Fully self-consistent study of charge-exchange resonances and their impact on the symmetry energy parameters†

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A comprehensive effort is currently being devoted to the determination of the nuclear symmetry energy, particularly concerning its density dependence. The symmetry energy is defined starting from the nuclear matter equation of state. The energy per particle in a uniform system characterized by a density ρ and a relative neutron-proton asymmetry $\beta \equiv (\rho_n - \rho_p)/\rho$ can be estimated by expanding up to second order in β as

$$\frac{E}{A}(\rho,\beta) = \frac{E}{A}(\rho,\beta=0) + S(\rho)\beta^2. \quad (1)$$

This truncation has been found to be accurate for densities up to $2\rho_0$, where ρ_0 is the saturation density.

In this work, the basic idea is to use nuclear energy density functionals (EDFs) that provide different values for J, L and the neutron skin, and calculate the energy difference between the anti-analog giant dipole resonance (AGDR) and isobaric analog state (IAS), $E_{\rm AGDR} - E_{\rm IAS}$ in ^{208}Pb. After checking the existence of the above mentioned linear correlations, one can employ the experimental value for the energy difference $E_{\rm AGDR} - E_{\rm IAS}$ and deduce the corresponding values of J, L and the neutron skin. Here, we have achieved three improvements with our self-consistent model and its analysis: (i) the two-body spin-orbit interaction had not been taken into account in Ref. 1, while we adopt its exact form in the present study; (ii) we have checked the effect of implementing the exact Coulomb exchange; and (iii) we have checked the extraction method of the energy centroid of AGDR from the charge-exchange random phase approximation (RPA) calculations.

Table 1. Allowed range for J, L and the neutron skin when experimental data from both Refs. 2 and 3 are considered. The estimates from the previous calculations of Ref. 1 and from the current work are compared.

	Ref. 1	Present work
J	30.7 – 37.7 MeV	31.2 – 35.4 MeV
L	72.7 – 144.3 MeV	75.2 – 122.4 MeV
$\Delta R_{\rm np}$	0.192 – 0.316 fm	0.201 – 0.277 fm

We calculate the energy difference between AGDR and IAS energies and the impact on the symmetry

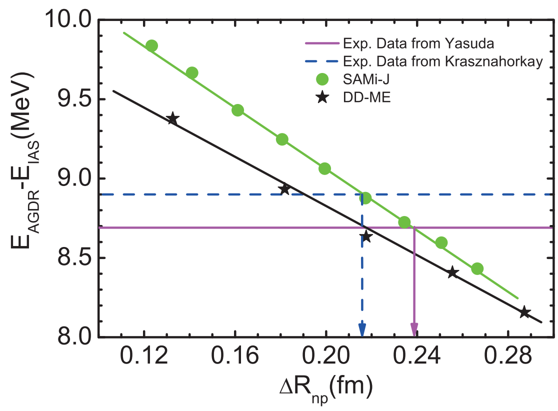

Fig. 1. (Color online) Energy difference $E_{\rm AGDR} - E_{\rm IAS}$ of AGDR and IAS as a function of the neutron-skin thickness, obtained by using the SAMi-J family of Skyrme functionals. The calculated values are presented as solid circles. Two different experimental data[2,3] are also shown as solid (magenta) and dashed (blue) lines, respectively. The arrows indicate the neutron skin constrained by these experimental data. We also display results obtained with the covariant DD-ME Lagrangians of Ref. 3.

energy and neutron skin in the fully self-consistent theory. The calculated results are shown in Fig. 1 together with the experimental results and the theoretical results obtained by means of relativistic mean field (RMF) calculations with the DD-ME effective Lagrangian introduced in Ref. 3. We obtained the neutron skin from the correlation plot in Fig. 1 as 0.239 ± 0.038 fm from experimental data of J. Yasuda *et al.*[2)] and 0.216 ± 0.010 fm from experimental data of A. Krasznahorkay *et al.*[3)]. These values give the symmetry energy coefficients J and L as listed in Table 1. The final results for the symmetry energy parameters J and L are changed by 10% at most compared with the previous analysis and tend to be slightly closer to the empirical values obtained in other analyses in the literature. There are still open problems, such as obtaining a better agreement with the experimental energy of IAS in ^{208}Pb and the strong correlation of the IAS energy with the neutron skin, in which the variation of the IAS energy is larger than expected from the change of the charge radii within the family.

† Condensed from the article in Phys. Rev. C94, 044313 (2016)

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