Microscopic Description of Excitation of Isoscalar Giant Monopole Resonance in ^{58}Ni by Inelastic Scattering of 240 MeV α−Particles.

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Recently, experimental studies of isoscalar giant resonance excitations in nuclei ranging from ^{12}C to ^{208}Pb were performed at Texas A&M University using 240 MeV bombarding energy α−particles [1, 2, 3, 4]. Excellent peak-to-continuum ratios in the observed inelastic scattering spectra were obtained and the ambiguity associated with the continuum subtraction was notably reduced. New conclusions regarding isoscalar monopole strength distributions in some $A < 90$ nuclei have been drawn [2, 3]. In particular, it has been reported [2] that almost 100 % of ISGMR energy weighted sum rule was exhausted in ^{40}Ca below 30 MeV excitation energy which almost triples previous experimental results [5, 6]. At the same time, in ^{58}Ni, only about 30 % of the ISGMR strength was experimentally located for $E_x < 30$ MeV [1], in contrast with almost a 100% of such strength obtained in theoretical HF-RPA calculations.

The problem of missing monopole strength in ^{58}Ni was addressed by Satchler and Khoa [7], who examined the theoretical aspects of the analysis of inelastic α−particle scattering data. Based upon the most realistic folding models, the authors came to the conclusion that up to 50% of the ISGMR sum rule limit has been observed in ^{58}Ni. However, these folding model calculations were done assuming that the collective model form is an adequate approximation for the transition densities.

In this work we consider the excitation of the ISGMR by inelastic scattering of α−particles and carry out an analysis of the $\alpha+$ ^{58}Ni reaction at 240 MeV bombarding energy based on microscopic results obtained from self-consistent Hartree Fock − Random Phase Approximation (HF-RPA) calculations with Skyrme effective interaction. We use the SL1 parametrization of the Skyrme interaction [8] which gives the value of nuclear matter incompressibility of 230 MeV and provide a theoretical description of the $\alpha+$ ^{58}Ni scattering reaction within the folding model Distorted Wave Born Approximation (DWBA) using microscopic ground state and isoscalar monopole (E0T0) transition densities.

Within the folding model approach, the optical potential $U(r)$ is given by:

$$U(r) = \int d\mathbf{r}' V(|\mathbf{r}-\mathbf{r}'|, \rho_0(r'))\rho_0(r') \qquad (1)$$

where $V(|\mathbf{r}-\mathbf{r}'|, \rho_0(r'))$ is the nucleon-α interaction, which is generally complex and density dependent, and $\rho_0(r')$ is the ground state (Hartree-Fock) density of a spherical target nucleus. In this work, both real and imaginary parts of the nucleon-α interaction were chosen to have the Gaussian shape with the density dependence:

$$V(|\mathbf{r}-\mathbf{r}'|, \rho_0(r')) = $$
$$= -V(1+\beta_V\rho_0^{2/3}(r'))e^{-\frac{|\mathbf{r}-\mathbf{r}'|^2}{\alpha_V}} -$$
$$-iW(1+\beta_W\rho_0^{2/3}(r'))e^{-\frac{|\mathbf{r}-\mathbf{r}'|^2}{\alpha_W}}. \qquad (2)$$

The parameters V, β_V, α_V and W, β_W, α_W in Eq. (2) are determined by a fit of the elastic scattering data. Similar form of nucleon-α interaction was used in Ref. [7] where scattering of 129 and 240 MeV α−particles by ^{58}Ni was considered.

For a state with the multipolarity L and excitation energy E, the radial form $\delta U_L(r, E)$ of the transition potential can be found from:

$$\delta U(r,E) = \int d\mathbf{r}' \left[V(|\mathbf{r}-\mathbf{r}'|,\rho_0(r')) + \right.$$
$$\left. + \rho_0(r')\frac{\partial V(|\mathbf{r}-\mathbf{r}'|,\rho_0(r'))}{\partial \rho_0(r')}\delta\rho_L(\mathbf{r}',E)\right], \quad (3)$$

where $\delta\rho_L(\mathbf{r}',E)$ is the transition density for the considered state.

At this point, we can distinguish between the microscopic and the macroscopic approaches to the $\alpha-$particle scattering description based on the folding model. Within the "microscopic" approach, both the ground state density and the transition density which enter Eqs. (1) and (3) are obtained from the self-consistent Hartree-Fock-RPA calculations. Within the "macroscopic" approach, the transition densities are assumed to have energy-independent radial shapes and are obtained from the ground state density using the collective model. In particular, the so-called Tassie radial shape of the E0T0 transition density [9] is used in experimental studies of ISGMR excitations:

$$\delta\rho_{L=0}(r) = -\alpha(E)\left(3\rho_0(r) + r\frac{d\rho_0(r)}{dr}\right), \quad (4)$$

where the energy-dependent factors $\alpha(E)$ are determined by fitting measured inelastic cross sections. The amount of E0T0 strength concentrated in a given resonance state can then be deduced from the knowledge of $\alpha(E)$ in a straightforward manner, bearing in mind that for the state E_R that exhausts 100% of E0T0 energy weighted sum rule (EWSR) the coefficient is given by [9]:

$$\alpha^2(E_R) = 2\pi\frac{\hbar^2}{mA\langle r^2\rangle E_R}, \quad (5)$$

with m, A, and $\langle r^K\rangle$ being the nucleon mass, the number of nucleons in the excited nucleus, and the $K-$th moment of the ground state density, respectively.

The results of our calculations for ^{58}Ni are shown in Fig. 1. The middle panel of Figure 1 shows 0° double differential E0T0 cross sections obtained with the RPA transition density. In the lower panel we show the 0° E0T0 cross sections found using the transition potential (3) and the collective model (dashed line) and microscopic (solid line) E0T0 transition densities, both normalized to 100% of E0T0 EWSR. The dashed and solid lines in the upper panel of Figure 1 are the ratios of the curve in the middle panel and dashed and solid lines in the lower panel, respectively. They represent the fraction of the E0T0 EWSR per unit energy reconstructed from the double differential cross sections. Clearly, the solid line in the upper panel gives the actual fraction of the E0T0 EWSR per unit energy as calculated from the RPA E0T0 transition strength distribution.

The described calculations provide a direct test of approximation (4). If the collective model shape (4) of the E0T0 transition density exactly reproduced the microscopic shape, the solid and dashed curves in the upper panel of Figure 1 would coincide. However, as follows from our calculations, the differences between the actual (RPA) strength distributions and those reconstructed from the cross section spectrum are noticeable. Moreover, these differences are not uniform which could result in differences between the E0T0 centroid energies calculated from the actual E0T0 strength distribution and the one reconstructed from the cross sections using collective model transition density (4). As follows from our calculations, the cross-section analysis based on using collective model shape for the E0T0 transition density overestimates the E0T0 strength in ^{58}Ni by 17% and shifts the centroid energy down by 0.4 MeV. We, thus, conclude:

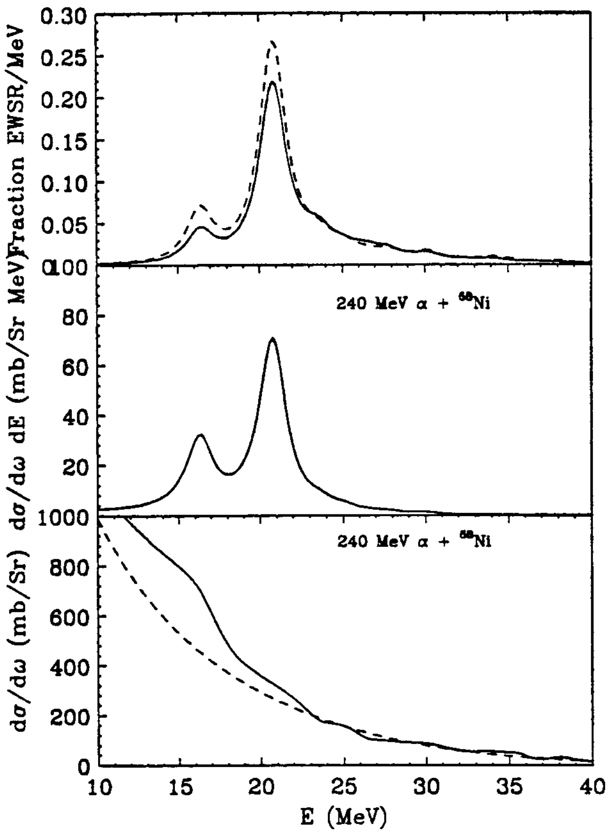
1) Significant discrepancy between experimental and theoretical predictions of the amount of E0T0 strength in ^{58}Ni does exist;

2) Since, as it follows from our results, the cross section analysis based on collective model form of the E0T0 transition density tends to overestimate the E0T0 EWSR, such a discrep-

ancy may be even larger than currently reported;

3) An error in experimentally determined centroid energies of E0T0 resonances might be present due to the use of collective model shape of E0T0 transition densities. For ^{58}Ni, however, this error is rather small (1.4%).

Figure 1. Reconstruction of the ISGMR EWSR from inelastic *alpha*−particle cross section for ^{58}Ni. For explanation of the figure, see text.



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