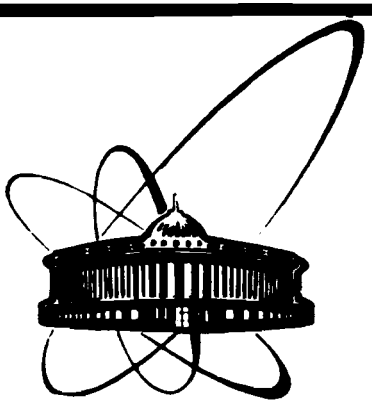

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R.Antalik*

NEUTRON-PROTON MATRIX ELEMENT RATIOS OF 2_1^+ STATES IN ^{58,60,62,64}Ni

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*Laboratory of Theoretical Physics, Joint Institute for Nuclear Research, Dubna,
Institute of Physics EPRC of the Slovak Academy of Science, 842 28 Bratislava

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1. Introduction

The problem of neutron-proton distribution differences has two particular aspects, namely the neutron-proton ground state density distribution differences and the nuclear excited state neutron-proton component strength differences.

The connection between these two particular problems can be shown in the following way. The neutron and proton strengths are characterized through the multipole matrix elements or multipole moments of a given excited state by the relation

$$M_x(\ell) = \int dr \; r^{\ell+2} \; \rho_\ell^x(r) \; , \qquad (1)$$

where $\rho_\ell^x(r)$ are the transition densities and where x stands for n(neutron) or p (proton). The commonly used collective model prescription for the excited state transition density analytically relates $\rho_\ell^x(r)$ the ground state density distribution $\rho_{gs}^x(r)$ as

$$\rho_\ell^x(r) = \delta_\ell \frac{d \; \rho_{gs}^x(r)}{d \; r} \; . \qquad (2)$$

As follows from these equations the transition matrix elements M_n and M_p are dependent on the ground state density distributions which can in turn be determined from elastic scattering data. Electrons are used for determining the charge/proton distribution, and protons interacting with both the neutron and proton nuclear componente can be used to determine the matter distributions. The neutron ground-state density distribution is thus obtained by the difference between the matter and proton density distributions. The situation is analogous to the determination of the neutron components of the nuclear excited states.

In the theoretical interpretation of the collective excited states within the shell model quasipartiole random-phase

approximation (QRPA) approach [1,2] one starts from a Woods-Saxon potential from which independently the neutron and proton single-particle energies and the corresponding wave functions are obtained. Thus, in the realistic situation, when significant uncertainties in the radial neutron ground-state extensions may take place, the result may be the distorted predictions.

The purpose of this paper is to study the dependence of the M_n/M_p ratios on the radial ground-state neutron-proton distribution differences for 2_1^+ states of $^{58,60,62}Ni$ and ^{64}Ni isotopes. A full account of this work will be published elsewhere.

Earlier studies of the M_n/M_p ratios may be found in papers [3-6].

2. Quasiparticle random-phase approximation

Calculations in this work are done in the framework of the quasiparticle random-phase approximation [7,8].The Hamiltonian contains the single-particle, pairing and multipole two-quasiparticle parts.

The excited states are in this frame generated by applying the phonon creation operator

$$Q^+_{\lambda\mu,i} = \frac{1}{2} \sum_{jj'} \left[\psi^{\lambda i}_{jj'} A^+(jj'\lambda\mu) - (-1)^{\lambda-\mu} \phi^{\lambda i}_{jj'} A(jj'\lambda-\mu) \right], \quad (3)$$

where $\psi^{\lambda i}_{jj'}$ and $\phi^{\lambda i}_{jj'}$ are the forward- and backward-going amplitudes, respectively, and $A^+(jj'\lambda\mu)$ is the two-quasiparticle creation operator.

The reduced matrix element of the neutron component of the one-phonon state is

$$M_n = M_n(\lambda) = \langle Q^+ \| O(N\lambda) \| 0 \rangle$$

$$= \frac{1}{2} \sum_{jj'}^{(n)} \left\{ \psi^{\lambda i}_{jj'} + \phi^{\lambda i}_{jj'} \right\} M^{(\lambda)}_{jj'} u_{jj'} \quad (4)$$

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

$$M^{(\lambda)}_{jj'} = \langle j' \| r^\lambda Y_{\lambda\mu} \| j \rangle \quad (5)$$

and

$$u_{jj'} = u_j v_{j'} + u_{j'} v_j \quad (6)$$

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

To compare the neutron and proton strength, it is more useful not to compare the M_n/M_p ratio but the neutron-proton ratio reduced to one nucleon

$$\eta = \frac{M_n}{N} \Big/ \frac{M_p}{Z} . \quad (7)$$

The usefullness of this quantity comes from the fact that in the collective model η equals unity. Deviations of η from 1 then measure the degree of correlation effects on a given excited state.

3. Model calculations

Input data for this framework are the single-particle basis, the BCS pairing parameters, and the parameters of separable forces. The standard adjustation method is described in [7]. In order to study the dependence of η on the radial neutron-proton ground-state density distribution differences, we have to modify that procedure taking into account radial variations of the neutron single-particle basis.

The empirical proton ground-state density distributions [9] for all studied isotopes were fitted by the Woods-Saxon single-particle density. Then, the Woods-Saxon parameters of the neutron density distributions were chosen to give the optimal description of the density diffuseness [10] and calculations of neutron single-particle bases with several various radii and for all isotopes were done. In these calculations, the single-particle

levels around the Fermi energy were kept at approximately similar energies. We have taken the BCS energy gap, in agreement with [11], to be approximately 1.1 MeV. We point out here also the fact that without isovector forces one cannot obtain reasonable agreement with experimental B(E2) values.

Applying this adjustation procedure, we have obtained one set of η ratios for all isotopes, where any of the η values corresponds to one actual difference between the paired neutron ground-state density distributions and the unpaired proton single-particle one. These sets determine functional dependences of the η ratios on the $\Delta^{np} = R^{n}_{rms} - R^{p}_{rms}$ differences which can be represented as

$$\eta = \eta_0 + \eta_1 \Delta^{np} , \qquad (8)$$

where η_0 and η_1 are the resulting QRPA constants.

To determine the absolute value of the theoretical η ratios from eq. (8), we need also information on Δ^{np} differences. To determine these quantities, we used the self-consistent Hartree-Fock approximation with the effective SIII Skyrme forces and with approximate pairing correlation treatment within the BCS method [12] (SkHFBCS). One should bear in mind, however, that using a different parameterization of effective forces the different resulting Δ^{np} differences are obtained.

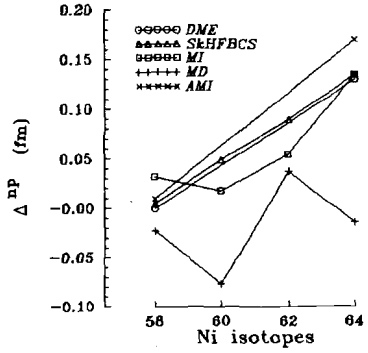

Fig. 1

Present SkHFBCS ground-state neutron-proton rms differences are shown together with other Δ^{np} differences in fig. 1. In fig. 1 there are also shown results obtained with another sophisticated theoretical method, namely using density matrix expansion method with the Skyrme effective forces (DME) [14]. Further, in fig. 1, there are shown the empirical results denoted as AMI and MI. The approximate model independent set (AMI) has been obtained [15] in analyzing 0.8 GeV proton elastic scattering cross-section data. The model independent data set (MI) has been obtained from analyses of the 1 GeV proton elastic scattering cross-section data [16]. Analyzing the same cross-section data in the model dependent way, the author of paper [17] has obtained the result denoted as MD.

As is seen from fig. 1, there is a rather good agreement for Δ^{np} differences, except the MD data set for ^{60}Ni and ^{64}Ni isotopes.

4. Dependence of η ratios on neutron-proton Δ^{np} difference

Comparing our present theoretical QRPA η ratio predictions with empirical η ratio results, we will rely on the very recent analysis of the 1 GeV proton elastic and inelastic scattering data [17]. In that, work the reduced isoscalar transition probabilities B(IS2) were obtained using the collective model transition densities. In evaluation of η_{emp} ratios from that empirical probabilities B(IS), we will use the model independent B(P2) value for ^{58,60,62}Ni from paper [18] and for ^{64}Ni the collective model B(P2) value from [19]. All the mentioned empirical data are shown in table I.

As concerns the theoretical B(P2) results, we may obtain practically the same values in the QRPA method by slight renormalization (within uncertainties) of the BCS pairing constants.

neutron-proton matrix element ratios. The empirical $\eta_{G\&}$ ratio shown in table II for the ^{58}Ni isotope has been obtained using the model dependent analysis of 0.8 GeV proton inelastic scattering [4]. The presumption of this analysis was that the neutron-proton Δ^{np} difference was zero. The second results $\eta_{B\&}$ are taken from the neutron-proton matrix element ratio systematics of paper [20]. The $\eta_{B\&}$ ratios have been obtained by analyzing the low energy proton scattering data. As is seen from table II, there is, except for the ^{64}Ni case, good agreement between the η ratio results.

5. Summary and conclusions

In this paper we have investigated neutron-proton matrix element ratios for 2_1^+ states of the ^{58,60,62}Ni and ^{64}Ni isotopes. Motivated by radial neutron extension uncertainties we studied also 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. With this method the η_0 and η_1 constants determining the η ratio Δ^{np} difference dependence were obtained. These η_1 constants, which measure the steep of Δ^{np} difference dependence, show that to have η ratio determined within 0.01 value, it is necessary to have Δ^{np} difference within 0.02 fm which is presently assumed to be known in ^{58}Ni only [4,13]. The knowledge of the η ratio Δ^{np} difference dependence enables us to understand the empirical η ratios obtained in the model dependent way.

It seems to us that the most probable η ratios are the $\eta_{SkHFBCS}$ and η_{MI} results of table II.

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