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NEUTRON COMPONENTS OF ISOSCALAR GIANT QUADRUPOLE RESONANCE STATES IN ^{58,60,62,64}Ni

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The collective model of nuclear excited states expects the ratio of the neutron to proton matrix elements to be equal to N/Z [1]. The recent experiments with inelastic scattering of resonance π^+ and π^- projectiles to the isoscalar giant quadrupole resonance region show, however, the systematic excess of the neutron strength component over the proton one [2-4].

In this letter, we report on the shell model quasiparticle random-phase approximation calculations of neutron and proton strengths of isoscalar giant quadrupole resonance states of ^{58,60,62}Ni and ^{64}Ni isotopes.

Calculations have been done in the quasiparticle random-phase approximation [5-8] with the Hamiltonian containing the single-particle , pairing and multipole two-quasiparticle parts. Excited states are in this frame generated by applying the phonon creation operator

$$Q^+_{\lambda\mu,i} = \frac{1}{2} \sum_{jj'} \Big[\psi^{\lambda i}_{jj'} \mathcal{A}^+(jj'\lambda\mu) - (-1)^{\lambda-\mu} \phi^{\lambda i}_{jj'} \mathcal{A}(jj'\lambda-\mu) \Big], \quad (1)$$

where $\psi^{\lambda i}_{jj'}$ and $\phi^{\lambda i}_{jj'}$ are the forward- and backward-going amplitudes, respectively, and $\mathcal{A}^+(jj'\lambda\mu)$ is the two-quasiparticle creation operator. The reduced matrix element of the neutron component of the one-phonon state is

$$M_n = M_n(\lambda) = < Q^+ \| \mathcal{O}(N\lambda) \| 0 >$$

$$= \frac{1}{2} \sum^{(n)}_{jj'} \left\{ \psi^{\lambda i}_{jj'} + \phi^{\lambda i}_{jj'} \right\} \mathcal{M}^{(\lambda)}_{jj'} \; \mathcal{U}_{jj'} , \quad (2)$$

where the reduced matrix element $\mathcal{M}^{(\lambda)}_{jj'}$ is

$$\mathcal{M}^{(\lambda)}_{jj'} = < j' \| r^{\lambda} Y_{\lambda\mu} \| j > \quad (3)$$

and

$$u_{jj'} = u_j v_{j'} + u_{j'} v_j \quad (4)$$

are the coefficients constructed from the BCS occupation coefficients u_j and v_j.

In discussion of the neutron and proton component strengths we will use the neutron-proton matrix element ratio reduced to one nucleon

$$\eta = \frac{M_n}{N} / \frac{M_p}{Z} . \quad (5)$$

This quantity, which equals unity in the collective model (usually named the hydrodynamical limit), directly measures the degree of correlation effects on a given excited state.

Input data for this framework are the single-particle basis, the BCS pairing constants, and the parameters of separable forces. The standard calculation method is described in [7]. Since we intended to study the η ratio dependence on the radial neutron-proton ground state density distribution differences, we calculated one sequence of the neutron single-particle bases for each isotope. The resulting η ratios are then parameterized as functions of the rms difference between the paired neutron ground state density distributions and the unpaired proton single-particle one. $\Delta^{np} = R^n_{rms} - R^p_{rms}$:

$$\eta = \eta_0 + \eta_1 \Delta^{np}, \quad (6)$$

where η_0 and η_1 are the resulting QRPA constants.

To determine the absolute value of the theoretical η ratios we calculated Δ^{np} differences using the self-consistent Hartree-Fock approximation with the effective SIII Skyrme forces and with the BCS pairing correlation treatment [9] (SkHFBCS). The

resulting ground state rms neutron-proton $\Delta^{np}_{SkHFBCS}$ differences are also shown in table 1. As it has thoroughly been discussed in paper [10], our $\Delta^{np}_{SkHFBCS}$ differences are in good agreement with other sophisticated mean-field models and the model- and approximately model- independent analyses of high energy proton elastic scattering data.

The present QRPA results on the excitation energies, isoscalar and proton strength components of the isoscalar giant quadrupole resonances are shown in table 2. Note that the strength depletions are measured in terms of the energy weighted sum rule as in ref. [11].

One can observe from this table that the QRPA excitation energies show the very smooth behaviour with the magnitude about one quarter MeV higher than the empirical $63.A^{-1/3}$ rule [11] and the difference between the lightest and heaviest isotopes pursuing this rule precisely.

The question of the amount of strength depletion is however a very problematic one. There are big differences between the new data obtained from the resonance pion inelastic scattering [4] (IS EWSR depletion from 125 to 234 %) and the results obtained by using the (e,α) reaction [12] and light-ion inelastic scattering [13] (IS EWSR depletion about 50 %). It can be seen from table 2, that our QRPA predictions, which agree [14] with the theoretically expected magnitudes of the strength depletions, are between these two empirical data sets.

As one can see [14], the main problem in empirical determination of the giant resonance strength depletion is estimation of the background on which the giant resonance

TABLE 1

Neutron-proton rms ground state density differences

	^{58}Ni	^{60}Ni	^{62}Ni	^{64}Ni
$\Delta^{np}_{SkHFBCS}$ (fm)	0.005	0.049	0.090	0.135

TABLE 2

Excitation energies, isoscalar and proton EWSR depletions and reduced transition probabilities of IS GQR states

		^{58}Ni	^{60}Ni	^{62}Ni	^{64}Ni
E	(MeV)	16.5	16.2	16.2	16.0
S(IS2)	(%)	80	83	74	61
B(IS2)	(fm^4)	2990	3380	3150	2770
S(P2)	(%)	45	48	44	35
B(P2)	(fm^4)	810	900	850	700

TABLE 3

η ratiosor isoscalar giant quadrupole resonances

	Ref.	^{58}Ni	^{60}Ni	^{62}Ni	^{64}Ni
η_0	this	0.85	0.76	0.71	0.60
η_1	this	1.37	1.16	1.22	1.27
$\eta_{SkHFBCS}$	this	0.86	0.82	0.82	0.77
η_π	4	1.09	0.91	1.54	1.74
η_e	12/16	0.86(6)	0.95(5)		

structure is sitting. This background is usually treated in an ad hoc manner. Thus, e.g., the authors of the paper [15] have taken so strong estimation of the radiative tail, that they do not saw any isovector giant quadrupole strength which has to, and also known to exist [16]. (Note that the present QRPA predicts isovector giant quadrupole resonance to be rather fragmented with the total strength comparable to the isoscalar depletion.) Summing, however, all the E2 strength under the giant resonance structure (with the center at 16.5 $\pm$ 3 MeV) measured in [15], one can obtain practically the same amount of the strength depletion as our calculation gives.

The theoretical η ratio predictions, we have obtained for isoscalar giant quadrupole resonance states, are shown together with the η_0 and η_1 constants and the empirical η ratio results in table 3.

It can be observed from table 3 that the η_0 constants representing η ratios corresponding to the vanishing Δ^{np} differences are up to 40 % lower than the hydrodynamical limit. The η_0 constants can also be compared with the same constants but calculated for 2^+_1 excited states. These last QRPA results [17] are all greater than the hydrodynamical limit and they are actually by 40, 59, 65, and 79 % greater than the IS GQR η_0 results for $^{58,60,62,64}Ni$ isotopes, respectively.

Concerning the QRPA η_1 constants - these are much greater than the same QRPA results for 2^+_1 states. This observation means that the collectivization of the neutron field components with growing Δ^{np} differences relative to the collectivization of the proton components is by 2.8, 2.0, 2.1, and 2.3 times stronger in

IS GQR states than in 2_1^+ excitations [17] for ^{58,60,62,64}Ni isotopes, respectively.

The QRPA $\eta_{SkHFBCS}$ ratios evaluated for $\Delta^{np}_{SkHFBCS}$ ground state neutron-proton density differences remain still lower than the hydrodynamical limit and they are systematically decreasing with growing mass number. The magnitudes of the differences between the hydrodynamical limit and the $\eta_{SkHFBCS}$ values are the same (from 14 to 23 %) as in the case of 2_1^+ states but with different signs. Qualitatively similar results, which are in agreement with the QRPA calculations in paper [18], are obtained also for ^{118}Sn and ^{208}Pb isotopes. Thus, the latter qualitative statement seems to be generally valid for heavier even-even nuclei.

The empirical η ratios (η_π in table 3), taken from paper [4], were obtained from the inelastic resonance $\pi^\pm$ scattering. The second empirical η ratio set (η_e in table 3) is evaluated from isoscalar and proton energy weighted sum rule depletions taken from papers [12,16]. Note that in the inelastic electron scattering study [16], the isovector giant resonance was, unlike ref. [15], clearly visible.

Commenting on the empirical η_π ratios, one should first observe the very strong variation throughout the isotopic chain. This feature is even more contrasting when the empirical η_π ratios are compared to the theoretical predictions. Comparing η ratios for ^{58}Ni one can see the coincidence in the $\eta_{SkHFBCS}$ and η_e ratios. The good agreement is observed in ^{60}Ni between the empirical and theoretical η ratios. Taking into account the Δ^{np} difference dependence of the η ratios we should say that although there are η_1 constants for isoscalar giant quadrupole resonance states 2-3 times greater than those for 2_1^+ states, this cannot

explain very big neutron matrix elements as those suggested by the resonance $\pi^\pm$ inelastic scattering on ^{62}Ni and ^{64}Ni isotopes. To obtain η ratio suggested for ^{64}Ni, e.g., the Δ^{np} should be twice as large as the ground state proton rms radius.

Concluding this letter, we may say that we investigated neutron-proton matrix element ratios for isoscalar giant quadrupole resonance states of the ^{58,60,62}Ni and ^{64}Ni isotopes. Being motivated by radial neutron extension uncertainties, we studied the dependence of η ratios on difference between neutron and proton ground state fields. The theoretical predictions of η ratios were obtained within the microscopic QRPA framework.

The QRPA EWSR depletions for isoscalar giant quadrupole resonances are between strongly different empirical results obtained from the inelastic light-ion scattering and (e,α) reactions, on the one hand, and resonance $\pi^\pm$ inelastic scattering results, on the other hand.

The good agreement was obtained between empirical and theoretical η ratios in the case of ^{58}Ni and ^{60}Ni isotopes. However, it seems to be impossible to understand the big neutron matrix elements M_n of the IS GQR states in ^{62}Ni and ^{64}Ni isotopes suggested by the resonance $\pi^\pm$ scattering within the QRPA model also with the variable radial extension neutron field.

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Нейтронные компоненты изоскалярных гигантских квадрупольных резонансных состояний в $^{58,60,62,64}Ni$

В рамках оболочечного приближения случайных фаз (QRPA) изучены отношения нейтронных и протонных матричных элементов (η) для изоскалярных гигантских квадрупольных резонансов четных изотопов Ni. Найдено, что отношения η зависят как $(1,0 \div 1,5)\Delta^{np}$ от разности радиальных распределений нейтронных и протонных полей основных состояний. Теоретические отношения η на $14 \div 23\%$ меньше гидродинамического предела. Согласие между теоретическими и экспериментальными отношениями η получено для изотопов $^{58,60}Ni$. Отношения η для изотопов $^{62,64}Ni$, полученные из неупругого рассеяния резонансных пионов, не удается интерпретировать даже с учетом радиальной вариации нейтронных полей.

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Antalik R. E4-89-804

Neutron Components of Isoscalar Giant Quadrupole Resonance States in $^{58,60,62,64}Ni$

The neutron-proton matrix element ratios (η) for IS GQR states of even Ni isotopes are investigated within the framework of the shell model QRPA. The dependence of η ratios on radial neutron and proton ground state density distribution differences (Δ^{np}) is found to be about 1.0-$1.5\ \Delta^{np}$. The theoretical η ratios are 14-23% lower than the hydrodynamical limit. The agreement between theoretical and experimental η ratios is observed for ^{58}Ni and ^{60}Ni isotopes. The η ratios for ^{62}Ni and ^{64}Ni suggested by the resonance $\pi^{\pm}$ inelastic scattering cannot be interpreted even including the radial variations of the neutron fields.

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

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