Self-consistent Hartree-Fock and RPA Green's function method for monopole response of neutron-rich Ni isotopes†

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We discuss low-energy monopole strength of Ni isotopes using the self-consistent Hartree-Fock calculation and the RPA Green's function method with Skyrme interactions. This study is strongly motivated by a recent observation of monopole strength by inelastic alpha scattering at 50A MeV on the unstable nucleus ^{68}Ni.[1)] The observation of soft monopole mode is reported at 12.9 ± 1.0 MeV, in addition to the isoscalar giant monopole resonance (ISGMR), for which the centroid is placed at 21.1 ± 1.9 MeV. To study the properties of low-energy monopole strength, the continuum effect must be properly taken into account in the theoretical calculations. Therefore, we perform the self-consistent HF+RPA calculations with the Skyrme interactions in coordinate system. The strength distributions $S(E)$ are obtained from the imaginary part of the RPA Green function, G_{RPA}, as

$$S(E) = \sum_n |< n \mid Q \mid 0 >|^2 \, \delta(E - E_n)$$
$$= \frac{1}{\pi} \, Im \, Tr(Q^\dagger(\vec{r}) \, G_{RPA}(\vec{r}; \vec{r'}; E) \, Q(\vec{r'})) \quad (1.)$$

where Q expresses one-body operators

$$Q^{\lambda=0,\, \tau=0} = \frac{1}{\sqrt{4\pi}} \sum_i r_i^2 \quad (2)$$

for isoscalar monopole strength. The calculated results are shown in Fig. 1. Note that the widths of all responses are due to the coupling to the continuum without any smearing factor. It is concluded that sharp monopole peaks with width on the order of 1 MeV can hardly be expected for ^{68}Ni in the low energy region below 20 MeV. Instead, a broad shoulder of monopole strength consisting of neutron excitations to non-resonant one-particle states (called threshold strength) with relatively low angular momenta (ℓ, j) is obtained in the continuum energy region above the particle threshold, which is considerably lower than that of the isoscalar giant monopole resonance. In the monopole excitations of ^{68}Ni there are no unperturbed particle-hole states below 20 MeV, in which the particle is placed in either a bound or a resonant state. It is emphasized that in the theoretical estimation a proper treatment of the continuum is extremely important.

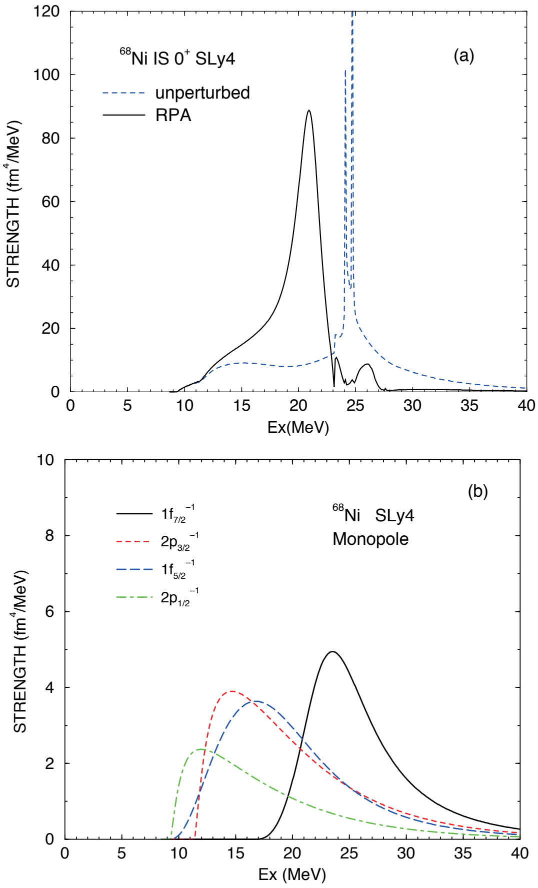

Fig. 1. (Color online) Monopole strength function (1) of ^{68}Ni . (a) Unperturbed monopole strength and isoscalar monopole RPA strength. The RPA strength denoted by the solid curve includes all strengths due to the coupling between bound and unbound states in RPA. In the unperturbed response, the p-h strengths, in which both particle and hole orbits are bound, are not included. The energies of those unperturbed p-h excitations are the $1d_{5/2} \to 2d_{5/2}$ excitation at 27.60 MeV for neutrons and the excitations of $1p_{3/2} \to 2p_{3/2}$ at 27.58 MeV and $1p_{1/2} \to 2p_{1/2}$ at 27.46 MeV for protons. In addition, the proton excitation at 27.3 MeV from the bound $1d_{5/2}$ orbit to the one-particle resonant $2d_{5/2}$ orbit has such a narrow width that the strength is not plotted. The narrow peaks at 24.1 and 24.7 MeV in the unperturbed strength curve are the proton $2s_{1/2} \to s_{1/2}$ and $1d_{3/2} \to 2d_{3/2}$ excitations, respectively. (b) Unperturbed neutron threshold strengths, which contribute to the total unperturbed strength below the energy of ISGMR in Fig. 1a, are shown for respective occupied hole orbits.

References

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