J\pi)} +$$
$$+ \sum_{\{n_1\}} \frac{\Gamma_{n_1}^{\uparrow}(l,\varepsilon_f,J\pi)}{\Gamma_{n_1}(J\pi)} \cdot \frac{\Gamma_{n-1,n_1}^{\downarrow}(J\pi)}{\Gamma_{n-1}(J\pi)} \cdot \left[\prod_{k=1}^{n-2} \frac{\Gamma_k^{\downarrow}(J\pi)}{\Gamma_k(J\pi)}\right] \times \qquad (2)$$
$$\times \tilde{\Lambda}_\mu(E_\mu, J\pi)$$

$$\Gamma_{n-1}^{\downarrow} = \sum_{\{n_1\}} \Gamma_{n-1,n_1}^{\downarrow} + \Gamma_{n-1,n_2}^{\downarrow}$$

where

$$\Gamma_{n-1,n_1}^{\downarrow} = \frac{|< \varphi_{N_{n-1}}(J\pi) \,|\, I_{N_{n-1},N_n} \varphi_{N_n}^{(n_1)}(J\pi) >|^2 \, \Gamma_{n_1}}{(E_\mu - E_{n_1})^2 + \Gamma_{n_1}^2/4}$$

Supposing the input state is isolated, in formalism of the input ph-states one could write as follows:

$$\tilde{\Lambda}_\mu = \frac{\Gamma_1(J\pi)\Lambda_\mu(\varphi_{in_i}(E_i, J\pi))}{(E_\mu - E_i)^2 + \Gamma_{n_1}^2/4}$$

where

$$\Gamma_1(\varphi_{in}) = \Gamma_1^{\uparrow} + \Gamma_{1,n_2}^{\downarrow} + \sum_{\{n_1\}} \Gamma_{1,n_1}^{\downarrow}$$

The other technical details of the presented approach can be found in refs. [2,4,5, 15,16,18].

3. RESULTS AND CONCLUSION

The wave functions of the input state $\{\phi_{in}\}$ in the reaction ^{40}Ca (μ^-n) are calculated within the shell model [12,15,18]. As one could wait for that a collectivity of initial input state leads to significant decreasing $\Gamma_i^{\downarrow}$. The separation into groups n_1 and n_2 is naturally accounted for the 2p2h configuration space [2,18] and the contribution of configurations "ph + phonon" and weakly correlated 2p2h states is revealed [4,5,16]. A probability of transition to the "dangerous" configurations *2p2h* is defined by the value of matrix element:

$$|< \varphi_{in}(ph, J\pi, E) \,|\, I_{ph,2p2h} \,|\, \varphi(2p2h, J\pi, E) >|^2$$

and additionally by density $\rho(2p2h, J\pi, E)$ for statistical group n_2. The contribution of weakly correlated 2p2h configurations is defined by the following expression:

$$\Gamma_{2p2h}^{\downarrow} = 2\pi \cdot <|<| I_{ph2p2h} |>|^2 > \rho_{2p2h}$$

The residual interaction has been chosen in the form of Soper forces (see [5]):

$$V = g_0(1 - \alpha + \alpha \cdot \sigma_1\sigma_2) \cdot \Delta(\mathbf{r}_1 - \mathbf{r}_2),$$

where $g_0/(4\pi r_o^3) = -3$ MeV, α=0,135.The phonons have been considered in the collective model and calculation parameters in the collective model and generalized random phase approximation are chosen according to ref.[4,5]. The phonons contribution is distributed as follows: 2^+ (E=3,9 MeV; β=0,075)~ 42%, 3^- (E=3,736 MeV; β=0,345)~8%, 5^- (E=4,491 MeV; β=0,216)~3% etc. with growth of the phonon moment.

Our theoretical results are compared with experimental data and other calculation results [2] in fig.2,3. In the range of 5-13MeV the experiment gives the intensity ~10% from the equilibrium one. As it has been shown earlier (c.f.[4,5], the 1^-, 2^- states do not give the significant contribution. However, these states exhaust ~80% of the intensity of the μ^--capture. This fact is completely corresponding to results [16] and independently to the data from ref. [5] and ref. [19].

The analysis shows also that only an accurate mutual account for $0^{\pm}$,1^+ 2^+,3^+ and more high multipoles (plus more less correct microscopic calculation of $\Gamma^{\downarrow}_{in}(J\pi,E)$, the input and 2p2h states, separation of the 2p2h space n configurations $n_1$and n_2 etc.) allows to fill the range of high and middle part of the spectrum. Preliminary estimates show that an agreement between theoretical and experimental data is more improved in this case, especially, in the high energy part of the spectrum.

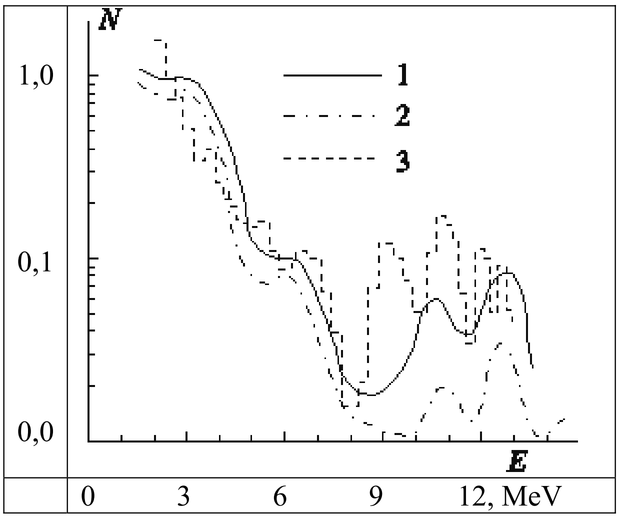

Fig. 2. The comparison of the calculated spectra (curve 1) with experimental data (curve 3) [20] and theoretical data from the Zhivopistsev-Slivnov model (curve 2) [5].

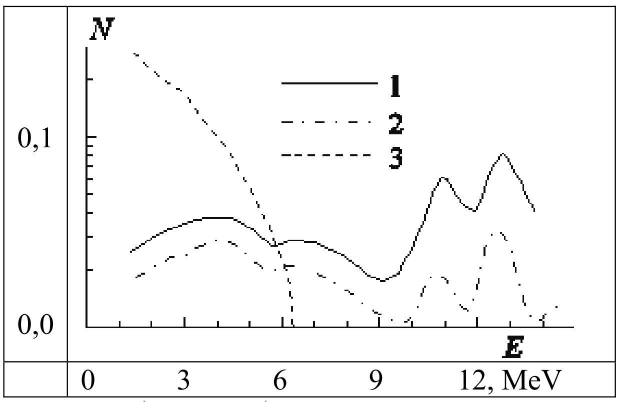

Fig. 3. The mutual account of the $0^{\pm}$, 1^+, 2^+, $3^{\pm}$, 4^-, 5^- — multipoles: the curve 1 — the present paper; the curve 1 is corresponding to the pre-equilibrium and direct part of the spectrum and the curve 3 is corresponding to the equilibrium part (see text).

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Abstract

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Key words: multipole giant resonances, generalized multiconfiguration model, reaction (μ^{-}n) on the nucleus ^{40}Ca.

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УСОВЕРШЕНСТВОВАННАЯ МНОГОКОНФИГУРАЦИОННАЯ МОДЕЛЬ РАСПАДА МУЛЬТИПОЛЬНЫХ ГИГАНТСКИХ РЕЗОНАНСОВ В ЯДРАХ

Резюме

Разработан усовершенствованный обобщенный многоконфигурационный подход для описания распада высоко возбужденных состояний (мультипольные гигантские резонансы) ядер, который базируется на одновременном использовании оболочечной модели (с расширенным базисом) и микроскопической модели предравновесного распада со статистическим учетом сложных конфигураций типа 2p2h, 3p3h и других. Новый подход использован для анализа реакции (μ^{-}n) на ядре ^{40}Ca.

Ключевые слова: мультипольные гигантские резонансы, обобщенная много-конфигурационная модель, реакция (μ^{-}n) на ядре ^{40}Ca.

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УДОСКОНАЛЕНА БАГАТОКОНФІГУРАЦІЙНА МОДЕЛЬ РОЗПАДУ МУЛЬТИПОЛЬНИХ ГІГАНТСЬКИХ РЕЗОНАНСІВ В ЯДРАХ

Резюме

Розвинуто удосконалений узагальнений багато конфігураційний підхід для опису розпаду високо збуджених станів (мультипольні гігантські резонанси) ядер, яка базується на одночасному використанні оболонкової моделі (з розширеним базисом) та мікроскопічної моделі предравновісного розпаду із статистичним урахуванням складних конфігурацій типу 2p2h, 3p3h та інших. Новий підхід використано для аналізу реакції (μ^{-}n) на ядрі ^{40}Ca.

Ключові слова: мультипольні гігантські резонанси, узагальнена багатоконфігураційна модель, реакція (μ^{-}n) на ядрі ^{40}Ca.